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Auditory target processing in an inter-modal oddball task: effects of stimuli from multiple sensory modalities on the auditory event-related potential

Christopher Robert Brown

University of Wollongong

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AUDITORY TARGET PROCESSING IN AN INTER-MODAL ODDBALL TASK: EFFECTS OF STIMULI FROM MULTIPLE SENSORY MODALITIES ON THE AUDITORY EVENT-RELATED POTENTIAL

A thesis submitted in (partial) fulfilment of the requirements for the award of the degree

DOCTOR OF PHILOSOPHY

from

UNIVERSITY OF WOLLONGONG

by

CHRISTOPHER ROBERT BROWN, B. Psyc (Hons.)

SCHOOL OF PSYCHOLOGY

2011
I, Christopher Robert Brown, declare that this body of work has not been submitted for a degree to any other university or institution, and that the work contained within is mine.

Signed:  

Dated:  18th May 2011
0.1 Acknowledgements

The author would like to acknowledge and offer heartfelt thanks to the many individuals whose support has lead to the completion of this research project.

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0.2 Abstract

This dissertation investigated auditory processing in an inter-modal oddball task. It represents a systematic investigation of ERP activity in inter-modal oddball conditions. The inter-modal oddball task utilises an oddball methodology which includes frequent visual standard stimuli (80%) and infrequent auditory targets (20%). The experiments presented herein showed that auditory targets in this task produce seven ERP components (N100, N130/N140, P200, N220, P250, P300, P350). The N100 was consistent with the traditional N1 and demonstrated refractory and frequency effects. The N130/N140 component had a topography that was consistent with the T-complex, but also showed evidence for activation in frontal regions and was modulated frontally by task requirements. The P200 was a large vertex component that was differentially modulated by response requirements. These early components were shown to be unaffected by the inclusion of the visual standard stimuli in the inter-modal oddball condition. The N220 component was a small negative going wave which was considered to be indicative of the omission of the visual standards at the time of auditory target presentation. The P250 component was consistent with the P3a, was experimentally modulated at frontal sites and showed difference in amplitude and topography as a result of task requirements. The P300 was consistent with the P3b, and was produced by auditory targets presented amidst visual standards. This was somewhat different to the P3b produced when targets are presented amidst auditory standards. The P350 represented a new late positivity that reflected the processing of inter-modal stimuli. It was suggested that it might represent a process of inter-modal feedback from frontal processing regions to the auditory cortex. Overall, these data suggest that
ERPs in inter-modal oddball conditions are processed in two stages – an early stimulus dependant stage and a late context dependent stage. They also suggest that there were separate top-down and bottom-up processes evident in the ERP. It was concluded from these experiments that each ERP component was produced in specific cortical regions and represented distinct aspects of auditory target processing. The evidence provided within this dissertation suggests that the inter-modal oddball task provides a new and novel means of understanding the processing of auditory stimuli and that this task might have advantages over traditional techniques that investigate auditory processing as it does not, by in large, suffer from the confounds related to component and process overlap that is evident in other tasks.
0.3 Overview

The experiments contained within this dissertation represent a systematic investigation of auditory processing in inter-modal oddball conditions. This course of investigation was undertaken as it was recognised that ERPs to inter-modal oddball stimuli in clinical studies were somewhat inconsistent with previous research. A search of the literature indicated that no analysis of inter-modal oddball processes had been here to for conducted.

The first three chapters represent a comprehensive review of experimental findings relevant to the current course of investigation. Chapter 1 presents a general introduction to key themes. It provides the rationale for investigating ERP activity in inter-modal oddball conditions – notably the use of this task in clinical investigations and the lack of any systematic investigation of the processes evident in this task. It also describes how the use of stimuli from multiple modalities provides information that may not be available in uni-sensory conditions – a theme further developed in chapter 3. Chapter 2 presents a review of the literature pertaining to event-related potentials. The focus is primarily on ERP activity produced by auditory stimulation – although the effect of some other forms of stimulation is also discussed. Chapter 3 reviews multi-sensory processing. This chapter focuses on the effect of multi-sensory integration on cortical activity, and the effects of cross-modal and inter-modal attention on the ERP.

Study 1 (Chapter 4) provides the first analysis of inter-modal oddball activity on the ERP of adults (n = 20). This study characterised ERP activity that is produced by auditory target stimuli presented amidst frequent visual standard
stimuli in inter-modal oddball conditions. It showed that there were three early (N100, N130 and P200) and three late (P250, P300 and P350) ERP components produced by auditory targets in this task. In order to interpret these results, the inter-modal oddball ERPs were compared to those produced by equivalent target stimuli in an auditory oddball task and a single tone condition (i.e. targets presented alone). The results showed that early auditory target ERPs (N100, N130 and P200) were unaffected by the inclusion of the visual standards in inter-modal oddball conditions – that is, they did not differ from those to early ERPs in the single tone task. This suggested independence of processing at early stages. It was also noted that this task does not produce a typical N200 component. The late ERP components (P250, P300 and P350) were different in the inter-modal oddball condition to those from the other tasks, indicating that they were affected by stimulus context. Overall, there were three main outcomes of these comparisons. Inter-modal oddball ERPs: 1) were not produced entirely independently of the visual standards – notably at late processing stages, 2) were not equivalent to processes evident in an auditory oddball task – noting that in auditory oddball conditions there were substantial intra-modal effects evident and, 3) were not consistent with processes evident in inter-modal selective attention studies. It was concluded from these data that inter-modal oddball targets were processed in two stages, an early stimulus specific stage and a later context dependant stage.

Study 2 (Chapter 5) investigated the effect of visual standard stimuli on auditory processing in an auditory-visual oddball task (n = 17). This task included the concurrent presentation of visual and auditory standard stimuli with infrequent auditory targets. The ERPs produced by targets in this task were
compared to those elicited by equivalent auditory targets in a traditional auditory oddball task. Both tasks produced intra-modal effects indicative of auditory standards affecting target ERPs – consistent with activity demonstrated in study 1. It was expected that differences between these tasks would represent the inclusion of the visual standard in the auditory-visual oddball condition. The data showed that the early ERPs N100, P200 and N200 were unaffected by the visual standard stimulus. This supported the concept of independent processing at early stages. These data also showed that the later components were modulated by visual standard stimulus attributes, suggesting an effect of stimulus context on the ERP. The later effects further suggested evidence for two separate P3 components representing the processing of target stimuli amidst visual and auditory standard stimuli respectively.

Study 3 (Chapter 6) used a variant of the inter-modal oddball task to investigate how modulating infrequent stimulus parameters affected the ERP. This study compared target ERPs in a two-stimulus and a three-stimulus version of the inter-modal oddball task (n = 17). It also compared ERPs to targets and non-targets in the three-stimulus condition. These tasks produced six ERP components (N100, N140, P200, P250, P300, P350) that were broadly consistent with those identified in study 1. It also showed an additional small negative going wave (N220) that had not previously been identified. This component was consistent to all infrequent stimuli and was considered indicative of activity produced by the omission of the ongoing visual standard stimuli in this task. That is, it was not specifically related to the processing of the auditory stimuli. The early negative components (N100 & N140) were experimentally dissociated, showing differences in amplitude, latency,
topography and response to experimental manipulation. The differences in N100 and P200 components between tasks suggested that stimulus attributes rather than task requirements were responsible for the modulation of these components. The N140 component was modulated at frontal sites in the three-stimulus condition indicating that it was affected by the requirements of the task. The P250/P3a component was also modulated at frontal sites, suggesting that it was also affected by the requirements of the tasks – notably the effect of probability differences or the need to discriminate targets from non-targets in the three-stimulus condition. Both the N140 and P250 components showed similar modulations at frontal sites, however, these effects represented global and stimulus specific effects respectively. The P300 component in the three-stimulus condition showed focal enhancements in the right hemisphere that were interpreted as modulation of poly-modal processing areas. Thus, it was suggested that this component was indicative of an inter-modal P3b produced by auditory target stimuli presented amidst visual standards – supporting the findings of study 2. The P350 component varied as a function of the task that elicited it. In the two-stimulus task, P350 was broadly consistent with the results of study 1. In the three-stimulus conditions, target P350 showed attributes of a second P3b produced by auditory targets presented amidst other auditory stimuli – that is, an intra-modal P3b component. The non-target P350 showed a different morphology to either component produced by target stimuli. Its attributes lead to the conclusion that it was indicative of a no-go P3 component produced by non-targets in this task. Overall, the results presented in this chapter provided support for interpretations previously made, and extended the understanding of activity produced in inter-modal oddball conditions.
Study 4 (Chapter 7) was a confirmatory analysis of inter-modal oddball target ERPs. It included a larger number of subjects (n = 43), considered two quantification methods - peak-picking and principle components analysis, and considered the results produced in this study with respect to data presented in previous chapters. Overall, this chapter showed that the results of the two quantification methods were broadly consistent. It also indicated that the data presented in previous chapters were reliably produced. Key findings suggested that the second early negative component to auditory targets in the inter-modal oddball task (N130/N140) was consistent with an interpretation of the T-complex. It showed that the P200 component, a large vertex positivity, was affected by response mode effects. It indicated that the N220 component was indicative of a response to the omission of the visual standards stimulus in this task. It also suggested that the topography of the P3a component differed as a function of the task used to elicit it. Overall, this chapter enhanced the understanding of inter-modal oddball target processing and demonstrated the reliability of the interpretations made throughout this dissertation.

Chapter 8 presents a general discussion of the results produced in these experiments and contextualises the seven key ERPs produced in inter-modal oddball conditions (N100, N130/N140, P200, N220, P250, P300) in relation to both the task parameters and more broadly with auditory processing in other tasks. The results presented in this dissertation were used to formulate a theoretical interpretation of auditory processing as determined by the comparison of inter-modal oddball target ERPs with those identified in other studies. It is suggested that each ERP component is produced in distinct cortical regions and represents specific auditory processes. These results
extend the understanding of auditory target processing and suggest that the inter-modal oddball task represents a parsimonious means of investigating these processes. This was primarily due to the fact that the predominance of activity in this task does not suffer from component overlap or other confounding processes that are typically evident in other auditory conditions.

Overall, the data presented in this dissertation characterise the attributes and function of ERP components presented in inter-modal oddball conditions. It has shown that they are somewhat different to that produced in other oddball tasks and investigations of inter-modal attention, and have shown that the inter-modal oddball task represents a new and novel means of investigating auditory processing.
### 0.4 Abbreviations

Table 0.1. Abbreviations used in the text throughout this thesis. All abbreviations will be defined on their first use in the text.

<table>
<thead>
<tr>
<th>Abbreviation</th>
<th>Term</th>
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<tbody>
<tr>
<td>ACC</td>
<td>Anterior cingulate cortex</td>
</tr>
<tr>
<td>AD/HD</td>
<td>Attention-deficit/hyperactivity disorder</td>
</tr>
<tr>
<td>AD/HDcom</td>
<td>Attention-deficit/hyperactivity disorder of the combined type</td>
</tr>
<tr>
<td>AD/HDin</td>
<td>Attention-deficit/hyperactivity disorder of the predominantly inattentive type</td>
</tr>
<tr>
<td>AER</td>
<td>Auditory evoked response</td>
</tr>
<tr>
<td>ANOVA</td>
<td>Analysis of variance</td>
</tr>
<tr>
<td>BESA</td>
<td>Brain electrical source analysis</td>
</tr>
<tr>
<td>CM</td>
<td>Cross-modal</td>
</tr>
<tr>
<td>EEG</td>
<td>Electroencephalography</td>
</tr>
<tr>
<td>ERP</td>
<td>Event-related potential</td>
</tr>
<tr>
<td>fMRI</td>
<td>Functional magnetic resonance imaging</td>
</tr>
<tr>
<td>ICA</td>
<td>Independent components analysis</td>
</tr>
<tr>
<td>IPS</td>
<td>Intra-parietal sulcus</td>
</tr>
<tr>
<td>ISI</td>
<td>Inter stimulus interval</td>
</tr>
<tr>
<td>LORETA</td>
<td>Low resolution electromagnetic tomography</td>
</tr>
<tr>
<td>MEG</td>
<td>Magnetoencephalography</td>
</tr>
<tr>
<td>MMN</td>
<td>Mismatch negativity</td>
</tr>
<tr>
<td>MS</td>
<td>Multi-sensory</td>
</tr>
<tr>
<td>MSI</td>
<td>Multi-sensory integration</td>
</tr>
<tr>
<td>Nd</td>
<td>Negative difference wave</td>
</tr>
<tr>
<td>PCA</td>
<td>Principle components analysis</td>
</tr>
<tr>
<td>Pd</td>
<td>Positive difference wave</td>
</tr>
<tr>
<td>PFC</td>
<td>Pre-frontal cortex</td>
</tr>
<tr>
<td>PN</td>
<td>Processing negativity</td>
</tr>
<tr>
<td>SC</td>
<td>Superior colliculus</td>
</tr>
<tr>
<td>ST</td>
<td>Single tone task</td>
</tr>
<tr>
<td>STG</td>
<td>Superior temporal gyrus</td>
</tr>
<tr>
<td>STP</td>
<td>Supra-temporal plane</td>
</tr>
<tr>
<td>STS</td>
<td>Superior temporal sulcus</td>
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1. Introduction
1.1 General Introduction

This dissertation will investigate the processing of auditory stimuli using Event-Related Potentials (ERP). The focus will be auditory processing in inter-modal variants of the oddball task. The oddball task is an experimental paradigm that has been widely used to study the processing of sensory stimuli. Typically, it is used to investigate processes within a single sensory modality (e.g. auditory or visual stimuli) and there are well established data that describe the effect of many experimental manipulations on the ERP in such a task. However, little research has considered how, in oddball conditions, an infrequent target stimulus in one sensory modality is processed when presented amongst frequent stimuli in a different sensory modality. The experiments contained within will address this lack of research by considering the processing of auditory target stimuli when presented amongst frequent visual standards.

1.2 Attention

The use of ERPs to study attentional processes has a long history and the oddball paradigm is one of the earliest tasks used to do this. Parasuraman (1998) suggests that historically there have been several types of attention identified. Of these, sustained attention and selective attention are arguably the most widely studied in ERP research. The oddball task can be considered a sustained attention task. In order to respond to the imperative stimulus all stimuli must be continuously attended and are therefore task-relevant. The oddball task has been otherwise referred to as a one-channel task (Näätänen, 1990). Other sustained attention tasks frequently utilised include the Go/NoGo task and the continuous performance task. In contrast, selective attention tasks
require attention to be preferentially directed to one of many streams of stimuli. For example, the dichotic listening paradigm requires participants to attend to stimuli presented in one ear whilst ignoring concurrently presented stimuli in the other ear. Spatial attention tasks require attention to be directed to particular spatial locations and inter-modal attention studies require attention to stimuli in one sensory modality whilst ignoring concurrent stimuli presented in a different sensory modality.

1.3 The Oddball Task

The oddball task has been described as one of the simplest tasks that can be used to investigate ERPs sensitive to cognitive variables (Rugg, Pickles, Potter, Doyle, Pentland & Roberts, 1993). In its simplest form it consists of frequently presented (standard) stimuli randomly interspersed with less frequent (target) stimuli. When the infrequent stimulus is made task relevant the oddball task can provide information about factors such as expectancy, subjective probability, neuronal models and stimulus discrimination processes (Sams, Alho & Näätänen, 1983; Picton, Bentin, Berg, Donchin, Hillyard, Johnson Jr, Miller, Ritter, Ruchkin, Rugg & Taylor, 2000). Picton et al. (2000) argued that the interpretation of these processes can be parsimoniously made with reference to oddball findings. Typically, the oddball task uses stimuli from only one sensory modality at a time. Thus, the auditory oddball task may include a series of standard tones randomly interspersed with infrequent target tones differing on dimensions such as pitch, frequency, intensity or duration. In the visual modality target stimuli may differ from standards in luminosity, spatial frequency, shape or colour. It is noted that there are typically two types of oddball task that have
been employed in experimental investigation. The passive version of the oddball task (not used in this thesis) requires participants to perform another irrelevant task (e.g. read a book) whilst ignoring stimulus presentation. This allows for investigation into relatively automatic sensory processes. The active oddball task (most relevant to this thesis) requires attention to be directed to the stimulus train, with a response to be made to the infrequent target stimuli. This may be in the form of covert counting of targets or motor responses (e.g. button press). The typical auditory oddball task produces a characteristic ERP waveform to target stimuli, including the N1, P2, N2 and P3 components. The characteristics and function of ERP components will be discussed further in chapter 2.

1.4 The Processing of Stimuli from Multiple Modalities

The oddball task has typically been employed in the investigation of intramodal stimulus processing, that is, processes within the one sensory modality. However, attending to relevant stimuli in the environment is rarely a uni-modal process. A multitude of variables, often from distinct sensory modalities, can be involved in stimulus detection. There is substantial evidence suggesting that the presentation of stimuli in different modalities modulates both behavioural and cortical activity. For example, the presentation of a combination of auditory and visual stimuli has been shown to decrease response times (Donchin & Lindsley, 1965; Andreassi & Greco, 1975; Schröger & Widmann, 1998; McDonald, Teder-Sälejärvi & Hillyard, 2000; Molholm, Ritter, Murray, Javitt, Schroeder & Foxe, 2002), facilitate target localisation (Schröger & Widmann, 1998; Marks, Ben-Artzi & Lakatos, 2003; McDonald, Teder-Sälejärvi, Di Russo & Hillyard, 2003),
and enhance target properties and identification (Stein, London, Wilkinson & Price, 1996; McDonald et al., 2000; see also Calvert, Brammer & Iversen, 1998). Furthermore, the combination of stimuli from different modalities can affect ERPs (Giard & Peronnet, 1999; Teder-Sälejärvi, McDonald, Di Russo & Hillyard, 2002). These effects represent both cross-modal and inter-modal processes.

The study of cross-modal attention has investigated how the combination of stimuli from different modalities affects behavioural and cortical response production. Spence, Senkowski and Röder (2009) describe cross-modality as “…situations in which the presentation of a stimulus in one sensory modality can be shown to exert an influence on our perception of or ability to respond to, the stimuli presented in another sensory modality” (p. 107). Research has shown that multi-sensory stimuli presented together within close spatial and temporal proximity, produce a perceptual superadditive effect, within which stimuli are “…integrated to form a unified perceptual object…” (McDonald, Teder-Sälejärvi & Ward, 2001a: p. 1791a). The effect of cross-modal integration typically produces enhanced behavioural responses, a speeding of response times, an enhancement of cortical activity in uni-sensory cortical regions, activation of sub-cortical and cortical poly-sensory regions and has been shown to modulate the ERP (see chapter 3.2 for further discussion).

Multi-sensory stimuli presented at the same location or time, that is, in spatial or temporal synchrony, is sufficient to produce cross-modal effects. Thus, cross-modal spatial attention studies have shown that the presentation of stimuli at a given location in one sensory modality facilitates or cues a response
to a subsequent stimulus in a different modality, when presented at the same compared to a different spatial location. This is apparent whether attention is overtly or covertly directed to the location in space. The effect of cross-modal spatial attention typically produces an enhancement of response production, improved stimulus discrimination and modulation of the ERP. Cross-modal spatial attention effects have been demonstrated to all combinations of auditory, visual and somato-sensory stimuli (Hillyard, Simpson, Woods, Van Voorhis & Munte, 1984; Butter, Buchtel & Santucci, 1989; Farah, Wong, Monheit & Morrow, 1989; Ward, 1994; Spence & Driver, 1996, 1997; Driver & Spence, 1998a, 1998b; Eimer & Schröger, 1998; Spence, Nicholls, Gillespie, & Driver, 1998; McDonald & Ward, 1999, 2000; Rorden & Driver, 1999; Teder-Sälejärvi, Munte, Sperlich & Hillyard, 1999b; Eimer & Driver, 2000; McDonald, et al., 2000; Schmitt, Postma & De Haan, 2000; Spence, Pavani & Driver, 2000a; Spence, Ranson & Driver, 2000b; Ward, McDonald & Lin, 2000; Kennett, Eimer, Spence & Driver, 2001; McDonald, Teder-Sälejärvi, Heraldez & Hillyard, 2001b; Eimer & van Velzen, 2002; Eimer, van Velzen & Driver, 2002; Lloyd, Merat, McGlone & Spence, 2003; McDonald et al., 2003).

Similarly, multi-sensory stimuli presented in temporal synchrony at distinct spatial locations may produce an integration of stimulus characteristics. Thus, the presentation of near simultaneous auditory and visual stimuli at different locations may be interpreted as emanating from a common source producing a bias in perceived location. This has been referred to as the ventriloquist effect (Howard & Templeton, 1966; Bertelson, Vroomen, de Gelder & Driver, 2000; Bischoff, Walter, Blecker, Morgen, Vaitl & Sammer, 2007). Overall, there are well established data describing the effect of multi-sensory stimuli on
behavioural and cortical activity, which identify processes not evident in uni-modal conditions.

Inter-modal attention studies are another means of investigating the effect of presenting stimuli from multiple modalities on response production. In general, inter-modal attention studies use a selective attention paradigm to consider the effect of attending to a stimulus in one modality amid stimuli in another modality (e.g. Hackley, Woldorff & Hillyard, 1990; Alho, Woods Algazi & Näätänen, 1992; Alho, Woods & Algazi, 1994; Woods, Alho & Algazi, 1992). Inter-modal attention studies typically present a rare and a regular stimulus in each of two modalities and require subjects to attend to one stimulus in one modality at a time (e.g. Hackley et al., 1990; Alho et al., 1992, 1994; Woods et al., 1992; Eimer & Schröger, 1998; Talsma & Kok, 2001, 2002). These studies have shown that inter-modal attention can affect early ERP processes, namely modulating the N1/Nd and P2/Pd waves (see chapter 3.6).

Cross-modal and inter-modal attention studies represent the predominant means of investigating the presentation of stimuli from different sensory modalities. The effects of these processes on cortical and ERP activity are comprehensively discussed in chapter 3. It is noted that the wide range of studies into multi-sensory processing have not previously incorporated stimuli from different sensory modalities into a task that appropriates the oddball methodology. Given that the oddball task is valuable in investigating sensory and attentional processes, it is argued that the use of multi-sensory stimuli within an oddball paradigm should provide a further means of investigating both sensory and multi-sensory processes.
1.5 The Inter-modal Oddball Task as a Study of Sustained Attention

In this dissertation, the primary experimental paradigm is an inter-modal version of the oddball task. In keeping with the protocols of the oddball paradigm, the inter-modal oddball task includes frequent standard and infrequent target stimuli. Although, it differs from the traditional task in that standards are presented in the visual sensory modality (as a pattern-reversal checkerboard) and targets are infrequent auditory tones.

The inter-modal oddball protocol incorporates, as far as practical, the basic structure common to the oddball task. These are: 1) the stimuli are presented from the same spatial location. Due to the need for a central presentation of the visual stimuli, the auditory target tones are presented through speakers placed either side of a monitor, 2) the standard and target stimuli are not presented together. When a target is presented the standard stimulus remains unchanged on the monitor, 3) the imperative stimuli are presented with a lower probability than standards (20 vs. 80 %) and, 4) stimuli are presented with common temporal contingencies – that is, a fixed inter-stimulus interval (ISI) is used. These factors ensure that the inter-modal oddball task can be considered a sustained attention task, noting that all stimuli are task-relevant and attended in order to facilitate performance.

1.6 Studies using the Inter-modal Oddball Task

The use of the oddball paradigm with stimuli from different sensory modalities has little precedent. There are a few studies that have used an inter-modal oddball task – with equivalent characteristics to that described above – to
investigate clinical populations. Brown, Clarke, Barry, McCarthy, Selikowitz and Magee (2005) reported ERP differences in children with attention-deficit/hyperactivity disorder (AD/HD) of the predominantly inattentive type (AD/HDin) compared with controls using an inter-modal oddball paradigm. In this study, participants were presented with a frequent visual stimulus (pattern-reversal checkerboard) and an infrequent target tone. This task was effective in differentiating the clinical group from a control group showing that they had several differences in the ERP to both auditory and visual stimuli. In two subsequent studies, which used the inter-modal oddball paradigm, differences in the ERP were identified in children with AD/HD of the combined type (AD/HDcom) compared with AD/HDin and controls (Barry, Clarke, McCarthy, Selikowitz & Brown, 2006) and two subtypes of AD/HDcom compared with controls (Barry, Clarke, McCarthy, Selikowitz & Brown, 2009b). A subsequent study found differences in adults with AD/HD (Barry, Clarke, McCarthy, Selikowitz, Brown & Heaven, 2009a). These results indicated the utility of this experimental paradigm. However, these data were interpreted based on pre-existing knowledge of both auditory and visual evoked potentials generated by tasks that typically used stimuli from a single sensory modality. Thus, the interpretations by Brown et al. (2005) and to some extent subsequent studies were made based on the assumption that ERPs in inter-modal oddball conditions were consistent with those generated in other fundamentally different tasks.

In the study by Brown et al. (2005) the direction of results were somewhat different from what may have been expected. For example, the AD/HDin children had smaller P2 amplitudes than controls, which was contrary to a
number of other studies (e.g. Satterfield, Schell & Nicholas, 1994; Kemner, Verbaten, Koelega, Buitelaar, van der Gaag, Camfferman & van Engelandel, 1996; Oades, Dittman-Balcar, Schpker, Eggers & Zerbin, 1996). The evident differences led to the speculation that the auditory and visual stimuli in this task might have been processed independently. Despite there being a large body of research into ERPs, using a vast array of experimental paradigms (e.g. oddball, selective attention, dichotic listening, choice reaction time, Go/NoGo, inter-modal attention, cross-modal attention) a review of the literature suggests little evidence of studies using an inter-modal oddball task. Given the utility of the oddball paradigm to investigate sensory and attentional processes, the demonstrated effect of multi-sensory stimuli on behavioural and cortical responses and the questions raised by these clinical studies, an investigation of the processes in inter-modal oddball conditions is warranted. The experiments presented within this dissertation represent a systematic investigation of stimulus processing in the inter-modal oddball task.
2. Electroencephalography and Event-related Potentials
2.1 General Introduction

This chapter will discuss electroencephalography (EEG) and the time-locked event-related potential (ERP). The focus will primarily be on ERPs to auditory stimuli, specifically long-latency auditory evoked potentials and the functional interpretation ascribed to them, although some discussion of ERP components produced by other forms of stimulation will be undertaken.

2.2 Electroencephalography and the Event-Related Potential

The EEG represents spontaneous electrical activity recorded from the scalp surface that is measured over time. EEG activity arises primarily, although not exclusively, from synchronous activation of post-synaptic potentials in large numbers of pyramidal cells within the cortex and some sub-cortical structures (e.g. thalamus) (Fisch, 1999; Fabiani, Gratton & Coles, 2000). Ongoing non-specific EEG activity may represent several different sensory and cognitive processes (Fornayova Key, Dove & Maguire, 2005).

The event-related potential is an allied measurement technique that is made up of averaged EEG responses, time-locked to a stimulus event. The underlying assumption of ERP averaging is that repeated stimulus events produce activation of common neuronal populations over successive trials (Fabiani et al., 2000). These responses are embedded amongst other random ongoing EEG activity. By averaging a sufficient number of trials, time locked to the stimulus presentation (signal), the ERP signal is enhanced, whilst ongoing EEG activity produced by random oscillations (noise) is reduced (Fisch, 1999; Fabiani et al., 2000; Picton et al., 2000; Luck, 2005). The result of ERP
averaging is a characteristic series of peaks that reflect cortical responses to a stimulus event. These peaks are generally labelled based on their polarity (negative [N] or positive [P]) and their latency or position (Fabiani et al., 2000). Thus, the N1 or N100 component is the first negative peak occurring at approximately 100 ms post-stimulus\(^1\) (Fornayova Key et al., 2005).

### 2.3 ERP Components

ERP peak activity cannot be considered the same as an ERP component. Theoretically, a component represents a function of stimulus processing that is produced by a specific generator process. The characteristic ERP waveform is potentially comprised of multiple different brain processes. Within any given peak waveform there may be several components present (Näätänen, 1992; Picton et al., 2000). Picton et al. (2000) state:

“Each of these “components” of the ERP has a specific topography, occurs over a particular period of time, and is related in a characteristic way to the experimental manipulations. ERP components are defined in terms of how they are distributed across the scalp and how they are affected by experimental manipulations” (p. 143).

\(^1\) It is noted that in this dissertation the use of peak latency as a descriptor for ERPs is used frequently. This is because the underlying functions evident in the ERP are yet to be established. That is, at the time of writing it has not been demonstrated whether ERP components in the inter-modal oddball task are equivalent to those produced by other paradigms.
The following sections will discuss the characteristics, functional interpretations and modulating factors of several ERP components. These will primarily, but not exclusively, be related to responses in the auditory modality.

2.3.1 The N1 component

The auditory N1 component is one of the first long latency potentials elicited by auditory stimulation. It is a negative deflection with a mean latency of approximately 100 ms and a fronto-central (Vaughan & Ritter, 1970) or vertex topography (Hari, Kaila, Katila, Tuomisto & Varpula, 1982). N1 is an exogenous cortical potential that has low inter-individual variability and high replicability (Roth, Kopell, Tinklenberg, Huntsberger & Kraemer, 1975; Shelley, Ward, Michie, Andrews, Mitchell, Catts & McConaghy, 1991; Sandman & Patterson, 2000; Fornayova Key et al., 2005). It is generated by cerebral mechanisms that are sensitive to relatively abrupt changes in the level of energy impinging on the sensory receptors, often, although not exclusively, from silence to sound (Näätänen & Picton, 1987). In the auditory modality it can be generated by a wide range of stimuli, from clicks to spoken words (Courchesne, 1990), although stimuli with very slow onsets do not elicit an N1 (Clynes, 1969). N1 has been associated with stimulus identification (Callaway & Halliday, 1982) or attribute selection (Hillyard & Picton, 1979). There are several processes that have been identified as modulating auditory N1 amplitudes including the temporal proximity of an eliciting stimulus to other auditory stimuli, stimulus frequency, whether attention is directed towards the eliciting stimulus and stimulus intensity (Näätänen & Picton, 1987; Näätänen, 1992; Fornayova Key et al., 2005).
The amplitude of the auditory N1 component is sensitive to the temporal proximity of the eliciting stimulus to other stimuli – that is, inter-stimulus interval (Davis, Mast, Yoshie, & Zerlin 1966; Butler, 1968; Nelson & Lassman, 1968; Hari et al., 1982; Fornayova Key et al., 2005). Early studies showed that as the time between stimulus presentation increases so does the amplitude of N1. Davis et al. (1966) showed a systematic decrease in their vertex potential, such that the amplitude was “…1/2 maximal at 3 sec, 1/4 at 1 sec and 1/6 at 0.5 sec” (p.112). Nelson and Lassman (1968) noted that increases in N1-P2 amplitude of “…about 1.85 μV with each twofold increase in ISI” (p. 1530). Both of these early studies suggested that maximal amplitude of N1 will be produced at ISIs of 6 seconds and possibly 10 seconds or more. Alternatively, as ISI becomes shorter amplitudes become smaller. This effect has been argued to reflect habituation to frequently presented stimuli (e.g. Butler, 1968). However, to be considered a reflection of habituation responses need to show response decrement over trials, response recovery to a change stimulus and dishabituation to a previously habituated stimulus (Thompson & Spencer, 1966). Several experiments suggest no evidence for dishabituation of the N1 (Thompson & Spencer, 1966; Fruhstorfer, 1971; Thompson, Groves, Teyler & Roemer, 1973; Woods & Elmasian, 1986; Barry, Cocker, Anderson, Gordon & Rennie, 1992; Barry, Feldmann, Gordon, Cocker, & Rennie, 1993. Budd, Barry, Gordon, Rennie & Michie, 1998). The study by Budd et al. (1998) found no evidence of dishabituation of the N1. They concluded that the reduction in N1 amplitudes, as a result of ISI, was largely due to refractoriness, potentially of two neural generators. Therefore, the amplitude of the N1 component is most
likely modulated by refractory period effects, mediated by the temporal proximity of intervening stimuli, rather than habituation.

Stimuli that are of a similar frequency also produce smaller N1 amplitudes. Butler (1968) found that as frequency differences between regular and intervening stimuli became larger so did N1 amplitudes. They noted increases of approximately 45% at frequency differences of 1000 Hz. The effects of stimulus frequency on the N1 are considered a reflection of the frequency specificity of neuronal populations in the auditory cortex. These have been shown to be tonotopically arranged in both animal (Brugge & Merzenich, 1973) and human subjects (Lauter, Herscovitch, Formby & Raichle, 1985). Intervening tones activate neural populations that are specific to the tones frequency. Thus, the number of non-refractory units that can be activated by the test tone varies as a function of the difference in frequency between test tones and intervening tones. That is, smaller N1 amplitudes are produced by tones of similar frequency as they activate common neuronal populations, which have refractory periods of several seconds. When frequency differences are large, previously inactive neurons are activated resulting in an enhanced response.

The N1 component is produced irrespective of whether attention is directed to the eliciting stimulus. However, the amplitude of N1 is enhanced by attention (Spong, Haider & Lindsley, 1965; Hillyard, Hink, Schwent & Picton, 1973; Knight, Hillyard, Woods & Neville, 1981; Mangun, 1995). Spong et al. (1965) were amongst the earliest to identify this ‘N1 attention effect’. They found marked increases in temporally recorded auditory evoked responses (AERs) when subjects attended a series of clicks than when they attended concurrently
presented visual stimuli. In a seminal paper on auditory selective attention, Hillyard et al. (1973) presented two separate streams of auditory tones binaurally to participants at a variable ISI of between 250 and 1250 ms and had subjects attend to infrequent deviant stimuli in one of the two streams. They demonstrated a clear increase in N1 amplitude to attended auditory stimuli using this dichotic listening task. They argued that this represented a “...tonically maintained set favouring ...” (p. 179) the attended ear, rather than an active stimulus discrimination and recognition process. That is, a stimulus set mode of attention, occurring at early processing stages, which allows stimuli in an attended channel to be processed further, whilst excluding unattended stimuli from further processing.

However, Näätänen and colleagues (Näätänen, Gaillard & Mäntysalo, 1978; Näätänen & Michie, 1979) challenged this conclusion, arguing that the apparent enhancement of this component might represent an additional endogenous process. Näätänen and Michie (1979) used a dichotic listening paradigm similar to that of Hillyard et al. (1973) but included constant long ISIs (800 ms compared with 250 – 1250 ms). In a comparison of ERPs to attended and non-attended inputs they identified a broad negative component beginning at 150 ms and continuing to 500 ms, which they called the processing negativity (PN). They argued that the PN was an endogenous component that arose from selective attention. They also suggested that the latency of this endogenous component may become shorter at faster stimulus presentation rates overlapping the exogenous N1. This was subsequently confirmed (Näätänen, Gaillard & Varey, 1981). Thus, it is argued that the enhancement of the N1 component to attended stimuli in selective attention tasks, as seen in the
Hillyard et al. (1973) study, may represent both an enhancement in the N1 generator process and the processing negativity (Näätänen & Michie, 1979; Näätänen, 1992).

The intensity of an eliciting stimulus can affect the amplitude and latency of the N1 component. The amplitude of N1 increases with increasing intensities and tends to level off with stimuli of high intensities and short ISIs (Buchsbaum, 1976). However, if ISIs are relatively long (> 2.5 s) or if intensities vary within a block then amplitudes can continue to increase (Gille, Böttcher & Ullsperger, 1986). In contrast, decreases in intensity reduce N1 amplitude and increase its latency (Rapin, Schimmel, Tourk, Krasnegor & Pollak, 1966; Beagley & Knight, 1967; Picton, Goodman & Bryce, 1970).

2.3.1.1 Multiple N1 components

The discussion of the N100 has presented a uni-dimensional account for this component. However, there is substantial evidence suggesting a multidimensional account is more appropriate, with several different overlapping components comprising the N1 wave (Näätänen & Picton, 1987). Kooi, Tipton and Marshall (1971) identified an additional negativity approximately 25-30 ms after N1 at temporal electrode sites. Wolpaw and Penry (1975) labelled this activity the T complex. They noted an auditory evoked response occurring at T3 and T4 electrodes that included N1 and P2 components plus additional superimposed activity. This T-complex comprised a positive (Ta) and negative (Tb) waveform at mid-temporal electrode sites in both hemispheres. Wolpaw and Penry (1975) demonstrated that the T-complex was larger contra-lateral to the ear of stimulation and in the right than left hemisphere. They suggested that
the T-complex was not the product of widespread non-specific cortical or subcortical activity, nor activity from the primary auditory cortex rather it most likely arose in the secondary auditory cortex. In a subsequent review of the literature, Näätänen and Picton (1987) suggested that generators of the T-complex may be in the auditory association areas on the superior temporal gyrus (STG).

Further evidence for multiple activity in the N1 latency range was reviewed by Näätänen and Picton (1987). They identified several components comprising the N1 and argued that there were potentially six contributors, with three being considered ‘true’ N1 components. Component I is consistent with the description first proposed by Vaughan and Ritter (1970). It is typically maximal at fronto-central electrode sites with a mean latency of approximately 100 ms. It was suggested that this component is produced in the auditory cortex on the supra-temporal plane (STP). The amplitude of Component I may be enhanced by stimuli of comparatively stronger intensities, as well as the direction of attention, and may be affected by refractory period effects. Component II is a biphasic component equivalent to the T-Complex as proposed by Wolpaw and Penry (1975 – see above). Component III has a mean latency of approximately 100 ms and is somewhat posterior to Component I – being maximal at the vertex and lateral central electrodes. The generators of this relatively non-specific component are unknown although this component may be generated by regions responsible for motor activity. Näätänen and Picton (1987) note that Component III is readily recorded “to auditory stimuli presented at intensities of greater than 60 dB SPL and at ISIs of greater than 4 – 5 s” (p. 412). They also suggest that this component would be evident to
stimuli from other modalities, that it would have ‘definite inter-modal refractory effects’ (p. 412) and knowledge of the timing of stimulus events would attenuate its amplitude. Component IV is the endogenous mismatch negativity - a broad negative component that overlaps N1 and represents activity to a mismatch between present stimuli and a previously established series of stimuli. This will be reviewed further below. Components V & VI represent sensory and attentional processing negativities respectively.

Later studies have identified additional early negativities when stimuli were presented at relatively long ISIs. Alcaini, Giard, Thévenet and Pernier (1994) presented subjects with a series of tones at individual ISIs of 1, 2, 4, 8, and 16 s in five separate blocks. For ISIs longer than 4 s they identified two negative components. The first was an early negativity (~95 ms) with a frontal topography that became larger as ISI increased up to, but not exceeding, 8 s. They argued that this component may represent an additional obligatory component in the auditory N1 wave. They also identified a later component (~140 ms), with a frontal topography, although more posteriorly oriented than the earlier negativity, that they suggested was consistent with Näätänen and Picton’s (1987) orienting Component III. Budd et al. (1998) also identified an additional late negative component (~140 ms) with a frontal topography in a study that had reasonably long ISIs (1, 3, or 10 sec). They also argued that this was consistent with Component III. Although they noted that there was no support for the claim that this component represents an orienting component as it did not express several criteria for habituation.
2.3.2 The P2 component

The P200 component is a positive deflection that peaks approximately 180 – 200 ms post-stimulus, and is maximal at centro-parietal electrode sites (Goodin, Squires, Henderson & Starr, 1978). P200 has several aspects in common with the N100 component. It is an exogenous cortical potential that has low inter-individual variability and high replicability (Roth et al., 1975; Shelley et al., 1991; Sandman & Patterson, 2000; Fornayova Key et al., 2005). P200 is sensitive to experimental conditions such as selective attention (Hillyard et al., 1973; Johnson, 1989; Hackley et al., 1990), stimulus change (Näätänen, 1990) and is larger when stimuli are attended (Picton, Hillyard, Krausz & Galambos, 1974; Goodin et al., 1978). P200 is larger to easily discriminated tones (Lindholm & Koriath, 1985), standard stimuli than targets (Hegerl & Juckel, 1993) and to irrelevant than relevant tones (Alho, Donauer, Paavilainen, Reinikainen, Sams & Näätänen, 1987). It has been described as representing a process of stimulus identification and analysis (Picton et al., 1974) or the early inhibition of irrelevant information or other channels competing for attention (Hansen & Hillyard, 1988; Rif, Hari, Hämäläinen & Sams, 1991; Hegerl & Juckel, 1993).

There is substantial overlap in the factors that affect both the N100 and P200 components and they tend to covary with similar stimulus conditions (Nelson & Lassman, 1973). This has led to these components historically being considered part of the N1/P2 complex or vertex potential (Davis P, 1939). However, there are several lines of evidence that suggests a dissociation of these components. For example, Paavilainen, Alho, Reinikainen, Sams and
Näätänen (1991) demonstrated a difference in scalp distributions of these components, showing that whilst the N100 inverted polarity above and below the sylvian fissure, the P200 did not. Furthermore, the N100 was larger in the hemisphere contralateral to the ear of stimulation whilst P200 was consistently larger in the right hemisphere. Other studies have shown that the amplitude of these components is also attenuated with the administration of alcohol - although, the amount of attenuation of P200 amplitude is more resistant to the effects of alcohol than that seen in the N100 (Pfefferbaum, Roth, Tinklenberg, Rosenbloom & Kopell, 1979; Jääskeläinen, Pekkonen, Hirvonen, Sillanaukee & Näätänen, 1996). P200 has also been shown to differ from the N1 in subjects with temporo-parietal lesions (Knight, Hillyard, Woods & Neville, 1980).

Although the generators of the P200 component have not been reliably separated from the N1 component (Fornayova Key et al., 2005) studies using magnetoencephalography (MEG) have suggested that they may be located in the auditory cortex. Godey, Schwartz, de Graff, Chauvel and Liégeois-Chauvel (2001) suggested possible sources may be evident in the planum temporal and/or auditory association areas.

### 2.3.3 The N2 component

The N200 is a negative component occurring between 100 – 250 ms post-stimulus. The N200 is considered an endogenous component, representing processes related to the deviation from an ongoing stimulus train (Hoffman, 1990). The N200 wave is comprised of several sub-components including the mismatch negativity – which reflects an automatic cerebral response to physical stimulus deviance, N2b – representing conscious
discrimination of stimulus change to attended stimuli and N2c – or classification N2 which occurs when a speeded response is required to target stimuli (Pritchard, Shappell & Brandt, 1991). The MMN and N2b components will be reviewed separately below.

2.3.3.1 The mismatch negativity (MMN)

The mismatch negativity (MMN) is a frontally distributed broad negativity which extends over 200 ms post-stimulus (Sams, Paavilainen, Alho & Näätänen, 1985; Näätänen, 1992). It reflects an endogenous process related to stimulus deviation – that is, the detection of a change between a neuronal trace produced by a previously established series of stimuli and a subsequent deviant stimulus (Näätänen & Picton, 1987; Näätänen, 1992). It is generally identified as a difference wave that results from the subtraction of ERPs to frequently presented auditory stimuli from those to infrequent deviant auditory stimulus events (Fabiani et al., 2000). MMN can be elicited in the absence of attention and is generally more evident when subjects are ignoring a stimulus train (e.g. reading a book), as it is not overlapped by other later negative activity (see below). The MMN can be elicited by changes in intensity (Snyder & Hillyard, 1976; Näätänen, Paavilainen, Alho, Reinikainen & Sams, 1987), duration (Näätänen, Paavilainen & Reinikainen, 1989), frequency (Näätänen et al., 1978; Sams et al., 1985) and changes in spatial location (Paavilainen, Karlsson, Reinikainen & Näätänen, 1989). It is the difference between subsequent stimuli rather than stimulus parameters themselves that is the key criteria for the elicitation of the MMN (Näätänen & Picton, 1987). As the magnitude of deviation becomes greater, MMN latency becomes shorter. This can mean that with large
deviations the MMN can overlap the N1 peak (Näätänen, Simpson & Loveless, 1982; Näätänen & Gaillard, 1983; Duncan & Kaye, 1987; Scherg, Vajsar & Picton, 1989; Novak, Ritter, Vaughan & Wiznitzer, 1990; Näätänen, 1992). Näätänen (1992) described two subcomponents of the MMN – a sensory-specific component evident over temporal electrode sites with generator sources on the supratemporal plane of the auditory cortex and a frontal component most likely with generators in the frontal lobe, mainly in the right hemisphere (see also Giard, Perrin, Pernier & Bouchet, 1990).

2.3.3.2 The N2b component

The N2b is a large central negative peak, occurring between 200 and 250 ms, that is elicited by deviant stimuli when subjects are attending to the stimulus train. Where stimuli are attended the N2b tends to overlap the MMN (Donchin, Ritter & McCallum, 1978). Both negative components represent processes related to stimulus change. However, when stimuli are ignored, physically deviant stimuli produce only the MMN, whereas when stimuli are attended both negative components are produced. The N2b differs from the MMN in topography – being more centrally distributed, and morphology – being a sharper peak with a later onset and shorter duration (Näätänen & Gaillard, 1983). It is differentially affected by factors such as magnitude and probability of deviance, as well as sequential or temporal effects (Näätänen & Gaillard, 1983). The latency of N2b correlates well with reaction time and may represent discrimination processes related to the detection of an attended stimulus (Ritter, Simpson, Vaughan & Friedman, 1979). The N2b is not dependant on physical deviance per se. It can be elicited by a single stimulus presented over long ISIs,
and also by stimulus repetition (Näätänen, 1986) and omission (Simson, Vaughan & Ritter, 1976; Renault, Ragot, Le Serve & Redmond, 1982) where these factors represent stimulus deviance. Furthermore, unlike the MMN, the elicitation of the N2b requires conscious detection of stimulus change (Sams et al., 1985). It has been suggested that the N2b might reflect expectancy violation (Näätänen, 1986) or a pre-conscious process that triggers later conscious processes (Näätänen, 1992). It has been suggested that the N2 has sources evident bilaterally in the supra-temporal auditory cortex (Bruneau & Gomot, 1998).

2.3.4 The P3b component

The P300 (also known as P3b) is one of the most widely studied ERP components. It is a large parietal positive going wave that can occur between 300-900 ms post-stimulus (Sutton, Braren, Zubin & John, 1965). P3b is readily elicited by stimuli that provide information or are salient to a subject (Sutton et al., 1965; Ritter & Vaughan, 1969; Hillyard, Squires, Bauer & Lindsay, 1971; Paul & Sutton, 1972; Hillyard et al., 1973; Picton & Hillyard, 1974). In their pioneering study, Sutton et al. (1965) found that the amplitude of the P300 was greater when subjects were uncertain about a subsequent stimulus. This indicated the importance of subjective (endogenous) rather than stimulus (exogenous) factors in the production of this component. The P3b is associated with cognitive activities such as decision making, signal probability, orienting, attention, discrimination, uncertainty resolution, stimulus relevance, stimulus evaluation, memory processes and information delivery (Courchesne, Hillyard & Galambos, 1975; Squires N, Squires & Hillyard, 1975; Knight, 1996; Andreassi,
The magnitude of the P300 component in auditory, visual and somatosensory modalities, is augmented when the probability of a relevant stimulus occurrence is low (Duncan-Johnson & Donchin, 1977; Donchin, 1981; Wickens, Kramer, Vanasse, & Donchin, 1983; Johnson, 1986; Polich & Comechero, 2003), and with greater stimulus intensities (Ritter & Vaughan, 1969; Picton & Hillyard, 1974; Roth, Blowers, Doyle & Kopell, 1982; Covington & Polich, 1996; Gonsalvez, Barry, Rushby & Polich, 2007) and significance (Squires et al., 1975; Squires K, Donchin, Herning & McCarthy, 1977; Picton & Stuss, 1980; Donchin & Coles, 1988). As the P3b is related to the relevance of a stimulus it is typically smaller if stimuli are not attended. The latency of the P3b component is considered a marker of stimulus evaluation time (Kutas, McCarthy & Donchin, 1977); as the categorisation of a stimulus becomes more difficult P3b latency increases (Courchesne, Hillyard & Courchesne, 1977; Kutas et al., 1977; Coles, Smid, Scheffers & Otten, 1995). P3b latency is dependent on the manipulation of perceptual variables rather than stimulus-response compatibility (McCarthy & Donchin, 1981; Magliero, Bashore, Coles & Donchin, 1984; Smid, Mulder, Mulder & Brands, 1992; Verleger, 1997) and has been shown to be independent of response production (Kutas et al., 1977; Duncan-Johnson, 1981; McCarthy & Donchin 1981; Donchin & Coles, 1988; Verleger, 1997).

Sources of the P3b are not clearly established. However, inter-cranial recordings, and scalp recorded source localisation suggests possible generators in the thalamus, hippocampus, parahippocampal gyrus, amygdala, medial temporal lobe, auditory association cortex, superior temporal gyrus, inferior parietal lobule and the temporal-parietal junction (Katayama, Tsukiyama
There are a few studies that have shown multiple P3b components elicited to a single stimulus within the one task (e.g. Poon, Thompson, Williams & Marsh, 1974; Johnson & Donchin, 1978; Stuss & Picton, 1978; Stuss, Toga, Hutchison & Picton, 1980). Johnson and Donchin (1985) using a time estimation feedback paradigm found two P3 components that occurred several hundred milliseconds after one another. They noted that both P3s had polarity, scalp distribution and wave shape consistent with P3b and these varied systematically with regard to psychological variables. Overall, this suggested evidence for successive mental events elicited by complex stimuli (i.e. stimuli in a feedback paradigm). Subsequently, Fein and Turetsky (1989) using a less complex three-tone oddball task found P3s to auditory targets occurring at different latencies. In a subset of subjects there was evidence of two separate P3s occurring to the one stimulus. They argued that these separate P3s represented a two-stage strategy for evaluating and classifying the stimulus. The first represented deviance detection, where the infrequent tone was identified as standard or non-standard. The second was a subsequent process that represented the classification of a stimulus as target as opposed to
infrequent non-target. Taken together, these studies suggest that task requirements may produce separate activation in response to an imperative stimulus.

2.3.5 The P3a component

The P3a is an additional positive component occurring in the P3 latency range. The P3a was initially described by Squires et al. (1975). In this seminal study they showed that the P3 wave to auditory stimuli comprised two separate positive components (P3a & P3b), with the P3a occurring earlier (220-280 ms). The P3a was generated by changes in an ongoing stimulus whether the subjects ignored or attended that stimulus (i.e. it was not task dependant), and regardless of whether the change was one of auditory frequency or intensity. When stimuli were ignored the P3a evinced a fronto-central topography. In contrast, when stimuli were attended the P3a had a centro-parietal distribution – a topography that was distinct from the P3b. They suggested that the difference in topography was potentially due to an overlap by positive going slow wave activity in attend conditions. Squires et al. (1975) tentatively suggested that the P3a represented “… a basic sensory mechanism which registers any change in a background stimulus, perhaps by means of mismatching a specific neural “model” established by repetition of the background” (p. 399). Subsequent research suggests that the P3a reflects stimulus deviance and involuntary shifts in attention to changes in the environment (Snyder & Hillyard, 1976; Näätänen, 1992; Holdstock & Rugg, 1993; Friedman & Simpson, 1994) as well as stimulus evaluation (Polich, 2007).
The P3a component has frequently been investigated in three-stimulus oddball tasks. This task is a variant of the traditional oddball task that includes an additional infrequent stimulus that does not require a response. In auditory variations of this task, the third stimulus may be an infrequent non-unique deviant tone, often with an equivalent probability to that of the targets or it may be a unique novel stimulus (e.g. distinct environmental sounds presented in an auditory context).

The P3a is sensitive to variations in stimulus probability (Friedman & Simpson, 1994; Simons & Perlstein, 1997; Friedman, Cycowicz & Gaeta, 2001) and the relationship of stimuli within a paradigm can affect amplitude, timing and topography (Katayama & Polich, 1998). Thus, in a three-stimulus task, P3a to infrequent non-target deviant stimuli typically exhibits a centro-parietal scalp distribution and tends to be smaller and later than the P300 to either targets or novel stimuli (Courchesne, Courchesne & Hillyard, 1978; Pfefferbaum, Ford, Roth & Kopell, 1980; Pfefferbaum, Ford, Wenegrat, Roth & Kopell, 1984; Grillion, Courchesne, Ameli, Elmasian & Braff, 1990; Oades, Zerbin & Dittmann-Balcar, 1995a; Oades, Dittmann-Balcar & Zerbin, 1995b; Cycowicz, Friedman & Rothstein, 1996; Cycowicz & Friedman, 1997, 1998; Katayama & Polich, 1996a, 1996b, 1998; Simons, Graham, Miles & Balaban, 1998; Goldstein, Spencer & Donchin, 2002; Gaeta, Friedman & Hunt, 2003). In contrast, the P3a to novel stimulus events tend to produce larger activity fronto-centrally (Courchesne et al., 1975; Courchesne, Kilman, Galambos & Lincoln, 1984; Knight, 1984; Courchesne, Lincoln, Kilman & Galambos, 1985; Grillon et al., 1990; Friedman, Simpson & Hamberger, 1993; Rugg et al., 1993; Friedman & Simpson, 1994; Kazmerski & Friedman, 1995; Spencer, Dien & Donchin, 1999).
It has been shown that frontal lobe functions are necessary for P3a generation (Knight, 1984). The activation of frontal regions represents a rare, novel and physically alerting stimulus activating frontal attentional systems (Potts, Liotti, Tucker & Posner, 1996; McCarthy, Luby, Gore & Goldman-Rakic, 1997; Verbaten, Huyben & Kemner, 1997). However, this frontal activity habituates rapidly — in as few as six presentations of a novel stimulus. With repeated presentation of a previously novel stimulus, frontal activity becomes smaller and the P3a becomes more parietally focussed. This change in topography with repetition represents the categorisation of a previously novel stimulus event (Friedman et al., 2001).

Despite the difference in scalp distribution, the P3a is considered to represent activity in frontal attentional systems, including the prefrontal cortex (PFC) and the anterior cingulate (ACC) (Friedman et al., 2001; Polich, 2003, 2007). However, Friedman et al. (2001) suggest that there is good evidence for a distributed network of brain regions involved in P3a elicitation. Regions implicated include the auditory cortex, posterior hippocampus, temporal-parietal junction, and the medial frontal gyrus (see Knight, Scabini, Woods & Clayworth, 1988; Knight, 1996; McCarthy et al., 1997; Menon, Ford, Lim, Glover & Pfefferbaum, 1997; Alho, Winkler, Escera, Huotilainen, Virtanen, Jääskeläinen, Pekkonen & Ilmoniemi, 1998; Opitz, Mecklinger, Friederici & von Cramon, 1999; Downar, Crawley, Mikulis & Davis, 2000).

2.3.6 Models of the P3

There are several models proposed to account for P3 activity. P3 has been linked with the amount of attentional resources available to a subject.
Kaneham (1973) proposed a capacity model of attention arguing that humans have a limited capacity to perform mental work and activities that demand attention compete for limited resources. Furthermore, physiological arousal varies with variations in effort and arousal is closely related to the resources available for task performance. In line with this, the amplitude of P3 is thought to index the resources available to perform a task, such that undemanding tasks produce relatively large P300 components with short latencies, whilst P300 amplitude is smaller and latency longer when task demands require greater effort or are completed in conjunction with a secondary task (Kok, 2001; Polich, 1987, 2007).

A further theoretical model of P300, largely derived from target processing in oddball tasks, was proposed by Donchin and colleagues (Duncan-Johnson & Donchin, 1977; Johnson & Donchin, 1978; Donchin, 1981; Donchin, Karis, Bashore, Coles & Gratton, 1986). The context updating model suggests that the P300 indexes the processing of an incoming stimulus that updates a previously established neural model of the environment. The P300 represents the comparison of an incoming stimulus to the representation held within working memory. A change in the stimulus environment produced by an infrequent stimulus event (i.e. target stimuli) requires an updating of the stimulus representation held within working memory. The allocation of resources to the updating of the stimulus context is responsible for P300 (P3b) production (Donchin, 1981; Donchin et al., 1986).

Polich (2003, 2007) proposed an integrative model that described processes related to both P3a and P3b sub-components. The generation of P3a
and P3b are likely to result from frontal and temporal/parietal activation respectively (Ebmeier, Steele, MacKenzie, O’Carroll, Kydd, Glabus, Blackwood, Rugg & Goodwin, 1995; Kirino, Belger, Goldman-Rakic & McCarthy, 2000). The P3a represents an updating of working memory in frontal lobe structures. These structures are activated by rare or physically alerting stimuli (Potts et al., 1996; McCarthy et al., 1997; Verbaten et al., 1997) (e.g. the discrimination processes in the oddball task) and are sensitive to attentional demands produced by task performance (Posner & Petersen, 1990; Pardo, Fox & Raichle, 1991; Posner, 1992). Polich (2007) argued that:

“…stimulus information is maintained in frontal lobe working memory and monitored by anterior cingulate structures. When focal attention for the standard stimulus is disrupted by the detection of a distracter or a target (stimuli that garner attention automatically or purposefully from task demands), the P3a is perhaps generated by the activation pattern of the anterior cingulate and related structures” (p. 11).

Information that requires further updating of stimulus context is subsequently transferred from these frontal attentional systems to infero-temporal regions (see Desimone, Miller, Chelazzi & Lueschow, 1995) potentially through attentional systems in the right hemisphere. This process engages memory storage operations by activating temporal/parietal cortical structures - via the hippocampus - which produces the P3b. Polich (2007) argued that every “P300” is composed of the P3a and P3b subcomponents. They suggest that the morphology of the P3 varies with the stimulus context that elicits them. Thus, infrequent irrelevant stimuli engages greater frontal resources which
produces larger activity over frontal scalp regions (i.e. large P3a), whilst infrequent task-relevant stimuli generates greater activity in temporal/parietal structures eliciting large parietal P3 activity (i.e. P3b).

2.3.7 Emitted stimulus potentials

When an expected stimulus does not occur, an event-related response to the stimulus omission is produced. The emitted stimulus response\(^2\) consists of a negative and a positive wave that occur approximately 200-300 and 300-400 ms after stimulus omission respectively. The negative emitted response is produced by omissions in visual (Barlow, Morrell & Morrell, 1967; Simson et al., 1976; Renault & Le Serve, 1978; Renault et al., 1982; Renault, 1983), auditory (Sutton, Tueting, Zubin & John, 1967; Weinberg, Grey Walter & Crow, 1970; Ruchkin, Sutton & Teuting, 1975; Simson et al., 1976) and somatosensory (Klinke, Fruhstorfer & Finkenzeller, 1968) stimulus modalities. In the visual modality the topography of the negative response is prominent at parieto-occipital regions (Renault & Le Serve, 1978, 1979; Simson et al., 1976; Renault et al., 1982). Renault et al. (1982) showed that this parieto-occipital negativity had onset at the time of stimulus omission and peaked around 220 ms later. They argued that this was indicative of the detection and evaluation of the stimulus omission and response selection, noting that where a response to stimulus omission was required, this negativity consistently preceded response production. Simson et al. (1976) compared the response to stimulus omissions in the visual and auditory modalities. They showed that, in contrast with the

\(^2\) Also referred to as the omitted stimulus response.
posterior topography of the emitted negativity to visual stimuli, omitted auditory stimuli produced a negativity with a fronto-central topography. This suggested that the emitted negativity may be modality-specific (Simson et al., 1976; Simson, Vaughan & Ritter, 1977; Renault, Ragot & Le Serve, 1980).

Several authors have identified a late positive component produced by omitted stimuli (Barlow, Morrell & Morrell, 1965; Sutton et al., 1967; Klinke et al., 1968; Barlow, 1969; Ritter & Vaughan, 1969; Weinberg et al., 1970; Picton et al., 1974; Picton & Hillyard, 1974; Weinberg, Grey Walter, Crow & Aldridge, 1974; Renault & Le serve, 1978; Simson et al., 1976; Renault et al., 1982). Sutton et al. (1967) suggested that stimulus omission acts as an endogenous stimulus and that the latency of the positive response reflects the time that the stimulus should have occurred. The emitted positive response has been shown to have a similar timing and morphology to the evoked response in visual (Barlow et al., 1967) and auditory modalities (Ruchkin et al., 1975). Overall, this suggests that the emitted response is consistent with the P3b. Furthermore, Simson et al. (1976), in a direct comparison of visual and auditory modalities, showed that the emitted positive component had a similar parietal focus regardless of modality. They argued that this component, unlike the negative response, may be modality non-specific.

In the above studies, attention was directed to the omitted stimulus. Busse and Woldorff (2003) demonstrated that irrelevant auditory stimulus omissions also produce an endogenous ERP response. Using functional magnetic resonance imaging (fMRI) they identified a negative omission response over posterior regions and a positive response over frontal regions to
unattended omitted stimuli. They noted that the frontal topography of the positive component suggested that it was indicative of a P3a response to omitted stimuli in this task.

The sources of the emitted stimulus response have been investigated using MEG. Raij, McEvoy, Mäkelä and Hari (1997) identified sources to auditory tone omissions bilaterally in the supratemporal cortex, in the superior temporal sulcus (STS) and posterolateral frontal cortex. They suggested that this demonstrated evidence for an auditory cortical template of expected events being modulated by the omission of an expected stimulus and activation of general frontal attentional systems.

2.4 Chapter Summary

This chapter has described the characteristics of several ERP components elicited by stimuli in various experimental paradigms. These have been discussed in terms of their latency, scalp topography and cortical sources. It has shown that several factors modulate both early sensory and late cognitive ERP components. The ERPs identified in this chapter will provide the framework from which ERPs to inter-modal oddball targets will be interpreted. The focus will be on activity occurring in the N1 – P3 latency range.
3. The Processing of Stimuli from Multiple Modalities
3.1 General Introduction

The previous chapter considered ERP components – primarily auditory – produced by paradigms that present stimuli largely within the one sensory modality. However, stimuli in the environment often comprise multiple components from different sensory modalities (e.g. visual cues as well as speech sounds in the processing of spoken language). Stimuli from different sensory modalities presented in close temporal and spatial proximity are typically perceived as a unified perceptual whole (Stein & Meredith, 1993; Giard & Peronnet, 1999). The binding and integration of multi-sensory stimuli conveys a distinct environmental advantage as it provides information that may be unavailable from a uni-sensory source. This can influence perceptual experience and response production. As noted in chapter 1, several lines of research have shown that the presentation of stimuli from different modalities, in varying contexts, affects behavioural and cortical responses (Donchin & Lindsley, 1965; Andreassi & Greco, 1975; Hillyard et al., 1984; Farah et al., 1989; Eimer & Schröger, 1998; Schröger & Widmann, 1998; Driver & Spence, 1998a, 1998b; Giard & Peronnet, 1999; Teder-Sälejärvi, Hillyard, Röder & Neville, 1999a; Teder-Sälejärvi et al., 1999b; McDonald et al., 2000; Fort, Delpuech, Pernier & Giard, 2002a, 2002b; Molholm et al., 2002; Teder-Sälejärvi et al., 2002; McDonald et al., 2003; Fort & Giard, 2004; Brown et al., 2005; Busse, Roberts, Crist, Weissman & Woldorff, 2005; Talsma & Woldorff, 2005). The inter-modal oddball task introduced in this dissertation uses stimuli from different sensory modalities (i.e. auditory & visual). The proceeding section will consider behavioural responses as well as sub-cortical and cortical processes.
identified with the processing of multi-sensory stimuli, with the focus primarily but not exclusively on the combination of auditory and visual stimuli.

3.2 Multi-sensory Processing

Multi-sensory integration (MSI) refers to the process of binding near-simultaneous stimuli from different sensory modalities (Spence et al., 2009). A frequent method of investigating processes related to MSI, taken and adapted from single cell studies in animals, is to investigate the difference in response to bimodal stimuli compared with stimulus elements from separate modalities presented alone. If responses to the combined stimuli are larger than the sum of responses to the uni-modal stimuli it may be concluded that some facilitatory integration has occurred (Teder-Sälejärvi et al., 2002; see also Calvert, 2001; Besle, Fort & Giard, 2004; Besle, Bertrand & Giard, 2009; Stein, Stanford, Ramachandran, Perrault & Rowland, 2009).

When stimuli from two sensory modalities are presented simultaneously, the response outcome is generally faster than responses to either of the stimulus elements when presented separately (Raab, 1962; Donchin & Lindsley, 1965; Andreassi & Greco, 1975; Miller, 1982, 1986, 1991; Schröger & Widmann, 1998; Giard & Peronnet, 1999; McDonald et al., 2001b; Molholm et al., 2002; Talsma & Woldorff, 2005). This has been referred to as the redundant signals effect. It was initially proposed that the mechanism leading to response time facilitation may represent a process of competition between bi-modal inputs, with responses produced by whichever of the sensory inputs is processed first; this is known as the race model (Raab, 1962). However, as reaction times are typically shorter than this model would predict an alternative
to the race model was proposed, initially by Miller (1982, 1986, 1991). Miller’s co-activation model suggests that facilitation is the result of co-activation rather than competing inputs and response production is activated when a threshold criterion is reached. This occurs earlier when two input sources are present. Several subsequent studies have shown support for this model (Schröger & Widmann, 1998; Giard & Peronnet, 1999; Fort et al., 2002a, 2002b; Teder-Sälejärvi et al., 2002).

### 3.3 Brain Regions Related to Multi-sensory Processing

A large body of research has shown that the mechanisms that produce facilitation effects to multi-sensory stimuli are mediated by the activation of subcortical and cortical structures. The most widely studied region is the superior colliculus (SC). This mid-brain structure has been investigated extensively in several animal models including cats (Gordon, 1973; Meredith & Stein, 1983; Peck, 1987; Wallace & Stein, 1994, 1997; Populin & Yin, 2002), monkies (Jay & Sparks, 1984), and ferrets (King & Palmer, 1985: for a review see Stein & Meredith, 1993). The SC contains overlapping neurons that respond to several modalities including audition, vision and somatosensation, with response to bi- and tri-modal stimulation often several magnitudes larger than that produced by uni-sensory inputs (Stein & Meredith, 1993; Calvert, Campbell & Brammer, 2000; Calvert & Thesen, 2004). The SC largely subserves processes related to spatial attention and orienting, with sensory stimuli originating from the same spatial location activating equivalent regions within this structure. Other subcortical structures that respond to multi-sensory stimuli (MS) – although not as extensively studied – include the insula/claustrum, the thalamus, the rhinal...

There are several cortical regions implicated in MSI. Animal studies have identified regions in the STS, intraparietal sulcus (IPS), parieto-preoccipital cortex, frontal cortical structures and sensory-specific regions (i.e. primary/secondary sensory cortices) (Jones & Powell, 1970; Chavis & Pandya, 1976; Seltzer & Pandya, 1978, 1980; Mesulam & Mufson, 1982; Pandya & Yeterian, 1985; Di, Brett & Barth, 1994; Barth, Goldberg, Brett & Di, 1995; Schroeder, Lindsley, Specht, Marcovici, Smiley & Javitt, 2001; Schroeder, Smiley, Fu, McGinnis, O’Connell & Hackett, 2003; Schroeder, Molholm, Lakatos, Ritter & Foxe, 2004; Klemen & Chambers, 2011).

Human studies provide converging evidence of poly-modal, ostensible uni-modal and other regions being activated by multi-sensory stimuli. For example, Giard and Peronnet (1999) showed that audio-visual objects enhanced activation of the auditory cortex (i.e. polarity inversion above and below the sylvian fissure) around the N1 latency range (i.e. 105 ms). Besle et al. (2009) noted that this effect was somewhat different from the N1 response to uni-modal stimuli and suggested that bi-modal response enhancement might only partially overlap the N1 generators. Teder-Sälejärvi et al. (2002) used brain electrical source analysis (BESA) to identify dipole sources evident to bi-modal stimuli at around 160 ms in the ventral occipital cortex and around 230 ms in the anterior temporal peri-sylvian fissure. They argued that the auditory component of the bimodal stimuli activated primary visual areas and that the combined
bimodal stimuli activated auditory association areas or polymodal cortices on the superior temporal plane.

Speech perception, a process that is specific to humans, often requires the integration of stimuli from different sensory modalities (e.g. the synthesis of speech sounds and lip movements in noisy environments). Several cortical regions have been implicated in the perception of speech. Callan, Callan, Kroos and Vatikiotis-Bateson (2001) investigated EEG activity produced by speech sounds presented with concordant or non-concordant linguistic facial movements. Independent components analysis (ICA) and low resolution electromagnetic tomography (LORETA) identified two facilitatory effects for concordant audio-visual stimuli in high frequency EEG activity. The first was an enhancement around 150-300 ms in the left superior temporal gyrus and the second was activation evident across the time course (with a peak around 100-250 ms) in parietal, occipital, temporal, prefrontal and sensorimotor regions. Further evidence from magnetoencephalography has shown that speech sounds matched with letters activate left fronto-parietal regions, the left and right STS, right frontal lobe and right temporo-parietal-occipital regions between 245 – 495 ms post stimulus (Raij, Uutela & Hari, 2000).

The anatomical regions modulated by multi-sensory stimuli have also been identified using imaging techniques. These have superior spatial resolution to electrophysiological measures. These studies have identified multi-sensory effects on several regions of the human brain including the SC, insula/claustrum, STS, IPS, frontal lobe structures and sensory specific cortices (Calvert, Bullmore, Brammer, Campbell, Williams, McGuire, Woodruff, Iversen...
& David, 1997; Calvert, Brammer, Bullmore, Campbell, Iversen & David, 1999; Calvert et al., 2000; Bushara, Grafman & Hallett, 2001; Calvert, Hansen, Iversen & Brammer, 2001; Macaluso, George, Dolan, Spence & Driver, 2004; Fairhall & Macaluso, 2009).

Calvert et al. (2001) conducted a functional magnetic resonance imaging (fMRI) study on integration effects using auditory-visual non-speech stimuli. They presented participants with a pattern reversal checkerboard and an infrequent burst of white noise. In two experiments, the tone bursts and visual stimuli were presented either synchronously or asynchronously. Synchronous auditory-visual stimuli produced enhanced activation in the SC, the insula/claustrum, the left STS, right IPS and the frontal lobe demonstrating the effect of MS stimuli on a broad range of sub-cortical and cortical structures.

Calvert et al. (1997) used fMRI to investigate the effect of multi-sensory speech stimuli on cortical activity. They showed that the auditory cortex was activated by silent lip reading. This suggested that visual speech stimuli activated primary auditory sensory areas. They subsequently showed enhanced activity in auditory and visual sensory cortices when speech stimuli were both heard and seen (Calvert et al., 1999). An investigation into the synthesis of speech identified integration effects in the left STS as well as enhancements in auditory and visual cortices (Calvert et al., 2000). This study showed that the left STS was the only area that met the criterion for multi-sensory integration (i.e. appropriate response enhancement and depression to congruent and incongruent stimuli respectively). It was argued that activity in the left STS might have a prominent role in integration processes, at least for speech stimuli, and
that the enhancement produced in sensory cortices was likely due to activation of hetero-modal cortical regions being projected to the sensory cortex.

In a subsequent review of the literature, Calvert (2001) suggested that the enhancements in sensory cortices might be produced through back-projections from left STS. However, this was most likely to occur when there were established connections between the stimuli (i.e. speech stimuli). For newly learned associations, such as those imposed by task demands, they suggested that enhancements in the sensory cortices might be mediated by processes in the frontal lobe. This author also suggested that the SC, STS and IPS, which represent poly-modal processing regions, may reflect different aspects of the integration process. It was argued that the SC may be sensitive to the temporal correspondence of cross-modal stimuli, the STS might be important in integrating complex featural information, and the IPS may be specialised for cross-modal links in attention and the synthesis of spatial cues.

Overall, the studies reviewed above suggest that sub-cortical regions such as the SC and insula/claustrum and cortical regions such as the STS (particularly in the left hemisphere), the IPS (in the right hemisphere), the frontal lobe and sensory cortices are all implicated in the processing of multi-sensory inputs.

3.4 Psychophysiological Effects of Multi-sensory Processing

Psychophysiological research has shown that there are enhancements in electrophysiological responses to multi-sensory stimuli. In an early bi-modal response time study Andreassi and Greco (1975) showed that along with a
facilitation of response time, ERPs recorded from O2 and Cz were larger to bisensory (auditory-visual) than uni-sensory stimuli.

Schröger and Widmann (1998), using an auditory-visual spatial oddball task, found faster responses to bi-modal than uni-modal stimuli and showed that the facilitation indicated a co-activation of inputs (i.e. these data did not support the race model). They also identified two co-activation processes within the ERP. The first represented independent co-activation up to 180 ms post-stimulus. The second later process was indicative of interactive co-activation, that reflected a central level process rather than one related to either sensory or motoric activation.

The effect of multi-sensory stimuli on the elicitation of ERPs has been shown to be affected by the direction of attention (Talsma & Woldorff, 2005; Talsma, Doty & Woldorff, 2007; see also Senkowski, Talsma, Hermann & Woldorff, 2005 for attention effects on gamma response). Talsma and Woldorff (2005), using a spatial attention task, showed that attention modulated the ERP frontally at 100 ms, and centro-medially at 190 ms (positivity), 250 ms (negativity) and 300-350 ms (positivity) post-stimulus. Subsequently, Talsma et al. (2007), using centrally presented multi-sensory stimuli, which avoided the effect of spatial differences, showed attention effects as early as 50 ms post-stimulus. This study showed that these were evident when both stimuli were attended. When subjects were required to attend only one sensory modality, there was evidence of a depression of integration in early ERP activity. However, they noted that later integration effects were evident even when only one stimulus modality was attended.
Several studies have suggested that ERPs to multi-sensory stimuli are affected across the processing chain – from early sensory to later cognitive stages (Giard & Peronnet, 1999; Fort et al., 2002a, 2002b; Teder-Sälejärvi et al., 2002). Giard and Peronnet (1999) showed that combined auditory-visual stimuli, compared with the sum of uni-modal inputs, produced larger ERP activity at several processing stages over posterior visual areas evident at 40 – 90 ms, 110 – 145 ms, and 155 – 200 ms, over temporo-central areas between 95 – 180 ms, and over the right frontal-temporal hemiscalp between 140 – 165 ms. These data were interpreted as evidence for co-activation at very early stages and at several stages through the stimulus processing chain. They argued that this represented the modulation of both sensory-specific and non-specific cortical structures.

In subsequent studies similar results have been demonstrated (Fort et al., 2002a, 2002b; Teder-Sälejärvi et al., 2002). However, the study by Teder-Sälejärvi et al. (2002) questioned the differences in early effects identified by Giard and Peronnet, specifically the effects evident over visual areas. They used a simple auditory-visual response time task and compared the difference between multi-sensory stimuli with the summation of uni-sensory inputs. The results were largely consistent with that of the Giard and Peronnet study, including significant facilitatory effects in the ERP to bi-modal stimuli as early as 10 – 20 ms post-stimulus. However, the earliest effects varied as a function of the baseline period. Thus, activity peaked earlier when the ERP baseline was

3 See Foxe et al. (2000) for an investigation of the time course of auditory and somatosensory integration effects.
shifted from -100 – 0 to -100 – -50 ms. They argued that this was largely a result of anticipatory potentials which were summed once but subtracted twice in the AV - A+V difference wave. They demonstrated that when the data were reanalysed after being high-pass filtered, which had the effect of minimising slow potential activity, the earliest significant deviation occurred around 160 ms post-stimulus. This suggested that the earlier activation seen in the Giard and Peronnet study might have been the result of neuronal processes other than cross-modal facilitation. However, these results are contrasted with those of Fort et al. (2002b). They used an audio-visual object recognition task and found early effects that were consistent with those of Giard and Peronnet (1999). These were unaffected by either filtering or baseline modulation. They suggested that the differences between their study and that of Teder-Sälejärvi et al. (2002) was the result of task specific effects, noting that “...the less ‘comfortable’ timing and attentional conditions...” (p. 1036) of the former study may have been responsible for evident differences.

3.5 The Effect of Spatial and Temporal Asynchrony on Cross-modal Processing

The effects of cross-modal attention typically enhance responses, perception, discrimination and neural activity to stimuli presented in a secondary sensory modality. These effects can last several hundred milliseconds (Driver & Spence, 1998b). The proceeding section will describe the effect of various forms of spatial attention and the effect of temporally congruent but spatially incongruent stimuli (i.e. the ventriloquist effect) on the processing of cross-modal stimuli.
3.5.1 Cross-modal spatial attention

Attending to a location in space produces response enhancements, including larger negative ERP activity, to uni-sensory stimuli presented at the attended location compared with stimuli presented at an unattended location. These effects have been seen for stimuli in the auditory (Hillyard et al., 1973; Näätänen et al., 1978; Näätänen & Michie, 1979), visual (Eason, Harter & White, 1969; van Voorhis & Hillyard, 1977; Eason, 1981; Hillyard & Munte, 1984; Hillyard, Munte & Neville, 1985) and somato-sensory (Michie, Bearpark, Crawford & Glue, 1987) modalities. Spatial attention effects have also been shown to spread from one modality to another; that is, they are evident cross-modally. Thus, attending to one sensory modality at a specific spatial location produces response enhancements to a second irrelevant stimulus from a different sensory modality presented at the attended compared to unattended location (Hillyard et al., 1984; Butter et al., 1989; Ward, 1994; Spence & Driver, 1996, 1997; Driver & Spence, 1998a, 1998b; Eimer & Schröger, 1998; Spence et al., 1998; McDonald & Ward, 1999, 2000; Rorden & Driver, 1999; Teder-Sälejärvi et al., 1999a; Spence et al., 2000a, 2000b; Eimer & Driver, 2000; McDonald et al., 2000; Schmitt et al., 2000; Ward et al., 2000; Kennett et al., 2001; McDonald et al., 2001b; Eimer & van Velzen, 2002; Eimer et al., 2002; Lloyd et al., 2003; McDonald et al., 2003; Van der Burg, Olivers, Bronkhorst & Theeuwes, 2008; Talsma, Senkowski, Soto-Faraco & Woldorff, 2010; Van der Burg, Talsma, Olivers, Hickey & Theeuwes, 2011).

Experiments investigating endogenous cross-modal attention effects, that is, attention directed voluntarily to a location in space, typically denote a location
to be attended either by instructing participants prior to a stimulus block or by
the presentation of informative cues presented on a trial by trial basis. Endogenously directed cross-modal spatial attention produces response enhancements to stimuli presented at the attended compared to unattended location, including faster response times and improved perception and discrimination. These effects were evident to stimuli in the primary (attended) sensory modality as well as to stimuli in a secondary (unattended) modality presented at the attended location, even when the secondary stimuli were irrelevant and more likely to be presented elsewhere. These behavioural enhancements, produced by endogenous cross-modal spatial attention, have been seen for all combinations of auditory-visual (Hillyard et al., 1984; Spence & Driver, 1996), visual-tactile (Butter et al., 1989; Spence et al., 2000a) and auditory-tactile (Lloyd et al., 2003) stimuli.

Electrophysiological studies have shown that endogenous cross-modal spatial attention augments ERP activity. In an early auditory-visual ERP study, Hillyard et al. (1984) demonstrated that when participants were directed to attend to stimuli in one modality at a given location, larger negative ERP activity was produced to the attended stimuli. They also showed that stimuli from a second irrelevant modality presented at the attended location produced larger negative responses, although the magnitude of this effect was somewhat smaller than that seen to relevant modality stimuli. Subsequently, Eimer and Schröger (1998) demonstrated similar effects in a task that manipulated the direction of attention on a trial by trial basis using centrally presented cue stimuli – this is in contrast to the aforementioned study that required spatial attention to be maintained throughout the entire block. They identified modulation of both
auditory and visual N1 components as well as enhancements of two negative difference waves (Nd1: 160-210 ms and Nd2: 220-280 ms) to the stimuli presented at the cued location. The enhancement of the Nd waves was evident at centro-parietal midline and fronto-central midline electrodes respectively. These were apparent regardless of which modality was being attended, although they were smaller to stimuli in the irrelevant modality. Several subsequent studies have shown enhanced negative activity, reflecting endogenous cross-modal spatial attention effects, for auditory-visual (Eimer & Schröger, 1998; Teder-Sälejärvi et al., 1999b; Eimer & van Velzen, 2002; Eimer et al., 2002) visual-tactile (Eimer & Driver, 2000; Eimer et al., 2002) and auditory-tactile stimulus combinations (Eimer & van Velzen, 2002; Eimer et al., 2002). The consistency of enhanced activation in both behavioural and electrophysiological data suggested that there were symmetrical links between stimulus modalities for endogenous cross-modal spatial attention (Eimer & Schröger, 1998; Eimer & Driver, 2000; Eimer et al., 2002).

Attention can also be directed exogenously to a location in space by the presentation of a sudden unpredictable spatially oblique cue stimulus. A preceding non-predictive cue stimulus in one sensory modality enhances responses, perception and modulates ERPs to a subsequently presented spatially coincidental target from a different modality at the cued location when presented at relatively short stimulus onset asynchronies (SOA: <300 ms) (Ward, 1994; Spence & Driver, 1997; Spence et al., 1998; McDonald & Ward, 1999, 2000; McDonald et al., 2000; Schmitt et al., 2000; Ward et al., 2000; Kennett et al., 2001; McDonald et al., 2001b). Several studies have shown that auditory cues modulate ERPs to visual targets presented at the cued location
McDonald et al. (2003) showed that visual targets at cued locations produced greater negative activity than those at uncued locations. They identified three negative difference (Nd) waves evident at (120-170 ms) over mid-parietal regions, (150-170 ms) over posterior parietal and occipital regions and at (240-260 ms) over fronto-central sites. Dipole source analysis suggested sources for these Nd waves in the STS/STG, ventral extrastriate visual cortex and perisylvian parietal cortex respectively. They argued that this potentially represented feedback from poly-sensory areas to sensory-specific cortices. Furthermore, fMRI studies have identified activation of fronto-parietal networks in cued visual spatial attention tasks (Woldorff, Hazlett, Fichtenholtz, Weissman, Dale & Song, 2004; Wu, Weissman, Roberts & Woldorff, 2007). Similarly, auditory targets produce enhanced negative activity when presented at locations cued by visual stimuli (McDonald et al., 2001b). McDonald et al. (2001b) identified two Nd waves to auditory targets over posterior parietal regions (120-140 ms) and fronto-central regions (200-300 ms). They suggested that the early parietal Nd wave represented activation of poly-modal processing regions feeding back to sensory areas, with cross-modal spatial attention modulating sensory areas at late rather than early processing stages. Exogenous cross-modal spatial attention effects have been seen for all combinations of auditory, visual and tactile cue-target stimuli (Ward, 1994; Spence & Driver, 1997; Eimer & Schröger, 1998; Spence et al., 1998; McDonald & Ward, 1999, 2000; McDonald et al., 2000; Schmitt et al., 2000; Ward et al., 2000; Kennett et al., 2001; McDonald et al., 2001b; McDonald et al., 2003).
Despite several results showing that visual cues modulate auditory target ERPs, this has not been identified consistently. Spence and Driver (1997) reported that exogenous cross-modal spatial attention in a speeded elevation discrimination task modulated visual target ERPs cued by auditory stimuli but visual cue stimuli, did not have the same effect on auditory targets (see also Rorden & Driver, 1999; Schmitt et al., 2000). They argued that this was indicative of asymmetrical links in exogenous cross-modal spatial attention. However, several subsequent studies have identified visual cue – auditory target effects when a speeded elevation decision was not required (Ward et al., 2000; McDonald et al., 2001b). McDonald et al. (2001b) suggested that the null effect of Spence and Driver (1997) and others might have been a result of task parameters (i.e. speeded elevation decisions) rather than evidence of asymmetrical cross-modal links in auditory-visual processing. They suggested that involuntary shifts in cross-modal spatial processing – consistent with endogenous shifts in cross-modal spatial attention that were discussed above – are likely to be symmetrical for auditory and visual modalities.

Evidence of links in cross-modal spatial attention has led to questions over whether these effects represent the same supra-modal process being activated for different sensory modalities (e.g. Farah et al., 1989) or whether these processes are separate but conjoined – that is, attentional shifts in one modality produce shifts of attention to another modality stimulus when a link between attentional mechanisms exists (McDonald et al., 2001b). Asymmetrical links in cross-modal processing have also been suggested (Spence et al., 1998).

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4 Symmetrical links have also been demonstrated with tactile stimuli (e.g. Spence et al., 1998).
cross-modal spatial attention suggest that the mechanisms are not entirely supra-modal (Spence & Driver, 1997; Rorden & Driver, 1999; Schmitt et al., 2000). However, it has also been suggested that the extent of integration across senses is unclear but that these mechanisms are not completely independent (Farah et al., 1989; Ward, 1994; Spence & Driver, 1997; McDonald & Ward, 2000; Ward et al., 2000). McDonald et al. (2001b) argued that the demonstrated links between audition, vision and somato-sensation in exogenous cross-modal spatial attention (e.g. Spence & Driver, 1997, Spence et al., 1998; McDonald & Ward, 2000; Schmitt et al., 2000; Ward et al., 2000) are most likely to indicate a supra-modal process or at least processes that are tightly linked. They note that they could not rule out a separate but linked account for cross-modal spatial processing, but the most parsimonious explanation for cross-modal spatial attention effects indicates activation of supra-modal mechanisms.

3.5.2 Ventriloquist effect

The preceding section considered cross-modal effects on spatial attention. It showed that spatially congruent multi-modal stimuli presented in close *temporal* proximity facilitate behavioural and cortical responses. Cross-modal effects are also evident in conditions where temporally congruent but spatially disparate multi-modal stimuli are presented. The near simultaneous presentation of auditory-visual stimuli at different spatial locations can produce a mislocation of a stimuli’s relative position. Typically, the perceived location of an auditory stimulus is biased towards the location of the visual stimulus presentation (Thomas, 1941; Pick, Warren & Hay, 1969; Platt & Warren, 1972; Bermant & Welch, 1976; Bertelson & Radeau, 1981; Warren, Welch &
McCarthy, 1981; Radeau & Bertelson, 1987; Radeau, 1992; Bertelson, Vroomen, Wiegaard & de Gelder, 1994; Bertelson, 1999). This is referred to as the ‘ventriloquist effect’ – named after the perceptual illusion produced by ventriloquists in which their speech, produced in the absence of lip and head movements, is perceived as occurring from the ventriloquists puppet when its mouth and head are moved in approximate synchrony with the speech sounds (Howard & Templeton, 1966; Bertelson et al., 2000; Bischoff et al., 2007). Bertelson et al. (2000) noted that a similar effect is experienced in movie theatres when the soundtrack, that is typically presented at peripheral locations, is perceived as emanating from actors on the screen.

The ventriloquist effect has been demonstrated in experimental situations using realistic bimodal stimuli, for example, concurrent speech sounds and facial movements (Bertelson et al., 1994; Radeau & Bertelson, 1977; Warren et al., 1981), the sight of whistling kettles (Jackson, 1953) and of beating drums (Radeau & Bertelson, 1977). It has also been shown to occur in simple unrealistic situations such as with meaningless sound bursts and flashes of light (Bermant & Welch, 1976; Radeau, 1985; Slutsky & Recanzone, 2001). In the latter, factors such as temporal synchrony, spatial separation and relative saliency are implicated in the extent of cross-modal interactions (Choe, Welch, Gilford & Juola, 1975; Bertelson & Radeau, 1981; Radeau, 1985; Radeau & Bertelson, 1987). Although most commonly investigated using auditory-visual stimuli, recent studies have shown that tactile stimuli can also produce ventriloquism effects on perceived auditory stimulus location (Caclin, Soto-Faraco, Kingstone & Spence, 2002; Bruns & Röder, 2010a, 2010b).
As noted above, instances of the ventriloquist effect most commonly show that auditory stimuli are displaced toward the location of the visual stimulus. It has been suggested that this might be the result of visual capture of auditory stimuli due to the relative dominance of the visual sense modality (Alais & Burr, 2004). However, the converse has also been demonstrated (Bertelson & Radeau, 1981; Radeau & Bertelson, 1987; Alais & Burr, 2004). Alais and Burr (2004) showed that the location of a visual stimulus is displaced toward auditory stimulus locations when the visual stimulus was made perceptually more difficult to localise. They argued that the mislocation of ventriloquised stimuli might be modulated by spatial resolution rather than dominance, with visual stimuli typically having higher spatial resolution than auditory stimuli in typical ventriloquism situations.

Ventriloquised stimuli also produce effects other than perceptual mislocation. These include perceptual fusion, where spatially disparate objects are reported to originate from a common source (Jack & Thurlow, 1973; Choe et al., 1975; Bertelson & Radeau, 1981) and biases in event identification (Saldaña & Rosenblum, 1993). Furthermore, ventriloquism related after-effects have been identified to stimuli presented near the location of a previously presented discordant cross-modal event. After-effects typically displace the perceived location of a subsequent stimulus toward the location of other modality stimuli presented in a prior exposure phase (Radeau & Bertelson, 1974, 1976, 1977). After-effects have been identified for both simple and realistic conflict situations (Radeau & Bertelson, 1977).
Electrophysiological and imaging data have been employed to determine the neural processes involved in the ventriloquist effect. Colin, Radeau, Soquet, Dachy and Deltenre (2002) showed that when ventriloquised auditory stimuli were perceived as occurring at the same location as a visual stimulus these stimuli produced no MMN. Subsequently, Stekelenburg, Vroomen and de Gelder (2004) elicited MMN to illusory changes in stimulus location that were similar to those produced by actual sound shifts. They noted that the ventriloquist illusion occurred at an early perceptual level and that as MMN is elicited preattentively, the ventriloquist effect is most likely not dependant on attention. Psychophysical results support this interpretation with both deliberate visual attention (Bertelson et al., 2000) and automatic visual attention (Vroomen, Bertelson & de Gelder, 2001) shown to exert little influence over the ventriloquist effect. Bonath, Noesselt, Martinez, Mishra, Schwiecker, Heinze and Hillyard (2007) showed that ventriloquised auditory stimuli produce larger negative activity (N260) in the hemisphere contra-lateral to the position of shifted sound. Using both BESA dipole source analysis and fMRI they showed contra-lateral activation evident in the auditory cortex of the planum temporal. They suggested that the enhancement of activity in the auditory cortex combined with the latency of the N260 indicated visual cortical activity modulating multi-modal processing regions which then activated auditory cortical regions in ventriloquism conditions. Imaging studies have shown that the ventriloquist effect modulates the right inferior parietal lobule (PET: Macaluso et al., 2004) and the upper part of the right insula, parieto-occipital sulcus, the upper posterior left STS and the middle portion of the right STS (fMRI: Bischoff et al., 2007).
3.6 **Inter-modal Attention**

Inter-modal attention is the process of attending to stimuli in one sensory modality amongst stimuli from a different modality. Inter-modal attention paradigms are arguably the most similar to the inter-modal oddball presented in this dissertation. However, as they require participants to selectively attend to one stimulus modality at a time this puts them in a category of selective attention. There are several studies that have investigated inter-modal selective attention with regards to the ERP. Hackley et al. (1990) investigated evoked potentials produced by auditory and visual stimuli in a mixed modality task. They considered potentials with very short latencies (brainstem potentials) through to longer latency ERPs and found inter-modal selective attention effects were reliably produced after approximately 100 ms. Effects included enhanced N1/Nd, vertex P2 and N2 components when subjects were required to attend to auditory stimuli compared to when they attended the visual stimuli. This appears to be the first study to report an enhancement of the N1 and P2 components in an inter-modal task. Subsequently, both Alho et al. (1992) and Woods et al. (1992) in companion papers found support for these inter-modal modulations, describing an enhanced negativity (Nd_a) and positivity (Pd_a) to standard stimuli in attend auditory conditions. They note that this effect is in contrast to the commonly-reported monophasic ‘processing negativities’ seen in intra-modal auditory tasks (see Näätänen, 1990). In a subsequent inter-modal attention study, Alho et al. (1994) failed to find the Pd_a wave despite there being an enhanced Nd_a. This suggested that the enhanced positivity may not be common to all inter-modal tasks. Furthermore, Talsma and Kok (2001) found an enhancement of both the N1 and P2 components to unattended frequency
(standard) auditory stimuli when audition was the relevant modality. However, a more complex pattern was evident to attended frequency (target) stimuli. The P2 to attended frequency stimuli was smaller than the P2 to the unattended frequency when audition was relevant, which is not uncommon (see Hansen & Hillyard, 1988; Hegerl & Juckel, 1993). The P2 to attended frequency stimuli was also smaller than auditory P2s when vision was the relevant modality, which suggested that in the P2 latency range there is a complex pattern of interactions in inter-modal processes. Overall, these data suggest that inter-modal attention affects the early components of the ERP.

It is noted that there are some concerns with earlier research into inter-modal attention. As noted above, spatial attention effects can affect the ERP (Driver & Spence, 1998a, 1998b; Eimer & Schröger, 1998; Eimer, 1999; Talsma & Kok, 2002; Eimer & Van Velzen, 2002). In all but the last of the inter-modal studies discussed previously, the auditory stimuli were presented primarily through headphones, whilst the visual stimuli were presented in front of subjects. The disparity between stimulus location confounds non-spatial inter-modal attention effects with attention to a location in space. Thus, it may be argued that the effect of spatial attention may be evident in the resultant ERPs of the majority of inter-modal attention studies.

3.7 Chapter Summary

This chapter has identified the key processes involved in the perception of stimuli in mixed modality conditions. These include the role of temporal and spatial synchrony, the effect of these processes on several brain regions including sub-cortical structures, uni-sensory and poly-modal processing
regions and the effect of both inter-modal and cross-modal processes on ERP responses. It is clear from the different methods used to investigate MSI, cross-modal and inter-modal attention that multi-modal stimuli modulate behavioural and neural responses. These effects are somewhat different from those produced by uni-sensory stimulus presentation. The effect of multi-sensory processing discussed in this chapter will be considered in relation to the processing of stimuli in inter-modal oddball conditions.

3.8 Aims and Hypotheses

The experiments presented in this dissertation will examine the effect of presenting frequent and infrequent stimuli from different modalities on ERPs to target stimuli in an inter-modal oddball task. The aim of the experiments contained within is to identify ERP components produced by auditory targets in the inter-modal oddball task and to describe and characterise their functions. It will address the question of whether auditory targets are processed independently of the visual standard stimuli in this task, as proposed by Brown et al. (2005). It will investigate the relationship of activity identified in this task with auditory processing in other experimental tasks – most notably activity to targets in auditory oddball conditions. It will also consider the effect of inter-modality on auditory target processing in inter-modal oddball conditions. The scope of these investigations are limited to an active version of the inter-modal oddball task, to stimuli presented with a fixed ISI and will be primarily focussed on the effects of auditory target stimuli on the ERP. Thus, it will not consider processes evident in a passive version of the inter-modal oddball task and will provide limited discussion of activity related to the visual standard stimuli.
Overall, these studies represent an investigation of the processes evident in inter-modal oddball conditions. At the end of this dissertation, the processes involved in auditory target processing in inter-modal oddball conditions, the effect that visual standard stimuli have on the processing of auditory targets, and the relationship of auditory ERPs in inter-modal oddball conditions with those from other experimental paradigms will be clearly identified.
4. Inter-modal Attention: ERPs to Auditory Targets in an Inter-modal Oddball Task

5 The main results reported in this chapter have been published in: Brown, C. R., Clarke, A. R., Barry, R. J. (2006). Inter-modal attention: ERPs to auditory targets in an inter-modal oddball task. International Journal of Psychophysiology, 62, 77-86 (see Appendix A).
4.1 Introduction

Psychophysiological research has repeatedly shown that several factors affect auditory ERPs (c.f. chapter 2). However, the majority of studies in auditory attention (e.g. those using an auditory oddball task) consider attended auditory stimuli presented amidst other auditory stimuli. This places the interpretation of effects contextually in the category of uni-modal attention.

Studies using an inter-modal oddball task, which consists of auditory target stimuli presented amidst an ongoing series of visual standards, have been conducted into children with attention-deficit/hyperactivity disorder (Brown et al., 2005; Barry et al., 2006; Barry et al., 2009b). This task proved effective in differentiating clinical groups from a control group. However, these data were interpreted using findings that were typically uni-modal in nature, which may not have been appropriate in inter-modal oddball conditions. It is noted that the direction of results in these studies was somewhat different from expectations. For example, Brown et al. (2005) reported that AD/HD children had smaller P2 amplitudes than controls, contrary to a number of other studies (e.g. Satterfield et al., 1994; Kemner et al., 1996; Oades et al., 1996). This led to speculation that the auditory and visual stimuli may have been processed independently in this task. The differences in the Brown et al. (2005) study were sufficient to call into question the effect that visual standard stimuli have on auditory target ERPs in an oddball type task and suggested that further study was warranted (c.f. chapter 1).

Studies of inter-modal and cross modal attention have shown that stimuli from multiple modalities affect cortical responses and modulate the ERP (c.f.
chapter 3). The effect of inter-modal attention has been investigated using tasks that typically present two or more stimuli from distinct sensory modalities - often at different spatial locations - which require attention to be directed to a specified modality (e.g. Hackley et al., 1990; Alho et al., 1992, 1994; Woods et al., 1992; Talsma & Kok, 2001). These selective attention tasks are arguably the most similar to the inter-modal oddball task and the results of inter-modal attention indicate a complex pattern of interactions evident in early (N1/Nd and P2/Pd) ERP components (c.f. chapter 3.6).

A review of inter-modal attention literature suggests that no study has systematically investigated inter-modal effects in an inter-modal oddball task, that is, where an individual auditory target is presented solely amidst frequent visual standard stimuli (i.e. not multiple stimuli in each modality). The purpose of this study is to explore ERPs produced by auditory target stimuli in an inter-modal oddball task. The aims are: 1) to describe the characteristics of ERPs produced by auditory targets in inter-modal oddball conditions, 2) to determine whether the ERPs have attributes that are common with auditory ERPs evident in uni-modal oddball conditions – and if not, to describe the differences, 3) to determine whether these support the notion of independent processing as proposed by Brown et al. (2005), and 4) to determine whether there is evidence of inter-modal processing apparent in the resultant ERPs.
4.2 Material and Methods

4.2.1 Participants

Participants consisted of 20 (15 female) undergraduate psychology students who participated as one means of satisfying a course requirement. Subjects were between 20 and 38 years old (mean = 24.8, SD = 4.8 yr). All participants had normal or corrected to normal vision, and self-reported normal hearing. Participants reported not taking any illicit or pharmaceutical drugs or alcohol for 24 hr prior to testing.

4.2.2 Procedure

Participants were tested in one session that lasted approximately 1.5 hr. After participants were fitted with an electrode cap they completed five tasks, of which three are reported here. They consisted of an inter-modal oddball task, an auditory oddball task and a single tone presented alone. In each of these tasks participants were seated in a test booth, one metre from a computer monitor. Both auditory and visual stimuli were presented from a central location to remove problems of spatial disparity in stimulus processing. In the inter-modal oddball the visual standard stimulus was a full-screen pattern-reversal of an 8 x 8 B/W checkerboard that sub-tended a visual angle at 1 m of 13°. Michelsons’ ratio for contrast between checkerboard squares was 96%. The auditory target stimulus was a 2000 Hz, 60 dB SPL tone (as measured centrally at a distance of 1 m from the speakers) that had a 10 ms rise, plateau and fall time. Participants were presented with 300 stimuli that consisted of 240 (80 %) visual (standard) stimuli, with 60 (20 %) random periods where no pattern-reversals occurred but an auditory target was presented. In the auditory oddball
task, the standard stimulus consisted of 240 (80%) 1000 Hz, 60 dB SPL tones (10 ms rise, plateau, and fall time) and targets were 60 (20%) 2000 Hz, 60 dB SPL tones (i.e. targets were identical to those in the inter-modal oddball). The SOA for stimulus presentations in both tasks was fixed to 1.03 sec. The single tone consisted of 60 tones identical to the targets in the preceding tasks, presented randomly with no other stimuli over period identical in duration (5 min 9 sec) to the other two tasks. Subjects were required to count only target tones in each of the three tasks and report totals to ensure compliance. Order of task presentation was randomised.

4.2.3 EEG acquisition

EEG was recorded using a NeuroScan NuAmps DC amplifier, sampled at 500 Hz with a range of 263 μV. Electrode placement was in accordance with the international 10/20 system. Cortical activity was recorded from 19 derivations at Fp1, Fp2, F3, F4, Fz, F7, F8, C3, C4, Cz, T3, T4, T5, T6, P3, P4, Pz, O1, O2, using tin electrodes in an electrode cap, referenced to linked ears. Horizontal EOG was recorded, using 9 mm tin electrodes, from the outer canthus of both eyes, and vertical EOG was recorded from above and below the right eye. Impedance levels for all electrodes were below 5 kΩ. Data were stored for offline analysis.

4.2.4 ERP averaging

ERP epochs containing EEG data points exceeding ±60 μV were automatically rejected and the trace was manually inspected to verify artefact removal. EEG data containing target stimulus presentations and no artefact
were epoched between 100 ms pre-stimulus and 600 ms post-stimulus. Epochs were averaged, passed through a 30 Hz low pass filter and baseline corrected across the entire baseline period.

4.2.5 Data analysis: ERP and topographic analysis

There were seven peaks evident in the grand average ERP data up to 400 ms post-stimulus, of which six were identified in all tasks. These included a fronto-central negative peak at approximately 100 ms (N100: 98 – 107 ms), a second fronto-central negative peak at 130 ms (N130: 126 – 138 ms), a central positive peak at 200 ms (P200: 193 – 204 ms), a fronto-central positive peak at 250 ms (P250: 244 – 257 ms), a parietal positivity at 300 ms (P300: 299 – 311 ms), and a fronto-central positive peak at approximately 350 ms (P350: 344 – 361 ms). An additional peak (N200: 190 – 208 ms) was evident only in the auditory oddball task. As no evidence for this component was seen in the inter-modal oddball or single tone tasks it was not included in the analysis of task differences. However, a post hoc analysis, using the analysis of variance (ANOVA) procedures described below, compared the latency of the auditory oddball N200 with the inter-modal oddball P200.

Analysis was conducted on 9 sites (F3, Fz, F4, C3, Cz, C4, P3, Pz, P4) comparing the inter-modal oddball and single tone, and the inter-modal oddball and auditory oddball tasks using a repeated measures analyses of variance. Within-subject factors included Task and Topography (Lateral (Left, Midline, Right) and Sagittal (Frontal, Central, Posterior)). Planned contrasts were conducted to clarify the topographic distribution of each component. Contrasts for the sagittal factor compared Frontal (F) vs. Posterior (P), and Central (C) vs.
the mean of the Frontal and Posterior regions. Contrasts for the lateral factor compared Left (L) vs. Right (R), and Midline (M) vs. the mean of Left and Right regions. As the contrasts were planned and did not exceed the degrees of freedom for effect, no Bonferroni-type adjustment of $\alpha$ levels is required (Tabachnick & Fiddell, 1989). Where there were significant main effects of task, data were submitted to vector scale normalization (McCarthy & Wood, 1985) and only task by topography interactions that remained significant after this procedure are reported. All contrasts had $df = (1, 19)$.

An additional post hoc analysis using the above ANOVA procedures was conducted comparing the amplitudes of the inter-modal oddball P300 and auditory oddball P350.

4.3 Results

4.3.1 Topography of the inter-modal oddball target ERPs

Figure 4.1 shows the grand average ERPs to targets for all tasks across the scalp. As can be seen, for the inter-modal oddball task there are early fronto-central negative components peaking at approximately 100 and 130 ms. Thereafter a broad series of positive components between 200 and 350 ms are apparent.

The top left panel of figure 4.2 indicates that the N100 component was predominantly fronto-central ($F > P$: $F = 19.01$, $p < 0.001$; $C > F/P$: $F = 12.93$, $p < 0.01$). Amplitudes at midline sites were also larger than the mean of the hemispheres ($M > L/R$: $F = 15.57$, $p < 0.001$; see figure 4.2 – top left panel). N100 latency (mean 102.1 ms) was shorter in the hemispheres than at the
midline (101.1 and 104.2 ms respectively: L/R < M: F = 5.87, p < 0.05) and latencies were longest at the vertex (106.4 ms: C > F/P x M > L/R: F = 5.22, p < 0.05).

The N130 component had a frontal enhancement that approached significance and was larger centrally than the mean of frontal and posterior sites (F > P: F = 4.21, p = 0.054; C > F/P: F = 10.08, p < 0.01 respectively; see figure 4.2 – mid-left panel). This indicates that the N130 had a fronto-central topography. The latency of N130 (mean 130.5 ms) was shorter at posterior sites than frontal sites (128.7 and 133.6 ms respectively: P < F: F = 4.51, p < 0.05), centrally compared with the mean of frontal and posterior sites (129.3 and 131.2 ms respectively: C < F/P: F = 6.91, p < 0.05), and at the midline compared to the mean of the hemispheres (129.7 and 131.0 ms respectively: M < L/R: F = 4.84, p < 0.05). The first of these effects was greatest in the midline; this difference approached significance (P < F x M < L/R: F = 4.20, p = 0.054).

The P200 was larger centrally than the mean of frontal and posterior sites (C > F/P: F = 50.28, p < 0.001; see figure 4.2 – bottom left panel) and at the midline compared with the hemispheres (M > L/R: F = 17.80, p < 0.001; see figure 4.2 – bottom left panel). The midline enhancement was larger in the posterior than frontal regions (P > F x M > L/R: F = 10.16, p < 0.01) and largest at the vertex (C > F/P x M > L/R: F = 17.33, p < 0.001). This indicates a centro-parietal midline topography for the P200 component. P200 latency (mean 200.2 ms) did not differ across the scalp.
Figure 4.1 Grand average ERPs across all sites to auditory targets in inter-modal oddball (thick black line), auditory oddball (grey line) and single tone (thin black line) tasks. Note that N200 is only evident in the auditory oddball task.
As is evident in figure 4.2 (top right panel) the P250 component is predominantly fronto-central (F > P: F = 6.26, p < 0.05; C > F/P: F = 27.06, p < 0.001). The top right panel of figure 4.2 reveals amplitudes at the midline were larger than the mean of the hemispheres (M > L/R: F = 44.10, p < 0.001). The central and midline enhancements together produced enhanced activity at the vertex (C > F/P x M > L/R: F = 18.67, p < 0.001). P250 latency (mean 253.2 ms) was shorter at frontal than posterior sites (251.5 and 256.0 ms respectively: F < P: F = 5.96, p < 0.05) and at the midline compared to the mean of the hemispheres (251.9 and 253.8 ms respectively: M < L/R: F = 6.38, p < 0.05).

As shown in figure 4.2 – mid-right panel, P300 amplitudes at posterior sites were larger than at frontal sites, a difference that approached significance (P > F: F = 3.80, p = 0.064). The P300 had a midline enhancement at frontal and posterior sites, which was reversed at central sites (F/P > C x M > L/R: F = 5.99, p < 0.05). These effects indicate a posterior midline topography for the P300 component. The latency of the P300 (mean 303.6 ms) was shortest at the vertex (301.5 ms: C < F/P x M < L/R: F = 10.60, p < 0.01).

P350 mean amplitudes were larger at frontal/posterior sites than at central sites (F/P > C: F = 8.34, p < 0.01; see figure 4.2 – bottom right panel) and the mean amplitude in the hemispheres was larger than at the midline (L/R > M: F = 5.60, p < 0.05; see figure 4.2 – bottom right panel). These effects reflect smaller amplitudes at the vertex (F/P > C x L/R > M: F = 22.35, p < 0.001). P350 latency (mean 344.8 ms) was shorter at central sites compared to the mean of frontal and posterior sites (343.5 and 345.5 ms respectively: C < F/P: F = 5.09, p < 0.05).
Figure 4.2 Sagittal – [F]rontal, [C]entral, [P]osterior (left panel) and lateral – [L]eft, [M]idline, [R]ight (right panel) distribution of each component in the inter-modal oddball task.
4.3.2 Comparison of inter-modal oddball ERPs with single tone ERPs

As can be seen in figure 4.3, N100 amplitudes did not differ between the inter-modal oddball and single tone tasks. The reduction in N100 mean latency in the hemispheres compared to the midline described above was greater in the inter-modal oddball than in the single tone task (mean difference 3.1 and 0.3 ms respectively: task x L/R < M: F = 7.50, p < 0.05).

The N130 component did not differ in amplitude between tasks (see figure 4.3). The reduction in latency at central sites compared to the mean of frontal/posterior sites was smaller in the inter-modal oddball task than in the single tone task (mean difference 1.9 and 4.6 ms respectively: task x C < F/P: F = 4.50, p < 0.05).

The overall P200 amplitudes did not differ between tasks. The P200 midline enhancement in the inter-modal oddball described above was smaller than in the single tone task, a difference that approached significance (task x M > L/R: F= 4.31, p = 0.051; see figure 4.3). As previously discussed, the latency of the P200 component in the inter-modal oddball did not differ across the scalp; in contrast, the single tone task had comparatively shorter latencies at posterior than frontal sites (task x P < F: F = 7.87, p < 0.05).

The amplitude of the P250 component in the inter-modal oddball was significantly larger than in the single tone task (6.6 vs. 4.2 µV: F = 9.04, p < 0.01; see figure 3). A comparison of P250 latency in the hemispheres indicated smaller differences in the inter-modal oddball task than in the single tone task,
Figure 4.3 Sagittal and lateral distribution of each component comparing the inter-modal oddball (black line with squares), auditory oddball (grey line with squares) and single tone (thin black line with squares) tasks.
largely as a result of shorter latencies in the right hemisphere in the single tone task (mean difference 0.0 and 3.9 ms respectively: task x R < L: F = 5.05, p < 0.05).

The amplitude of the P300 in the inter-modal oddball task was larger than in the single tone task (4.23 vs. 1.29 µV: F = 20.15, p < 0.001; see figure 4.3). The difference between midline amplitudes and the mean of the hemispheres was larger in the inter-modal oddball task than in the single tone task (task x M > L/R: F = 16.61, p < 0.001; see figure 4.3). No latency differences were evident.

The P350 in the inter-modal oddball task was larger than in the single tone task (2.76 vs. -0.20 µV: F = 23.29, p < 0.001; see figure 4.3). The latency of the P350 component was longer in the inter-modal oddball task than in the single tone task (355.8 vs. 347.6 ms: F = 14.53, p < 0.01).

4.3.3 Comparison of inter-modal oddball ERPs with auditory oddball ERPs

As can be seen in figures 4.1 and 4.3, the amplitude of the N100 component in the inter-modal oddball was larger than in the auditory oddball task (-4.36 vs. -2.62 µV: F = 29.48, p < 0.001). The central and midline N100 enhancements in the inter-modal oddball described above were larger than in the auditory oddball (task x C > F/P: F = 13.83, p < 0.01; task x M > L/R: F = 13.69, p < 0.01 respectively; see figure 4.3). The latter effect reflected enhanced frontal midline activity in the inter-modal oddball task (task x F > P x M > L/R: F = 6.96, p < 0.05). The shorter N100 mean latency in the hemispheres compared to the midline evident in the inter-modal oddball task
showed the opposite pattern in the auditory oddball (mean difference 3.1 and -1.1 ms respectively: task x L/R < M: F = 9.80, p < 0.01). This difference was greater at frontal than posterior sites, an effect that approached significance (task x F > P x M > L/R: F = 4.34, p = 0.051).

N130 amplitudes in the inter-modal oddball task were larger than in the auditory oddball task (-4.20 vs. -1.5 µV: F = 14.80, p < 0.01). As is evident in figure 4.3, the enhancement at central sites in the inter-modal oddball was larger than in the auditory oddball task (task x C > F/P: F = 12.47, p < 0.01). The inter-modal oddball also had comparatively larger midline N130 amplitudes than the auditory oddball (task x M > L/R: F = 8.33, p < 0.01; see figure 4.3). No differences in latency were found.

As is clearly seen in figures 4.1 and 4.3 the P200 component in the inter-modal oddball task was larger than in the auditory oddball task (6.77 vs. 2.73 µV: F = 25.83, p < 0.001). The central enhancement of the P200 component described above was larger in the inter-modal oddball than in the auditory oddball (task x C > F/P: F = 29.19, p < 0.001; see figure 4.3). P200 latency in the inter-modal oddball was substantially longer than in the auditory oddball (200.2 vs. 170.9 ms: F = 51.67, p < 0.001). It was also longer in the right than left hemispheres in the inter-modal oddball compared to the auditory oddball, which demonstrated the opposite effect (mean difference 1.7 and -2.4 ms respectively: task x R > L: F = 6.60, p < 0.05).

As can be seen in figure 4.3 the frontal enhancement of the P250 component in the inter-modal oddball task was not apparent in the auditory
oddball task (task x F > P: F = 13.42, p < 0.01). No latency differences were evident.

The posterior enhancement of the P300 component in the inter-modal oddball task was not apparent in the auditory oddball task, where it was larger frontally (task x P > F: F = 5.11, p < 0.05; see figure 4.3). This difference reflected the enhanced posterior midline activity in the inter-modal oddball task (task x P > F x M > L/R: F = 15.92, p < 0.001). No differences in P300 latency were evident.

The P350 component in the inter-modal oddball was smaller at posterior sites and larger at frontal sites than in the auditory oddball task (task x P < F: F = 16.29, p < 0.001; see figure 4.3). P350 latency was significantly shorter in the inter-modal oddball task than the auditory oddball task (344.8 vs. 359.7 ms: F = 12.41, p < 0.01). The reduction in central latencies in the inter-modal oddball task described above was reversed in the auditory oddball task (mean difference 2.0 and -2.6 ms: task x C < F/P: F = 6.06, p < 0.05).

4.3.4 Post hoc analyses

Two post hoc analyses were conducted. The first compared the latency of the inter-modal oddball P200 with that of the auditory oddball N200. The latency of these components did not differ significantly. The second compared the amplitudes of the inter-modal oddball P300 with the auditory oddball P350. This was due to the similar parietal topographies of these components. No overall differences in amplitude were found. However, the inter-modal oddball
P300 was larger at the midline compared to the auditory oddball P350 (task x M > L/R: F = 6.69, p < 0.05; see figure 4.4).

Figure 4.4 Sagittal (left panel) and lateral (right panel) distribution showing the comparison of inter-modal oddball P300 (black line) and auditory oddball P350 (grey line) components.

4.4 Discussion

This study investigated ERPs to auditory targets in an inter-modal oddball task. The data showed that auditory targets produced two early fronto-central negative components (N100 and N130), followed by a subsequent positivity (P200) maximal at the vertex. Thereafter, a broad series of positive peaks were seen that lasted approximately 100 ms. In order to understand the functional aspects of these components they were compared to ERP components elicited by the same target tone presented in the absence of any standard stimulus (single tone), and in an oddball task where the standards were also in the auditory modality (auditory oddball).

The N100 component, based on its latency and fronto-central topography, may be considered the traditional N1, a measure of the initial
registration, processing and attribute selection of an auditory stimulus (Hillyard & Picton, 1979; Callaway & Halliday, 1982). Presenting a tone alone and at random (i.e. single tone task), removes confounds related to the presentation of other (irrelevant) stimuli and therefore the amplitude of the single tone N100 should accurately reflect the registration of the target tones. Considering the similarity in amplitudes of the inter-modal oddball N100 and the single tone N100, it can be concluded that the presentation of a visual stimulus in the inter-modal oddball task did not have any apparent effect on the stimulus registration and attribute selection of the auditory target.

In comparison, the inter-modal oddball N100 was larger overall than the auditory oddball N100, and was also larger at central, midline and frontal midline sites (see figure 4.3). The comparatively smaller amplitudes in the auditory oddball suggest another process occurring, most likely related to the presentation of a second (standard) auditory stimulus. It may be argued that the frequent presentation of multiple auditory stimuli may have produced a generalised habituation resulting in smaller N100 amplitudes. However, Barry et al. (1992) have demonstrated that a decrease in N1 amplitudes to regularly presented auditory stimuli does not reflect habituation, as the N1 does not dishabituate. Alternatively, the decreases in amplitude seen in this experiment may be considered a reflection of refractory period effects, potentially of two neural generators (see Budd et al., 1998). Rist and Cohen (1987) found smaller N1 and P2 amplitudes to ispi-modal compared to cross-modal stimuli, which they argued reflects refractory period effects rather than a modality shift effect. Various researchers have suggested that the N100 component may have a refractory period of 10 seconds or more (Davis et al., 1966; Nelson & Lassman,
1968; Hari et al., 1982; Näätänen & Picton, 1987). For example, Nelson and
Lassman (1968) noted that increases in N1-P2 amplitude is “…about 1.85 μV
with each twofold increase in ISI” (p. 1530) up to ISIs of 6 seconds. Davis et al.
(1966) noted that, at regular intervals, there was a systematic decrease in their
vertex potential, such that the amplitude was “…1/2 maximal at 3 sec, 1/4 at 1
sec and 1/6 at 0.5 sec” (p.112), with maximal amplitudes occurring at longer
ISIs, probably 10 seconds or more. Furthermore, Butler (1968) found increases
in amplitude as frequency differences between regular and intervening stimuli
became larger. These increases were approximately 45% larger at frequency
differences of 1000 Hz. Based on these figures, the frequency difference
between targets and standards together with the shorter ISIs in the auditory
oddball task (compared to the average auditory target to target interval of 5.1 s
in the inter-modal oddball task) should produce almost a halving of N100
amplitudes in the auditory oddball, which is what was found (-4.36 vs. -2.62 μV
respectively). Therefore, refractoriness provides a parsimonious explanation for
the difference in amplitudes in the inter-modal oddball and auditory oddball
N100 components. These differences and the absence of an effect in
comparison to the single tone indicates that the inter-modal oddball N100 was
not affected by refractory period effects.

The inter-modal oddball task produced a second early negativity (N130),
which was equivalent to one seen in the single tone task. The N130 component
may be considered one of the multiple N1 components, elicited to auditory
stimuli, proposed by many authors (e.g. Wolpaw & Penry, 1975; Näätänen &
Michie, 1979; Hari et al., 1982; Näätänen & Picton, 1987; Sherg et al., 1989;
Alcaini et al., 1994; Budd et al., 1998). In their review, Näätänen and Picton
(1987) described six components, three of which they consider true N1 components. Their component III was considered a reflection of orienting to a rare stimulus (see also Hari et al., 1982). It is also related to cortical areas responsible for motor activity, is readily elicited to auditory stimuli of intensities greater than 60 dB, and at ISIs of greater than 4-5 s. Furthermore, they state that this component would have “...definite inter-modal refractory effects” (p. 412). Alcaini et al. (1994) described a late N1 component, peaking at about 145 ms, which had a large refractory period (longer than 16 s), and corresponded to Näätänen and Picton’s orienting component III. It is noted that the morphology of their ERPs and our inter-modal ERPs are similar (see their figure 1. particularly at Fz in ISIs of 8 s). Budd et al. (1998) also found a late component at long ISIs that corresponded to component III. However, they found no evidence of this component reflecting an orienting response. The N130 component, generated to stimuli at 60 dB, at long ISIs and arguably producing an orienting response, may be consistent with these interpretations. However, there are problems with ascribing this components attributes to Component III. Firstly, our task required subjects to count targets; therefore, no overt motor activity was required. Thus, the N130 component may not be generated by motor areas as was Näätänen and Picton’s (1987) Component III (N.B. neither the Alcaini et al. (1994) nor Budd et al. (1998) tasks required motor responses). Secondly, no differences in N130 amplitude were found between the inter-modal oddball and single tone tasks. This indicates that the visual standards had no effect on target amplitudes, which suggests no inter-modal refractory effects’ (Näätänen & Picton, 1987). The similarity of the N130 to previously
reported late N1s as well as the differences aforementioned, suggests that further clarification of this component is necessary.

The inter-modal oddball P200, a large central component, did not differ substantially from that in the single tone task, but was substantially different from the auditory oddball P200, which was a smaller centro-parietal component, evident earlier (170 ms) and with smaller amplitudes at central sites. It may be speculated that the smaller amplitudes in the auditory oddball condition resulted from attenuation by a proceeding negativity (N200) in the auditory oddball. As can be seen in figure 4.1, the auditory oddball P200 appears to be truncated by the N200. No N200 was evident in the inter-modal oddball and post hoc analysis confirmed that the inter-modal oddball P200 and auditory oddball N200 peaked at the same time. The differences between the inter-modal oddball and auditory oddball P200 and the presence of an N200 component suggest a substantial intra-modal effect in the two-tone condition – an effect that is not evident in the inter-modal context. That is, differences in the early ERP components appear to result from intra- rather than inter-modal processes.

The N200 in the auditory oddball task represents multiple negative components including the mismatch negativity (MMN) and N2b (c.f. chapter 2.3.3). Näätänen (1992) argues that in auditory oddball tasks, attended deviant stimuli elicit the N2b which overlaps the modality specific MMN. Unlike the MMN, which is elicited in conditions where stimuli are of the same modality, the N2b is considered a modality non-specific component (Näätänen et al., 1982). Thus, where it may be expected that both the MMN and N2b components would be elicited in the auditory oddball task, only the non-specific N2b component
should be evident in both intra-modal and inter-modal oddball contexts. No negative component corresponding to the auditory oddball N200 was found in the inter-modal oddball task. This leads to the conclusion that no inter-modal MMN is generated by the inter-modal oddball task. Furthermore, although the N2b can be elicited by stimuli in both the auditory and visual modalities (Näätänen et al., 1982; Renault et al., 1982) it is not produced in the inter-modal condition and thus it may not necessarily be a modality non-specific component.

The later ERPs occurring between 250-350 ms made up an apparent suite of endogenous positive components. The inter-modal oddball P250 was predominantly fronto-central and may be analogous to the P3a, which reflects stimulus deviance and involuntary shifts in attention to changes in the environment (Squires et al., 1975; Friedman & Simpson, 1994). The inter-modal oddball P250 was larger than the single tone P250. This may be due to the visual standards capturing the subjects’ attention, a process that cannot occur in the single tone task. The inter-modal oddball P250 was also larger frontally than the auditory oddball P250. It is unclear whether this is due to specific differences between tasks or simply the trailing edge of the N200 attenuating the auditory oddball P250 component at frontal regions.

The inter-modal oddball P300, which had a parietal midline topography, may be likened to the P3b. The P3b is elicited by low probability, relevant stimuli (Donchin & Coles, 1988; Kok, 2001) and its amplitude may vary based on the amount of effort required to process a stimulus (Kok, 2001). The inter-modal oddball and single tone P300s demonstrated similar parietal topographies (see figure 4.3), although the single tone P300 was demonstrably
less positive. This difference may reflect the overall ease of processing the single target. In contrast, the inter-modal oddball and auditory oddball P300s differed in topography, indicating that they were distinct components, and thus at a latency of 300 ms the two oddball tasks produced different effects.

Post hoc analysis comparing the inter-modal oddball P300 to the auditory oddball P350 showed that their topographies were substantially similar. Due to this, it could be suggested that there is a comparative delay in the production of a parietal P3b component in the auditory oddball task. However, there was also a specific enhancement at the midline of the inter-modal oddball P300 when compared to both the single tone P300 and auditory oddball P350, which we suggest may represent activity that is specific to the inter-modal task. Overall, the presence of the regular visual stimulus increased the amplitude of the late positive components to the auditory target and at the same time produced components temporally and/or topographically distinct from those seen in the other tasks. This suggests that subjects attended the visual stimuli (i.e. did not disregard them and focus only on the auditory targets) and although attention to the visual standard did not affect the early ERP s, it is evident that it plays a role in the cognitive processes represented by the later components. Based on these results further investigation of the later positive components in inter-modal conditions seems warranted.

The inter-modal oddball task was designed to replicate characteristics of oddball tasks more frequently employed (e.g. the auditory oddball). This meant that in both the inter-modal and auditory oddball tasks the standard stimulus was omitted when the targets were presented. The omission of an expected
stimulus has been shown to produce both a late negative and positive ERP response (c.f. chapter 2.3.7). This effect might be incorporated in the resultant ERP of both oddball tasks in this study. Whether this effect is apparent and how it differs in inter-modal and intra-modal conditions awaits further investigation.

The comparison of the inter-modal oddball to the single tone task showed no overall effect of the visual standard on the early components N100, N130 and P200. Analysis of topographies found only larger P200 amplitudes at the midline in the inter-modal oddball. In contrast, the later components P250, P300 and P350 were all significantly more positive in the inter-modal oddball than in the single tone task, potentially reflecting the increased task demands of the inter-modal oddball. This suggests that the presentation of a visual *standard* stimulus affects the generation of only some auditory ERP components, with inter-modal effects restricted to later processing stages. This contrasts with the majority of previously reported inter-modal studies that have described an enhancement of the N100, and in some cases an enhanced P200, in inter-modal conditions (Hackley et al., 1990; Alho et al., 1992; Woods et al., 1992; Alho et al., 1994; Talsma & Kok, 2001).

In each of the earlier inter-modality studies, subjects were presented with multiple auditory and visual stimuli, confounding intra- and inter-modal effects. This concern was noted by a number of authors (Woods et al., 1992; Alho et al., 1994; Talsma & Kok, 2001: see chapter 3.6). In contrast, this study presented a single auditory stimulus in the inter-modal context, removing intra-modality as a confounding variable. This resulted in larger N100 and P200 components in the inter-modal oddball compared to the auditory oddball. However, these
differences reflected the presence of the second auditory stimulus in the auditory oddball task rather than any inter-modality. It is suggested that any future inter-modal research, particularly if using multiple auditory stimuli, needs to consider these results when interpreting differences in early components. A failure to do so risks confusing intra- and inter-modal effects further, which may lead to invalid conclusions.

It is concluded from these results that inter-modal target processing apparently occurs in two-stages. That is, initial processing occurs independently of the standards, whilst the later processes generate distinct activity through the integration of stimulus characteristics. This two-stage process with inter-modal oddball stimuli has not been suggested previously, and warrants further investigation. Furthermore, these data provide evidence of contextual differences in the processing of an auditory target tone. In contrast to inter-modal ERPs, those to targets in the auditory oddball task demonstrated difference at both early and later stages. This indicates that intra-modality is likely to be implicated in the generation of all ERPs in auditory oddball conditions. This effect suggests that further research using both inter- and intra-modal tasks should lead to a greater understanding of auditory processing.
5. Auditory Processing in an Inter-modal Oddball Task: Effects of a Combined Auditory/Visual Standard on Auditory Target ERPs

5.1 Introduction

The preceding chapter investigated the processing of auditory targets in an inter-modal oddball task – principally, how infrequent auditory target stimuli are processed when presented amidst visual standards. These data demonstrated six ERP components produced by targets in this task (N100, N130, P200, P250, P300, P350). The comparison of these ERPs with those from the single tone and auditory oddball tasks showed that the stimuli were processed in two distinct stages – an early stimulus dependant stage in which targets were processed independently of the visual standards and a later context dependant stage. This indicated that the visual standard stimuli in inter-modal oddball conditions modulated late and not early ERP components.

One aim of the preceding chapter was to determine whether the ERPs to inter-modal oddball targets were consistent with those produced by auditory targets in uni-modal oddball conditions. The data showed that ERPs to identical targets in the auditory oddball task differed in amplitude, latency and morphology from those in the inter-modal oddball condition. This suggested that a large amount of the variation evident in the auditory oddball ERP was due to intra-modal processes affecting all stages of processing.

The purpose of this chapter is to further investigate the effect that visual standard stimuli have on auditory target processing using a variant of the inter-modal oddball task. The auditory-visual oddball task, introduced in this chapter, combines standard stimulus attributes from both the inter-modal and auditory oddball tasks used in chapter 4. Thus, it contains a frequently presented combination of auditory and visual standard stimuli and an infrequent target
tone. The primary aim of this study is to determine how the inclusion of the visual standard stimulus affects the ERP to auditory targets. This will be achieved by comparing target ERPs in this task to those produced in an auditory oddball task. It is considered that due to the presence of multiple auditory stimuli, both tasks will elicit intra-modal effects, consistent with those seen in the previous chapter. Thus, any differences evident should represent the putative effect of including the visual stimulus in the auditory-visual oddball condition. A secondary aim of this study is to investigate whether there is evidence of integration effects within the combined auditory-visual standards.

5.2 Material and Methods

5.2.1 Participants

Participants consisted of 17 (15 female) undergraduate psychology students who participated as one means of satisfying a course requirement. Subjects were between 18 and 43 (Mean = 23.17, SD = 6.82) years old. All participants had normal or corrected to normal vision, and self-reported normal hearing. Participants reported not taking any illicit or pharmaceutical drugs, or alcohol in the 24 hrs prior to testing.

5.2.2 Procedure

Participants were tested in one session that lasted approximately 1.5 hr. After participants were fitted with an electrode cap they were seated in a test booth, 1 m from a computer monitor and speakers, and completed six tasks, of which three are included in this paper. These three tasks are an auditory-visual oddball task, an auditory oddball task and an inter-modal oddball task. The
auditory-visual oddball task comprised a rare (20%) auditory target stimulus and a combined auditory and visual standard stimulus (80%). The auditory target was a 2000 Hz, 60 dB tone (as measured centrally at a distance of 1 m from the speakers). The standard stimulus was a 1000 Hz, 60 dB tone presented simultaneously with a full-screen pattern-reversal of an 8 x 8 B/W checkerboard. The checkerboard sub-tended a visual angle of 13° at 1 m and Michelsons’ ratio for contrast between checkerboard squares was 96%. The auditory oddball comprised a rare (20%) auditory target stimulus (2000 Hz – 60 dB) and a regular (80%) auditory standard stimulus (1000 Hz – 60 dB). This means that the auditory stimuli were identical to those presented in the auditory-visual oddball, but no visual stimulus was presented. The inter-modal oddball task comprised a rare (20%) auditory target (2000 Hz – 60 dB) and a standard stimulus which was a pattern-reversal checkerboard identical to that used in the auditory-visual oddball task. This means that the visual standards and auditory targets were identical to those in the auditory-visual oddball task, but no auditory standard was presented. All auditory stimuli had 10 ms rise, plateau and fall times. Participants received 300 stimulus presentations (240 standards and 60 targets) in each task at a fixed SOA of 1.03 sec. Auditory and visual stimuli in each task were presented from a central location to avoid problems of spatial disparity in stimulus processing. Participants were required to fixate on a centrally located fixation point. This was centred in relation to both the auditory tones and the checkerboard stimulus. Subjects were instructed to attend all stimuli and to press a button with their dominant hand as quickly as they could when an auditory target was presented.
5.2.3 EEG acquisition

EEG was recorded with a sampling rate of 500 Hz and a range of 263 μV between 0.5 – 70 Hz using a NeuroScan NuAmps DC amplifier. Cortical activity was recorded from 19 derivations at Fp1, Fp2, F3, F4, Fz, F7, F8, C3, C4, Cz, T3, T4, T5, T6, P3, P4, Pz, O1, O2, using tin electrodes in an electrode cap, referenced to linked ears. Horizontal EOG was recorded from the outer canthus of both eyes, and vertical EOG was recorded from above and below the right eye, using 9 mm tin electrodes. Impedance levels for all electrodes were below 5 kΩ. Data were stored for offline analysis.

5.2.4 ERP averaging

EEG data were filtered with a 30 Hz low-pass filter, and ERP epochs containing EEG data points exceeding ±60 μV were automatically rejected and the trace was manually inspected to verify artefact removal. EEG data from the auditory-visual oddball and auditory oddball tasks containing target stimulus presentations and no artefact were epoched between 100 ms pre-stimulus and 600 ms post-stimulus. EEG data from the auditory-visual oddball, auditory oddball and inter-modal oddball tasks containing standard stimulus presentations and no artefact were separately epoched between 100 ms pre-stimulus and 600 ms post-stimulus. All epochs were averaged, and baseline corrected. The ERPs generated by the standard stimuli in the auditory oddball and inter-modal oddball tasks, that is the auditory standard and visual standard respectively, were added together for each subject. This produced a separate ERP, the summated auditory-visual standard response, which was compared to
the response to the combined auditory-visual standard stimulus presented in the auditory-visual oddball task.

5.2.5 Data analysis

The primary analysis in this study compared the ERP from targets in the auditory-visual oddball task with that from targets in the auditory oddball task. The ERPs for each participant were subjected to an automated peak detection process, with manual confirmation, to identify maximum peak amplitudes within a specified latency range. The latency ranges for peaks, determined through observation of grand average ERPs, were N100 (70 – 160 ms), P200 (120 – 210 ms), P250 (220 – 290 ms), P300 (260 – 350 ms) and P350 (310 – 370 ms).

A second analysis compared the ERP to the standards in the auditory-visual oddball task with the summation of responses to auditory and visual standards from the other two tasks. The same peak detection process was employed for these ERPs. The latency ranges for peak data to standards were N100 (80 – 130 ms), P130 – evident at parietal sites only (120 – 160 ms), N160 – evident at parietal sites only (140 – 190 ms), P200 (190 – 250 ms), N300 (260 – 330 ms) and P350 (310 – 390 ms). All ERPs were manually inspected to verify accuracy of the peak detection process.

Peak data were analysed over nine sites (F3, Fz, F4, C3, Cz, C4, P3, Pz, P4) using a repeated measures analysis of variance. Within-subject factors included Task and Topography (Lateral [Left, Midline, Right] and Sagittal [Frontal, Central, Posterior]). Planned contrasts were conducted to clarify the topographic distribution of each component. Contrasts for the sagittal factor
compared Frontal (F) vs. Posterior (P), and Central (C) vs. the mean of the Frontal and Posterior regions. Contrasts for the lateral factor compared Left (L) vs. Right (R), and Midline (M) vs. the mean of Left and Right regions. The P130 and the N160 components to standards at parietal sites (P3, Pz, P4) were analysed separately. For this analysis, planned contrasts compared Left (P3) vs. Right (P4), and the Midline (Pz) vs. the mean of Left and Right sites. As all contrasts were planned and did not exceed the degrees of freedom for effect, no Bonferroni-type adjustment of $\alpha$ levels is required (Tabachnick & Fiddell, 1989). Where there were significant main effects of task, data were submitted to vector scale normalization (McCarthy & Wood, 1985) and only task by topography interactions that remained significant after this procedure are reported. All contrasts had $df = (1, 16)$.

5.2.6 Difference waves

A subsequent analysis was conducted to further investigate multisensory integration effects to standards in the auditory-visual oddball task. Difference waves were produced by subtracting the ERPs generated by the summated auditory and visual standard stimuli from those to the combined auditory-visual standards (AV – (A+V)). The resultant difference waveform was digitally high-pass filtered at 2 Hz (12 dB attenuation) with zero phase shift. This was done to minimise the effect of anticipatory slow potentials (see Teder-Sälejärvi et al., 2002). Visual inspection of the difference waves identified four peaks. These spanned 20 – 40, 80 – 100, 120 – 170 and 220 – 270 ms respectively. The mean amplitude of each peak, at each of nine electrode sites (F3, Fz, F4, C3, Cz, C4, P3, Pz, P4), was compared to zero using analysis of
variance. Planned contrasts (as described above) were also conducted to
determine topographic effects. All contrasts had $df = (1, 16)$.

5.3 Results

5.3.1 Comparison of auditory target ERPs in the auditory-visual oddball and
auditory oddball tasks

As is evident in figures 5.1 and 5.2, no significant differences in N100,
P200, or N200 amplitudes or topography were evident. The P200 component
had a comparatively shorter latency at frontal midline sites than parietal midline
sites in the auditory oddball task than in the auditory-visual oddball (task x
latency differences for these three components were found.

The auditory-visual oddball P250 was significantly larger than the
auditory oddball P250 (12.7 vs. 8.4 $\mu$V: $F = 4.74$, $p < 0.05$). The auditory-visual
oddball P250 was also comparatively larger at the parietal midline than the
frontal midline (task x P > F x M > L/R: $F = 8.51$, $p < 0.05$). No differences in
latency were evident.

As is evident in figure 5.2 the auditory-visual oddball target P300 had a
centro-parietal topography whilst the auditory oddball target P300 was
equipotentially distributed across the scalp. The auditory-visual oddball P300
was significantly larger than the auditory oddball P300 (11.98 vs. 8.72 $\mu$V: $F =
12.25$, $p < 0.005$). The auditory-visual oddball P300 was also comparatively
Figure 5.1 Grand average ERPs across all sites to auditory targets in auditory-visual oddball (black line) and auditory oddball (grey line) tasks. Note the similarity in ERP components up to 200 ms in each task, whilst the ERP between 200 – 400 ms is substantially larger in the auditory-visual oddball task. The thin black line, included at the central nine sites, represents the difference between the ERPs. These waves show clear differences between approximately 220 and 350 ms, which is consistent with analyses conducted on the peak data. (Note: Difference waves were high pass filtered at 2 Hz).
Figure 5.2 Sagittal — [F]rontal, [C]entral, [P]osterior and lateral — [L]eft, [M]idline, [R]ight distribution of each component, comparing the auditory-visual oddball (black line with squares) and auditory oddball (grey line with squares) tasks.
larger than the auditory oddball P300 at parietal sites compared to frontal sites and central sites compared to the mean of the frontal and parietal regions (task x P > F: F = 7.67, p < 0.05; task x C > F/P: F = 11.41, p < 0.05 respectively) and had an enhancement at the parietal midline (task x P > F x M > L/R: F = 4.71, p < 0.05). The latency of the auditory-visual oddball P300 component was comparatively longer at right frontal sites than the auditory oddball P300 (task x P < F x L < R: F = 5.59, p < 0.05).

Figure 5.2 shows that the P350 component had a parietal topography in both tasks. P350 amplitudes were larger in the auditory-visual oddball than the auditory oddball task (7.1 vs. 4.5 µV: F = 6.14, p < 0.05), but did not differ in latency or topography.

5.3.2 Comparison of ERPs for the combined auditory-visual standards and summated auditory-visual standards

As is evident from the grand averages depicted in figure 5.3 there was no apparent enhancement of the combined auditory-visual standard ERPs. Analysis of the peak data showed that there was no task difference in overall amplitude for any of the peaks identified.

However, the N100 to the combined auditory-visual standards was significantly earlier than the N100 to the summated auditory-visual stimuli (102 vs. 108 ms: F = 18.67, p < 0.05). It was also comparatively earlier at frontal sites (task x F < P: F = 18.53, p < 0.005) and comparatively later in the right parietal region (task x P > F x R > L: F = 5.13, p < 0.05).
Figure 5.3 Grand average ERPs for the combined auditory-visual standards (black line) and summated auditory and visual standards (grey line). Note that the P130 and N160 components are evident only at parietal sites. The thin black line represents the difference between ERPs to the standard stimuli. Difference waves were high pass filtered at 2 Hz to reduce the effect of anticipatory potentials.

Figure 5.4 Difference waves of responses to combined auditory-visual standards minus summated responses to auditory and visual standards (AV − (A+V)) at the midline.
Topographic analysis showed that the P200 and 350 components to the combined auditory-visual standard stimuli had comparatively larger amplitudes at the midline than the summated response (task x M > L/R: F = 5.87, p < 0.05 and task x M > L/R: F = 5.60, p < 0.05 respectively). No other differences in amplitude or latency were evident.

5.3.3 Difference waves

As is evident in figure 5.4 there were four distinct peaks in the difference wave: early positive (Pd(e): 20 – 40 ms) and negative (Nd(e): 80 – 100 ms) components, and late positive (Pd(l): 120 – 170 ms) and negative (Nd(l): 220 – 270 ms) components.

The mean amplitude of the Pd(e) was significantly larger than zero (0.423 µV: F = 7.93, p < 0.05). Topographic analysis showed no differences, indicating that amplitudes were consistent across the scalp.

The Nd(e) was also significantly different from zero (-0.955 µV: F = 18.63, p < 0.005). This component was larger frontally than parietally (F > P: F = 13.29, p < 0.005) and more so in the right frontal regions (F > P x R > L: F = 5.61, p < 0.05).

The Pd(l) was significantly larger than zero (0.776 µV: F = 18.39, p < 0.005). The amplitude at central sites was larger than the mean of the frontal and posterior regions (C > F/P: F = 14.41, p < 0.005). This was primarily due to larger amplitudes at the vertex (C > F/P x M > L/R: F = 4.89, p < 0.05).
The mean amplitude of the Nd(l) was also different from zero (-0.430 µV: F = 4.97, p < 0.05). This was most evident at central sites (C > F/P: F = 17.28, p < 0.005).

5.4 Discussion

The purpose of this study was to investigate auditory processing in two oddball tasks and determine how the inclusion of a visual standard stimulus affected the ERP to auditory targets. Both tasks required intra-modal processing, that is, detecting auditory targets amongst auditory standards. However, the auditory standard stimulus in the auditory-visual oddball task was presented simultaneously with the visual standard. It is argued that the target ERP in the auditory-visual oddball condition represents intra-modal processes plus additional effects produced by the inclusion of the visual standard stimulus. These additional effects should be evident as differences in target ERPs between the auditory-visual oddball and auditory oddball tasks.

It can be assumed that, based on evidence from the previous chapter that showed auditory standards but not visual standards affected ERPs up to 200 ms post-stimulus, the early auditory N100 and P200 components to targets would not be affected by the inclusion of the visual stimulus. As is evident in figures 5.1 and 5.2, no differences in the N100 and P200 components were apparent, which supports this assumption. These data provide further evidence that visual standards in inter-modal oddball conditions do not affect early components in the auditory target response.
Within the 200 ms post-stimulus period, a third component was evident, the N200, that did not differ between tasks. The N200 consists of overlapping sub-components, which include the MMN and N2b (Näätänen et al., 1982; Näätänen, 1992; see chapter 2.3.3). There were no differences in the N200 component, which suggests that neither of the sub-components were affected by inclusion of the visual stimulus. The modality-specific MMN (see Näätänen, 1992) was not modulated by differential inter-modal processes, as might have been expected. However, the N2b, which is generated by attended infrequent stimuli, has been described as modality non-specific (Ford, Roth & Kopell, 1976; Näätänen, 1992). Therefore, it should reflect the infrequency of target presentation in both single and mixed modality conditions, that is, regardless of the modality of the standards. The last chapter indicated that the N2b is not generated in inter-modal oddball conditions, that is, by auditory targets when presented amongst only visual standards, and this suggested that the N2b was not necessarily modality non-specific. It can be argued that although the N2b was elicited in the auditory-visual oddball task in this study, inter-modal processes were not responsible for its generation. This is because it did not differ from the equivalent component in the auditory oddball task, a task that represents intra-modal processes only. Therefore, the N2b represents processing of an infrequent stimulus presented amongst frequent stimuli in the same, but not a different modality, suggesting some modality specificity.

It is clear that components up to approximately 200 ms post-stimulus are unaffected by the inclusion of the visual stimulus. The current findings extend earlier results by demonstrating that all components up to 200 ms post-stimulus in inter-modal oddball conditions, including the N200, are unaffected by the
inclusion of stimuli from a different modality. It may be argued that one reason for this is that subjects were required to detect targets in only one modality, which may have had the effect of directing attention to that modality. Recent research suggests that the integration of multi-sensory stimuli requires attention to a multi-sensory object in its entirety (Talsma & Woldorff, 2005; Talsma et al., 2007). If subjects were primarily attending the auditory stimuli in the auditory-visual oddball task then this may have mitigated any multi-sensory effects.

In contrast to the early components, the later part of the ERP, between 200 and 400 ms post-stimulus, was typified by a broad positivity that encompassed three separate components (P250, P300, P350), each of which differed between tasks. All components were larger in the auditory-visual oddball, and both the P250 and P300 were topographically distinct from components at equivalent latencies in the auditory oddball. It can be argued that these differences in the late components between tasks indicate that the visual stimulus affected auditory target processing.

The earliest of the three components evident in this late positivity is the P250 component, which had a centro-parietal topography in both tasks. The P250 in the auditory-visual oddball task was larger than in the auditory oddball task and also had a comparative parietal-midline enhancement. Based on its topography, the P250 component is equivalent to the P3a, first identified by Squires et al. (1975). They demonstrated that in attend conditions the P3a has a centro-parietal topography, comparable to the P250 in this study (see their figure 5 - right panel). The P3a component has been shown to be sensitive to stimulus probability (Simons & Perlstein, 1997), becoming more parietally
focussed as stimulus categorisation occurs (Courchesne, 1978; Friedman & Simpson, 1994). As the probability of target occurrence was identical in each task, we argue that probability was not responsible for the enhancement of the P250/P3a in the auditory-visual oddball task. The P3a also represents the mismatch process related to detecting a rare stimulus in an ongoing train (Squires et al., 1975; Snyder & Hillyard, 1976; Näätänen, 1992; Holdstock & Rugg, 1993). It can be argued that this mismatch process is occurring in both tasks, with the difference in amplitudes representing differences in target processing, differences that would be due to the addition of the visual standard. Friedman et al. (2001) claim that the P3a is modality non-specific. This means that it should be modulated in both conditions. It would also mean that it reflects a general mismatch process rather than a stimulus-specific mismatch process. It can be further argued that the larger P250/P3a amplitude and differences in topography in the auditory-visual oddball represents the aggregation of parallel mismatch processes, an intra-modal mismatch process, and a separate overlapping process reflecting stimulus deviation from the visual standard stimulus train.

It is noted that both the N2b and P3a have been described as modality non-specific markers of a mismatch detection process (Ford et al., 1976; Näätänen, 1992; Friedman et al., 2001). However, the N2b is not elicited by stimuli from different modalities. This would suggest dissociation between the N2b and P3a, with these components reflecting modality specific and non-specific mismatch processes respectively.
The P300 was evident as a centro-parietal component in the auditory-visual oddball. At the same latency, activity in the auditory oddball task was equipotential across the scalp, implying different activity at this latency. It can be argued that, as the centro-parietal P300 component was evident to targets only in the auditory-visual oddball task, this component reflects activity related to the inclusion of the visual standards. A similar parietal P300 component was evident to stimuli in the inter-modal oddball task in the previous chapter. It can be argued that this component, which is generated in tasks that include the visual standard stimulus, is specifically related to auditory processing amongst visual standards. If this were the case, it would represent the first clear indication of a specific inter-modal component evident in the ERP. Further research is required to investigate this possibility.

The P350 component had a similar parietal topography in both tasks and was larger in the auditory-visual oddball. The parietal topography of the P350 component in the auditory oddball task replicates the results to auditory oddball stimuli from the previous study. However, these data extend that finding, showing that an equivalent component is elicited by the auditory-visual oddball stimuli. Based on its latency and topography we argue that the P350 is equivalent to the P3b component (see Squires et al., 1977). The similarity of topography of the P350/P3b component in these tasks suggests that they reflect the same process; that is, the process of detecting auditory target stimuli amid the auditory standards. However, the larger amplitudes of the auditory-visual oddball P350/P3b potentially reflect increased task demands produced by the inclusion of multiple standard stimuli.
The two components, P300 and P350, reflect different aspects of the target detection process. We have argued that the P300 represents target detection amongst the visual standards, and the P350 represents target detection amongst the auditory standards. In chapter 4 there were separate parietal P300 and P350 components identified in the inter-modal oddball and auditory oddball tasks respectively, and it was argued that the difference in latency of these parietal components represented a delay in processing in the auditory oddball task. That is, they were conceptualised as the same component occurring later when multiple auditory stimuli were presented. The current results suggest that this is not the case. In both this and the previous study, the parietal P300 component occurred only when visual standards were presented. The parietal P350 component occurred when an auditory standard and target were presented, regardless of whether a visual standard was present. This implies that these components represent separate aspects of the target detection process. In this study the auditory-visual oddball task produced both a parietal P300 and parietal P350 component, suggesting that these distinct components represent separate inter-modal and intra-modal processes in this task.

The present study demonstrates effects on the auditory target ERP by the visual standards in the auditory-visual oddball task. However, it is noted that the visual standard in the auditory-visual oddball is omitted when the targets are presented, a general feature of the oddball task – the target occurs instead of the standard within the stimulus train. Hence it may be argued that, when the visual standard stimulus is omitted in the auditory-visual oddball task, instead of inter-modal processes, participants may separately process both the auditory
target presentation and the visual stimulus omission. This would mean that the differences evident in the auditory-visual oddball result from activity related to the omission of the standard rather than an inter-modal process. Until the effects of the visual stimulus omission in this task are investigated, conclusions about inter-modal processes remain tentative.

Two subsequent analyses were conducted to investigate multi-sensory integration effects in the combined auditory-visual standard stimuli. The first analysis tested peak amplitude, latency and topography. These results indicated that the ERP peaks to the combined auditory-visual standard stimulus did not differ substantially from the summated ERP peaks to auditory and visual standard stimuli. This suggests that analysis of the strength and timing of ERP components provides little evidence for auditory-visual integration effects. However, it could be argued that effects of multi-sensory integration may superimpose upon the ERP, an effect that may not be detectable by analysis of peak data alone. Therefore, the second analysis investigated the difference wave formed by subtracting the summated auditory-visual standard ERP from the combined auditory-visual standard ERP. It is argued that the difference between the combined and summated ERPs should represent the putative activity elicited by multi-sensory stimulation (Barth et al., 1995; Fort & Giard, 2004). These data show two positive difference waves (Pd(e):20 – 40 ms and Pd(l):120 – 170 ms) and a late negative difference wave (Nd(l): 220 – 270 ms) that are consistent with previously reported multi-sensory integration data (Giard & Peronnet, 1999; Foxe, Morocz, Murray, Higgins, Javitt & Schroeder, 2000; Fort et al., 2002a, 2002b; Fort & Giard, 2004). The Pd(e) was marginally earlier than similar components reported by other authors (Giard & Peronnet,
Fort et al., (2002b) note that activity around 40 ms may be considered the earliest genuine reflection of multi-sensory integration. The Pd(l) occurred between 100 – 180 ms post-stimulus and was largest at the vertex. It is clear from figure 5.4 that the Pd(l) represents differences occurring between the N100 and P200 peaks, particularly at frontal and central sites, which implies an underlying process evident in the ERP to the combined auditory-visual standards. Activity at this latency is consistent with a number of other integration studies (Giard & Peronnet, 1999; Teder-Sälejärvi et al., 2002; Fort et al., 2002a, 2002b; Fort & Giard, 2004; Talsma & Woldorff, 2005; Talsma et al., 2007). These effects have been reported to be larger at central sites (Teder-Sälejärvi et al., 2002; Fort et al., 2002b; Talsma & Woldorff, 2005), consistent with these data, as well as at frontal and right frontal sites (Fort et al., 2002a; Fort & Giard, 2004). Thus, there is evidence that the combining of auditory-visual standard stimuli produces underlying activity not related to peaks in the ERP. The Nd(l) was evident between 220 – 270 ms. Activity at this latency has been previously reported (Teder-Sälejärvi et al., 2002). However, Fort & Giard (2004) note that interactions later than 200 ms post-stimulus may be contaminated by general task related potentials (e.g. motor responses, N2b, P3). The Nd(l) has a latency consistent with the peak of the P200 component (see figure 5.4) and it may be suggested that this component represents a modulation of the P200 component rather than integration activity per se. Nonetheless, taken together, these data provide evidence of multi-sensory integration effects in the auditory-visual standard stimuli.
An additional early peak, the Nd(e) was evident between 80 and 100 ms post-stimulus. This is consistent with activity in the ascending portion of the N100 component (see figure 5.4) and may represent the difference in N100 latency evident in the peak data. It is noted that despite shorter latencies, these data show no effect of the combining of auditory-visual standards on N100 amplitude. In multi-sensory integration studies enhancement at this latency is not commonly seen, although some authors have reported larger N100 amplitudes to attended multi-sensory stimuli (Talsma & Woldorff, 2005; Talsma et al., 2007). The Nd(e) was primarily larger frontally, particularly at right frontal sites. A number of studies have shown that bimodal and not unimodal stimuli activate right frontal and fronto-temporal regions (Giard & Peronnet, 1999; Fort et al., 2002a, 2002b; Fort & Giard, 2004), generally between 120 – 200 ms. It has been argued that this represents activation of poly-sensory integration sites (Fort et al., 2002a, 2002b; Fort & Giard, 2004). It may be suggested that the right frontal enhancement of the Nd(e), albeit earlier than in previous reports, may reflect similar activation of poly-sensory rather than sensory-specific processing areas.

These data have shown that early components of the ERP to auditory target stimuli are unaffected by the simultaneous presentation of an auditory-visual standard stimulus, whilst the later components show substantial differences that were mediated by the context in which the targets were presented. This provides further evidence of auditory processing occurring in two stages. Furthermore, the present experimental methodology incorporated two tasks that induced intra-modal effects on the auditory target ERP (c.f. chapter 4). The results of the present study indicate that the intra-modal
processes involved in producing early component amplitude, latency and topography are unaffected by the inclusion of the visual standard. This suggests modality specificity of these components. These data demonstrate that, in contrast to inter-modal attention tasks, which requires selective attention and show effects at early processing stages, the early processes in an oddball paradigm remain unaffected by other modality stimuli. To my knowledge the intransience of these early intra-modal ERP components to the presence of other modality stimuli in oddball conditions has not been demonstrated previously. The clearest effect produced in this experiment was an enhancement of the later positive components. Specific effects included a P250/P3a component, consistent with previous reports in oddball tasks, that was topographically distinct in different conditions. It was argued that this component represented the aggregation of parallel mismatch processes. There was also evidence of two parietal positivities (P300 and P350), which represented separate inter-modal and intra-modal processes within this task. It is argued that these separate components evident to equivalent stimuli within the one task warrant further investigation. By incorporating stimuli from multiple modalities in an oddball task this study has identified separate modality specific and context specific effects, which further the understanding of cortical activation during auditory processing.
6. ERPs to Infrequent Auditory Stimuli in Two- and Three-stimulus Versions of the Inter-modal Oddball Task

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7 The main results reported in this chapter have been published in: Brown, C. R., Barry, R. J., Clarke, A. R. (2009). ERPs to infrequent auditory stimuli in two- and three-stimulus versions of the inter-modal oddball task. International Journal of Psychophysiology, 74, 174-182 (see Appendix C).
6.1 Introduction

The previous chapters (4 & 5) investigated auditory target processing in inter-modal oddball conditions. These investigations were largely a study of how auditory target ERPs were affected by the inclusion of a visual standard stimulus. The results suggested that auditory ERPs in inter-modal oddball conditions were processed in two separate distinct stages. In both of these studies the characteristics of the auditory target stimulus was equivalent across comparisons. Thus, the results primarily represent the effect that modulating frequent standard stimuli has on the resultant ERP. That is, each task differed on the dimension of standard stimulus attributes.

The experiment presented in this chapter will investigate ERPs in a two- and three-stimulus version of the inter-modal oddball task. The two stimulus task is equivalent to that presented in chapter 4, whilst the three stimulus task will include two infrequent auditory stimuli, a target and a non-target deviant stimulus presented amidst visual standards. These tasks are analogues of experimental paradigms frequently used in the study of auditory attention – comparisons of which can allow for the investigation of factors such as the effect of tone type and rarity on auditory processing (Oades, 1997). The purpose of this study is to investigate how variations to the attributes of infrequent stimuli affect auditory processing in inter-modal oddball conditions. The aim is to determine how the addition of an infrequent auditory non-target stimulus in a three-stimulus version of this task affects auditory processing. This will be achieved by comparing ERPs to target stimuli in each task and ERPs to targets with those to non-targets in the three-stimulus task.
6.2 Material and Methods

6.2.1 Participants

Participants were 17 (15 female, 16 right-handed) undergraduate psychology students who participated as one means of satisfying a course requirement. They were aged between 18 and 43 (Mean = 23.2, SD = 6.8) years. All participants had normal or corrected to normal vision, and self-reported normal hearing. Participants reported not taking any illicit or pharmaceutical drugs, or alcohol, for 24 hr prior to testing.

6.2.2 Procedure

Participants were tested in one session that lasted approximately 1.5 hr. After participants were fitted with an electrode cap they were seated in a test booth, 1 m from a computer monitor and speakers. They completed two versions of the inter-modal oddball task. The two-stimulus inter-modal oddball task was identical to that presented in chapter 4. The three-stimulus inter-modal oddball task comprised a visual standard stimulus identical to that in the two-stimulus task. Two auditory stimuli were randomly interspersed amidst standards. They were a rare (10 %) auditory target stimulus (2000 Hz – 60 dB) and an equally rare (10 %) auditory non-target stimulus (1000 Hz – 60 dB). Auditory and visual stimuli in each task were presented from a central location to avoid problems of spatial disparity in stimulus processing. All auditory stimuli had 10 ms rise, plateau and fall times. Participants received 300 stimulus presentations in each task at a fixed SOA of 1.03 sec and were required to
press a button with their dominant hand as quickly as they could to the target stimulus\textsuperscript{8}.

6.2.3 EEG acquisition

EEG was recorded with a sampling rate of 500 Hz and a range of 263 μV between 0.5 – 70 Hz using a NeuroScan NuAmps DC amplifier. Cortical activity was recorded from 19 derivations at Fp1, Fp2, F3, F4, Fz, F7, F8, C3, C4, Cz, T3, T4, T5, T6, P3, P4, Pz, O1, O2, using tin electrodes in an electrode cap, referenced to linked ears. Horizontal EOG was recorded from the outer canthus of both eyes, and vertical EOG was recorded from above and below the right eye, using 9 mm tin electrodes. Impedance levels for all electrodes were below 5 kΩ. Data were stored for offline analysis.

6.2.4 ERP averaging

EEG data points exceeding ±60 μV were automatically rejected and the trace was manually inspected to verify artefact removal. EEG data from the two-stimulus and three-stimulus tasks containing auditory target and auditory non-target stimulus presentations and no artefact were epoched between 100 ms pre-stimulus and 600 ms post-stimulus. All epochs were filtered using a 30 Hz low-pass filter, baseline corrected around the pre-stimulus interval, and averaged.

\textsuperscript{8} Both tasks include 20% of stimulus presentations as auditory tones. This was done so that the time on task and the probability of change from ongoing visual standards was equivalent across conditions. It also avoided processes such as refractory period effects that would alter the ERP if more stimuli were presented in the three-stimulus condition. However, it is noted that this means that the probability of receiving a target presentation is different across tasks and effects on later ERP components may represent activity related to this difference.
6.2.5 Data analysis

ERPs for each participant were subjected to an automated peak detection process, with manual confirmation, to identify maximum peak amplitudes within a specified latency range. ERP labels were based on the approximate peak latency of the component. The latency ranges were N100 (90 – 140 ms), N140 (110 – 175 ms), P200 (160 – 230 ms), N220 (190 – 275 ms), P250 (210 – 285 ms), N285 (250 – 320 ms), P300 (260 – 350 ms) and P350 (300 – 400 ms).

Peak data were analysed over nine sites (F3, Fz, F4, C3, Cz, C4, P3, Pz, P4) using a repeated measures analysis of variance. Within-subject factors were Stimulus and Topography (Sagittal [Frontal, Central, Posterior] and Lateral [Left, Midline, Right]). Within the factor Stimulus, two planned contrasts were conducted. These compared components produced by target stimuli in the three-stimulus condition with those to targets in the two-stimulus condition, and with those produced by auditory non-targets in the three-stimulus task. Where ERP components were evident to only two stimulus types (e.g. target stimuli only) analysis was limited to the relevant data. Within the factor Topography, planned contrasts compared the nine electrode sites in a 3 x 3 matrix. Contrasts within the sagittal factor compared Frontal (F) vs. Posterior (P), and Central (C) vs. the mean of the Frontal and Posterior regions. Contrasts for the lateral factor compared Left (L) vs. Right (R), and Midline (M) vs. the mean of Left and Right regions. Where a component was not apparent at all nine sites, comparisons were restricted to those sites where it appeared. As all contrasts were planned and did not exceed the degrees of freedom for effect, no Bonferroni-type
adjustment of α levels is required (Tabachnick & Fiddell, 1989). Where there were significant main effects of Stimulus, data were submitted to vector scale normalization (McCarthy & Wood, 1985), and only Stimulus by Topography interactions that remained significant after this procedure are reported. All contrasts had $df = (1, 16)$.

6.3 Results

The number of infrequent stimuli presented in the two tasks totalled 30 targets and 30 non-targets in the three-stimulus task [T(3)], and 60 targets in the two-stimulus [T(2)] task. The mean number of trials retained after artefact rejection were 25.5 (SD = 4.1), 24.5 (SD = 4.1) and 49.9 (SD = 5.9) respectively. Signal to noise ratio for each task was calculated as 3.8:1, 5.9:1, and 6.2:1. Figure 6.1 shows a representative sample of individual ERPs. Panel A shows the superimposition of all subjects’ waveforms for each condition. Panel B shows a sample of selected subjects’ data overlayed by condition. As is evident in this figure, the peak data are reasonably well characterised.

Figure 6.2 depicts grand average ERPs to target stimuli in the three-stimulus and two-stimulus inter-modal oddball conditions, and to auditory non-targets in the three-stimulus task. As is evident in figure 6.2 – panel A, all three stimuli produced a series of early ERP components (N100, N140, P200, N220). In the two oddball conditions both target stimuli produced late positive components (P250 and P300: see figure 6.2 – panel B) which were not evident to the auditory non-targets. The non-targets produced a late negative-going wave (N285) at a comparable latency (see figure 6.2 – panel C). All three stimuli produced a late positivity (P350). However, as is evident in figures 6.2
and 6.3, the topography of this positivity differed as a function of the condition in which it was elicited.

The N100 had a mean latency of 112.1 ms (SD = 1.2). It was larger at frontal compared to parietal sites (F > P; F = 5.95, p < 0.05), at central sites compared to the mean of frontal and parietal sites (C > F/P; F = 32.88, p < 0.001), and at the midline than the mean of the hemispheres (M > L/R; F = 9.34, P < 0.01: see figure 6.3 – top left panel). These effects were largest at frontal midline sites (F > P x M > L/R; F = 6.60, p < 0.05) and at the vertex (C > F/P x M > L/R; F = 5.26, p < 0.05). Overall, this indicates a fronto-central midline topography.

The N100 to targets in the three-stimulus condition compared with targets in the two-stimulus condition showed no difference in amplitude, latency or topography.

The comparison of N100 to targets and auditory non-targets in the three-stimulus task showed that non-targets elicited larger N100 amplitudes (-7.45 vs. -6.42 µV; F = 5.47, p < 0.05). The non-target N100 was also comparatively enhanced at left parietal regions (NT > T(3) x L > R x P > F; F = 6.79, p < 0.05).

As can be seen in figures 6.2 and 6.3, the N140 component was evident at frontal sites only. Therefore, analysis was conducted only in the lateral dimension of the frontal electrodes (F3, Fz, F4). The N140 had a mean latency of 141.5 ms (SD = 1.3) and was earlier in the right than left hemisphere (R < L; F = 4.77, p < 0.05). N140 was larger at the right frontal than left frontal electrode
Figure 6.1 Superimposition of grand average ERPs for individual subjects. Panel A represents each subject's average ERPs across the midline. The thick black line is the grand average of these data. Panel B is a representative sample from five individual subjects. Each plot contains ERPs from Fz (thick lines) and Cz (thin lines) for the T(3) [black lines], T(2) [dark grey lines] and NT [light grey lines] stimuli. The shaded areas indicate the latency ranges for the N100 and P350 components. As is evident, the peaks contained within are clearly identifiable and distinguishable from other ERP components in individual data.
(R > L: F = 8.82, p < 0.01) and at midline compared to the mean of left and right electrode sites (M > L/R: F = 21.44, p < 0.001). Overall, the frontal N140 had a mid-right topography.

The frontal N140 was larger to targets in the three-stimulus task than in the two-stimulus task (-8.64 vs. -6.78: F = 5.83, p < 0.05). It did not differ in topography or latency for this comparison.

In the three-stimulus condition, the N140 to targets and non-targets did not differ in amplitude, latency or topography.

The P200 had a mean latency of 192.8 ms (SD = 1.7). It was larger at parietal than frontal regions, and centrally compared to the mean of frontal and parietal regions (P > F: F = 7.23, p < 0.05; C > F/P: F = 45.06, p < 0.001 respectively). It was also somewhat larger in the right hemisphere (R > L: F = 5.41, p < 0.05), and larger at the midline (M > L/R: F = 15.94, p < 0.005). These effects were accompanied by enhancement at the parietal midline and vertex (P > F x M > L/R: F = 18.23, p < 0.005; C > F/P x M > L/R: F=10.40, p < 0.01 respectively). There was also evidence of comparatively reduced activity at right parietal regions (P < F x R < L: F = 5.76, p < 0.05). Overall, the P200 had a centro-parietal midline topography with activity greatest at the vertex (see third left panel of figure 6.3).

The P200 to targets in the three-stimulus and two-stimulus tasks did not differ in amplitude, latency or topography.
Figure 6.2 Grand average ERPs to targets in the three-stimulus condition [T3] (thick black line), targets in the two-stimulus condition [T2] (grey line) and non-targets [NT] (thin black line). Panel A shows a comparison of ERPs across the midline for all conditions. Panel B shows separate ERPs to the target stimuli in the two oddball conditions. Panel C shows a comparison of target and non-target ERPs in the three-stimulus task.

As is evident in figures 6.2 and 6.3 (third left panel), in the three-stimulus task, P200 was somewhat larger to non-targets than targets (9.05 vs. 6.66 µV: F = 3.85, p = 0.067). The non-target P200 had comparatively larger amplitudes at parietal sites (NT > T(3) x P > F: F = 4.33, p = 0.054) and central sites (NT > T(3) x C > F/P: F = 34.20, p < 0.001). The difference between the right and left hemispheres was larger for targets than non-targets (T(3) > NT x R > L: F = 5.57, p < 0.05). Non targets produced comparatively larger amplitudes at the midline compared to the hemispheres (NT > T(3) x M > L/R: F = 10.62, p < 0.01) and at the vertex (NT > T(3) x C > F/P x M > L/R: F = 4.93, p < 0.05).
The N220 was a negative-going wave with a mean latency of 221.9 ms (SD = 2.0). As is evident in figure 6.2 and the bottom left panel of figure 6.3, N220 did not have a negative amplitude. This is probably due to the large P200 component that precedes it. Nonetheless, this negative going wave was more negative at frontal sites (F > P: F = 8.12, p < 0.05) and the mean of frontal and parietal regions was larger than at central sites (F/P > C: F = 27.90, p < 0.001). N220 was more negative in the left than right hemisphere and the mean of the hemispheres was larger than the midline (L > R: F = 6.08, p < 0.05; L/R > M: F = 25.09, p < 0.001, respectively). The N220 was also comparatively smaller at parietal midline sites (P < F x M < L/R: F = 5.22, p < 0.05) and at the vertex (C < P/F x M < L/R: F = 6.57, p < 0.05). Overall, the N220 component had a predominantly non-midline frontal topography with a left hemisphere bias.

The N220 to targets in the two oddball conditions did not differ in amplitude, latency or topography.

In the three-stimulus task, N220 to non-targets and targets did not differ in amplitude, latency or topography.

The P250 component was produced by target stimuli in the two oddball conditions. It had a mean latency of 251.3 ms (SD = 2.3). P250 was enhanced parietally (P > F: F = 4.22, p = 0.057) and centrally (C > F/P: F = 16.79, p < 0.005). It was larger in the right compared to the left hemisphere (R > L: F = 7.89, p < 0.05) and at the midline (M > L/R: F = 27.92, p < 0.001).
Figure 6.3 Sagittal – [F]rontal, [C]entral, [P]arietal and lateral – [L]eft, [M]idline, [R]ight distribution of early (left panel) and late (right panel) ERP components. Note: 1) the N140 component was analysed only across frontal electrode sites, 2) the average represents mean amplitudes across all conditions.
There was also evidence of a reduction at the left frontal region (F < P x L < R; F = 7.34, p < 0.05). Overall, the target P250 had a centro-parietal mid-right topography.

The P250 to targets in the three-stimulus task had longer latency than in the two-stimulus task (254 vs. 247 ms: F = 4.83, p < 0.05). It had comparatively larger amplitudes at frontal sites (T(3) > T(2) x F > P: F = 7.94, p < 0.05: see figure 6.3 – top right panel) and the left frontal reduction was less evident (T(3) < T(2) x F < P x L < R: F = 5.36, p < 0.05).

The N285 component was produced by non-target stimuli only. As is evident in figures 6.2 and 6.3, the N285 did not become negative at any point in the epoch. This is most likely due to the large activation of the preceding positivity (P200). None the less, the N285 was a negative going component that peaked at approximately 285 ms post-stimulus. Figure 6.3 suggests that this component had greater negative activity at frontal sites and in the right hemisphere. However, topographic analysis indicated that this effect was not significant.

The P300 component was produced by target stimuli only. It had a mean latency of 302.8 ms (SD = 2.8) and was larger at parietal sites than frontal sites (P > F: F = 4.83, p < 0.05; see figure 6.3, third right panel). This effect was due to comparatively greater activity at the parietal midline (P > F x M > L/R: F = 19.60, p < 0.001) and comparatively less activity at the vertex (C < P/F x M < L/R: F = 15.69, p < 0.005). Overall, the P300 had a parietal midline topography.
The target P300 did not differ in overall amplitude between tasks. In the three-stimulus condition, P300 had a comparative enhancement at right parietal regions \( (T(3) > T(2) \times P > F \times R > L: F = 4.87, p < 0.05) \). The latency of P300 in this condition was also comparatively longer at parietal sites \( (T(3) > T(2) \times P > F: F = 4.61, p < 0.05) \).

The three auditory stimuli produced late positive components with mean latencies of 343.0 ms (SD = 2.0) [three-stimulus targets], 340.4 ms (SD = 1.4) [two-stimulus targets] and 343.9 ms (SD = 1.6) [non-targets] respectively. As is evident in figure 6.3 these components – labelled P350 – had predominantly parietal, frontal and fronto-central topographies respectively, suggesting that they are distinctly different components.

The target P350 in the three-stimulus condition was larger than in the two-stimulus condition, a difference that approached significance \( (6.99 \text{ vs. } 5.44 \mu V: F = 4.07, p < 0.07) \). Analysis of target stimuli confirmed the difference between parietal and frontal topographies \( (T(3) > T(2) \times P > F: F = 5.04, p < 0.05) \) and showed a comparative enhancement at the midline in the three-stimulus condition \( (T(3) > T(2) \times M > F/P: F = 5.20, p < 0.05) \).

The comparison of non-target P350 with target P350 showed larger amplitudes to the non-target stimuli \( (8.94 \text{ vs. } 6.99 \mu V: F = 7.27, p = 0.05) \). Topographic analysis confirmed the difference in fronto-central and parietal topographies of these components \( (NT > T(3) \times F > P: F = 4.36, p = 0.053; NT > T(3) \times C > F/P: F = 9.18, p < 0.01) \).
6.4 Discussion

The purpose of this study was to investigate auditory processes in two and three-stimulus versions of the inter-modal oddball task. All auditory stimuli produced several early and late ERP components, with differences evident between the two tasks and within the three-stimulus task. Early and late components will be discussed separately.

6.4.1 Early ERP components

There were three auditory stimuli presented in two conditions in this study. All auditory stimuli (both targets and the non-target) produced a fronto-central N100 component that did not differ in latency or topography. It was argued previously that this component is indicative of the traditional N1 produced by auditory stimuli (c.f. chapters 4 and 5). The N1 is elicited by changes in the energy impinging upon the senses (Näätänen & Picton, 1987) and represents stimulus identification or attribute selection (Hillyard & Picton, 1979; Callaway & Halliday, 1982). The N1 can be affected by several factors including the direction of attention (Hillyard et al., 1973; Hillyard & Picton, 1978; Giard, Fort, Mouchetant-Rostaing & Pernier, 2000; Thornton, Harmer & Lavoie, 2007), overlapping endogenous processes (Näätänen & Michie, 1979; Näätänen & Picton, 1987; Näätänen, 1992) and the temporal proximity of the eliciting stimulus to other auditory stimuli and associated refractory period effects (Davis et al., 1966; Nelson & Lassman, 1968; Hari et al., 1982). It is unlikely that attentional requirements of these two sustained attention tasks would differ, particularly as they include easily discriminable tones presented at long ISIs. Furthermore, both tasks were of the same length and had an
equivalent number of auditory stimuli, which should produce similar refractory
effects on the ERP. Thus, neither attention effects, nor refractory period effects,
should have affected the N1 component. N1 amplitude can also be modulated
by the physical characteristics of the eliciting stimulus (Näätänen & Picton,
1987). In the present study, non-target stimuli, which were of a lower auditory
frequency than targets, produced marginally larger N100 amplitudes. Butler
(1968) described enhancements to the amplitude of the N100 with changes in
auditory frequency – although these were of substantially greater magnitude
than the effects seen in the present study. Hence it is possible that the
observed differences in N100 amplitude represent frequency-specific variations.
That is, they may reflect the difference in physical characteristics of the stimuli
rather than their subjective relevance.

The auditory stimuli in this study produced a second early negative
component (N140). This component differed from the N100 in morphology,
topography and task, indicating that it is a distinct negative component
(Spencer, Dien & Donchin, 2001). Näätänen and Picton (1987) described
several components that occur in the N1 latency range. Utilising their
nomenclature, the first component (N100) would be consistent with their
Component I. The N140 is somewhat harder to characterise, as it has not been
substantially described in the literature. A few studies have identified a negative
component, similar to the N140, which they likened to Component III (see
Alcaini et al., 1994; Budd et al., 1998). However, in chapter 4 this ascription was
questioned, suggesting that both these studies did not require motor response,
which was an attribute assigned to Component III. It was also noted that several
aspects of the N140\textsuperscript{9} to targets in the inter-modal oddball task were not necessarily consistent with this conclusion.

The present data provide some insight into the characteristics of the N140. This frontal component was larger to auditory stimuli in the three-stimulus task than to targets in the two-stimulus task\textsuperscript{10}. This suggests an enhancement that was specific to the three-stimulus condition. There are two task-specific differences between the three-stimulus and the two-stimulus tasks. Firstly, participants are required to discriminate between target and non-target deviants only in the three-stimulus task. Secondly, the probability of receiving a particular stimulus type (target or non-target) was halved in the three-stimulus condition compared with the two – although the total number of tones presented in the two conditions was equal. It can be argued that the enhancement of the N140 may reflect either or both these differences. As the N140 can be mediated by differences in task requirements, it is suggested that further research into the characteristics of this component is required.

The three auditory stimuli in these two tasks produced a P200 component which had a vertex maximum. The topography of this component was consistent with previous reports (c.f. chapter 4), being more anteriorly focussed than the earlier typically centro-parietal P200 commonly seen in two-

\textsuperscript{9} The N140 occurred 10 ms earlier in chapter 4 and was labelled N130 there. It is suggested that this may have been due to different task requirements. In the former paper, participants were required to count target stimuli, whereas in the present study they made a motor response.

\textsuperscript{10} Note that this claim is inferred from the data and that no direct comparison was made between targets in the two-stimulus task and non-targets in the three-stimulus task.
tone oddball tasks (c.f. chapters 4 and 5). It was argued previously that P200 differences in two-tone conditions largely is due to overlapping intra-modal processes – not present in the inter-modal oddball task (c.f. chapter 4). The vertex maximum of P200 in this study replicates the earlier results, and it may be argued that this component provides a reliable representation of P200 activity unaffected by other stimuli.

The P200 in the three-stimulus condition was somewhat larger to non-targets than targets. This enhancement is consistent with suggestions that it represents the inhibition of irrelevant information from further processing (Hansen & Hillyard, 1988; Oades, 1998). It is noted that the enhancement of the non-target P200 was largely was due to modulation at the vertex. This enhancement, as well as evidence of maximal activity at the vertex – both in this study and previously – and results suggesting that P200 is not overlapped by other processes in inter-modal oddball conditions, provides convergent evidence indicating that P200 may be produced by generators underlying the vertex.

Targets and non-targets produced a small negative-going wave (N220) that did not differ substantially across comparisons. An N2 component has not been identified previously in inter-modal oddball conditions, and it is noted that the characteristics of this negativity are not consistent with the typical auditory N2. Renault et al. (1982) identified an N220 component that they argued represented perceptual processing of the omission of an expected visual stimulus. The N220 in the present study has substantial similarities with that component, and it is suggested that it represents similar perceptual processes.
However, it is noted that the N220 had differences in topography from that produced by Renault et al.’s (1982) visual omission paradigm. This may indicate additional activity related to the processing of the auditory stimuli in this task. Furthermore, N220 latency was greater to non-targets than targets. This may be a reflection of the temporal uncertainty produced by the omitted visual stimulus differentially affecting processing of the stimulus that required withholding of a response.

6.4.2 Late ERP components

The target stimuli in each task produced a suite of late positive components subsequent to the early components discussed above. The first of these was the P250, which was largest at centro-parietal mid-right regions. We have argued previously that P250 is consistent with the P3a component generated in attended oddball conditions (e.g. Squires et al., 1975; c.f. chapters 4 and 5). The P3a component has been described as having both frontal and posterior activation (Friedman et al., 2001). The frontal activity is sensitive to variations in stimulus probability (Simons & Perlstein, 1997, Friedman & Simpson, 1994; Friedman et al., 2001) and may represent stimulus evaluation (Polich, 2007). The comparison of P250 between tasks showed that, despite having a centro-parietal topography, this component was comparatively larger at frontal sites in the three-stimulus condition. It is suggested that this enhancement may be a reflection of probability differences or target evaluation processes, which represent the primary differences between the two and three-stimulus tasks in this study.
In the three-stimulus inter-modal oddball task, stimulus evaluation and differences in probability have been associated with a frontal enhancement of both the N140 and P250 components. However, it is apparent that these components reflect task requirements in different ways. The N140 was affected equally by both target and non-target stimuli. This suggests it was modulated independently of stimulus relevance – that is, it represents a global task effect. In contrast, the P250 was modulated by the target stimuli only, which suggests stimulus specificity\textsuperscript{11}. Overall, this suggests that despite similar frontal enhancements of these two components, the underlying mechanisms that led to their modulation appear to be somewhat different.

The P200 and P250 components to targets were somewhat larger in the right than left hemisphere, a topographic effect that was not evident in chapter 4. Looren De Jong, Kok & Van Rooy (1989) reported a decrease in P2 and P3 components in motor areas contra-lateral to responding hand. They argued that this was potentially due to overlap with negative motor and readiness potentials – an effect that was more pronounced for right than left handed responses. In the current study subjects responded to target stimuli using their dominant hand - the former study required subjects to count targets. As sixteen of the seventeen subjects in the present study were right handed, it could be argued that the lateralisation of P200 and P250 reflects activation of motor regions in the left hemisphere, producing a small negative response around this latency (see also Shibasaki, Barrett, Halliday & Halliday, 1980).

\textsuperscript{11} Non-targets produced broad negative-going activity at this latency.
The P300 was the second late positive component produced by target stimuli. This component had a parietal midline topography that did not differ in overall amplitude between tasks. The P300, in inter-modal oddball conditions, is considered a representation of processing auditory targets amidst visual standards – that is, it reflects an inter-modal process (c.f. chapters 4 and 5). It can be argued that, in the current study, the similarity of P300 in the two tasks supports this view. Furthermore, despite no differences in overall amplitude between tasks, the P300 to targets in the three-stimulus condition showed focal enhancements in right parietal regions. Several neuroimaging studies have identified areas in parietal brain regions that respond to asynchronous bimodal stimuli, including the superior temporal sulcus, intra-parietal sulcus (right), right superior parietal lobe, and the parieto-occipital junction (Calvert, 2001; Calvert et al., 2001). It is suggested that the focal enhancements to targets in the three-stimulus task might represent the modulation of these supra-modal processing areas. Overall, these data complement the earlier findings, and provide further evidence for a specific inter-modal process elicited in the inter-modal oddball task.

The third positive component was the P350. As is evident in figure 6.3, this component demonstrated task-related topographic differences. The P350 in the two-stimulus task was clearly largest at frontal sites. This is broadly consistent with the findings in chapter 4\textsuperscript{12}. In contrast, P350 to targets in the

\textsuperscript{12} It is noted that the P350 in the former study had activation that was more equipotentially distributed across frontal and parietal regions. It is suggested that this reflects differences in
three-stimulus task had a parietal topography. This is consistent with activity produced by auditory targets presented amidst frequent auditory standards (c.f. chapters 4 and 5). As this component is evident in the three-stimulus task only, it may be argued that it represents the processing of auditory target stimuli presented amongst other, albeit infrequent, auditory tones. That is, it represents an intra-modal process.

The target stimulus in the three-stimulus task produced two parietal positive components (P300 and P350), both of which may be considered consistent with the P3b. There are a few studies that have identified multiple P3s elicited to a single stimulus within the one task. Johnson and Donchin (1985) identified two P300 components, which occurred several hundred milliseconds after one another, that were produced by an imperative stimulus in a feedback paradigm. Similarly, Fein and Turetsky (1989) found multiple P3s to auditory targets in a subset of subjects in a three-tone oddball task. They argued that this represented a two-stage strategy for evaluating and classifying a stimulus where “… a tone is first classified as standard or non-standard (i.e. deviance detection) and then further classified as infrequent target or infrequent non-target” (p. 392). It is conceivable that participants in the present study may also have used dual strategies in detecting auditory target stimuli in the three-stimulus task. These strategies would entail the detection of the auditory target stimulus occurring in place of visual stimulus change (i.e. an inter-modal process), and then the further classification of the stimulus into auditory target task requirements, as the former study required a mental count of targets, as opposed to a button press response in the present study.
or auditory non-target (i.e. an intra-modal discrimination process). Taken together, this would suggest separate inter-modal and intra-modal P3b components occurred concurrently in this task.

Non-target stimuli, which were presented with equal probability to targets, produced a broad negative-going response in the late post-stimulus period (see figure 6.2 – panel C). This is in contrast with the suite of positivities produced by targets at this latency. This broad negativity produced a non-target specific peak at approximately 285 ms post-stimulus (N285). The N285 may be considered similar to the N2 component produced by NoGo stimuli in a Go/NoGo task, which has a frontal topography. However, the N285 was comparatively smaller and later than the typical NoGo N2 (see Falkenstein, Hoormann & Hohnsbein, 2002; Barry, Johnstone, Clarke, Rushby, Brown & McKenzie, 2007). It is noted that the fundamental differences between the three-stimulus inter-modal oddball task and the typical Go/NoGo task is the comparative infrequency of non-target stimulus presentation and the inclusion of the frequent standard stimulus. Based on its characteristics, it is argued that the N285 may represent a NoGo response to non-target stimuli, which is overlapped by additional processes representing the infrequent presentation of non-targets amongst the visual standards.

The broad negativity that characterises the response to non-targets was followed by a late positivity (P350). This non-target positive component was different from those produced by targets at this latency. The fronto-central topography and latency of this P350 is consistent with activity elicited by infrequent non-targets in three-tone oddball tasks (e.g. Pfefferbaum et al., 1980;
Pfefferbaum et al., 1984; Grillon et al., 1990) and by NoGo stimuli in Go/NoGo tasks (e.g. Pfefferbaum, Ford, Weller & Kopell, 1985; Kok, 1986; Eimer, 1993; Schröger, 1993; Falkenstein, Koshlykova, Kiroj, Hoormann & Hohnsbein, 1995; Falkenstein, Hoormann & Hohnsbein, 1999; Falkenstein et al., 2002; Fox, Michie, Wynne & Mayberry, 2000; Barry et al., 2007). The similarity of the present non-target P350 with P3s from these other paradigms suggests that these NoGo responses are processed in much the same way. This means that the response to non-targets in this study probably was unaffected by inter-modal processes.

The distinction between early and late components represents separate stages of stimulus processing in inter-modal oddball conditions (c.f. chapters 4 and 5). The early components represent a modality specific processing stage, in which the auditory stimuli are processed independently of the visual standards. That is, they represent activity that is not overlapped by effects produced by the frequent standards. The early components showed small difference in response to targets and the non-target, that represent sensory and task-related effects. It is argued that these effects would not be discernable easily in more common types of oddball tasks, as they would be overlapped by intra-modal activity – that is, activity modulated by the presentation of a frequent auditory standard stimulus (c.f. chapter 4; see also Breton, Ritter, Simpson & Vaughan, 1988). This means that the inter-modal oddball task may be a useful way to investigate small changes in early auditory sensory processing. The late ERP components represent a context-dependent stage, being affected by the relevance of the stimulus and its relationship to other stimuli. Context-dependent processing was evident in this study, with ERPs to targets in the three-stimulus task differing
from those to both targets in the two-stimulus task and the non-targets. Overall, this study extends the earlier work on the inter-modal oddball paradigm, by showing how variations to the task – in this case the inclusion of an additional infrequent non-target auditory stimulus – alter the ERP at both early and late processing stages.
7. Inter-modal Oddball ERPs Analysed Using Different Quantification Methods: A Validation Study
7.1 Introduction

The preceding chapters have investigated auditory target processing in the inter-modal oddball task and its variants. These studies have described the characteristics and function of several ERP components produced by auditory targets in this task (N100, N130/140, P200, N220, P250, P300 and P350). The quantification of ERPs was achieved by picking the maximal amplitude of peaks in individual subjects waveforms, a quantification method frequently used in ERP research. However, peak-picking may be criticised on the basis that ERP components are not always readily identifiable in an individual subjects data (e.g. when SNR are small) and ERP waveforms do not necessarily equate to ERP components – several components may underlie a given waveform (Näätänen, 1992; Picton et al., 2000). This may decrease reliability, particularly when epoch numbers or sample sizes are small. Picton et al. (2000) suggested that principle components analysis (PCA) can be an effective method of deconstructing the ERP in order to demonstrate the nature of the underlying components. PCA simplifies the data set, leaving data that is more likely to represent pure signal than noise, and this can be useful in separating components associated with different perceptual or cognitive processes (Dien, 1998; Spencer et al., 2001; Dien, Spencer & Donchin, 2003; Dien & Frishkoff, 2005).

The purpose of this study is to investigate ERPs produced by auditory targets in an inter-modal oddball task using two quantification methods – peak-picking and PCA. The aims of the study are: 1) to further elucidate the characteristics and morphology of inter-modal oddball target ERPs by
considering data produced by these different quantification methods, and 2) to compare the characteristics of ERPs in this study with those reported in previous chapters in order to demonstrate the validity and reliability of the interpretations made in this dissertation.

7.2 Material and Methods

7.2.1 Participants

Participants consisted of 43 (11 males: 2 left handed) undergraduate university students participating as one means of satisfying their course requirements. Subjects were between 17 and 38 years old (mean = 22.9, SD = 5.3). Screening criteria for all subjects were consistent with that reported in previous chapters.

7.2.2 Procedure

Participants completed an inter-modal oddball task with parameters that were identical to those reported in chapter 4.

7.2.3 EEG acquisition

EEG was recorded using a NeuroScan NuAmps DC amplifier, sampled at 500 Hz with a range of 263 μV. Electrode placement was in accordance with the international 10/20 system. Cortical activity was recorded from 19 derivations at Fp1, Fp2, F3, F4, Fz, F7, F8, C3, C4, Cz, T3, T4, T5, T6, P3, P4, Pz, O1, O2, using tin electrodes in an electrode cap, referenced to linked ears. Horizontal EOG was recorded, using 9 mm tin electrodes, from the outer canthus of both eyes, and vertical EOG was recorded from above and below
the right eye. Impedance levels for all electrodes were below 5 kΩ. Data were stored for offline analysis.

7.2.4 ERP averaging

ERP epochs containing EEG data points exceeding ±60 μV were automatically rejected and the trace was manually inspected to verify artefact removal. EEG data containing target stimulus presentations and no artefact were epoched between 100 ms pre-stimulus and 600 ms post-stimulus. Epochs were averaged, passed through a 30 Hz low pass filter and baseline corrected.

7.2.5 Data analysis

7.2.5.1 ERP components - peak-picked data

The average ERP waveforms demonstrated seven peaks consistent with those reported in previous chapters. These were N100 (84 – 136 ms), N140 (104 – 164 ms), P200 (172 – 222 ms), N220 (192 – 258 ms), P250, (220 – 290 ms), P300 (276 – 334 ms) and P350 (310 – 378 ms).

Consistent with the analyses reported in previous chapters, planned contrasts using analysis of variance (ANOVA) was conducted on 9 electrode sites (F3, Fz, F4, C3, Cz, C4, P3, Pz, P4) to clarify the topographic distribution of each ERP peak. Contrasts for the sagittal factor compared Frontal (F) vs. Posterior (P), and Central (C) vs. the mean of the Frontal and Posterior regions. Contrasts for the lateral factor compared Left (L) vs. Right (R), and Midline (M) vs. the mean of Left and Right regions. As the contrasts were planned and did
not exceed the degrees of freedom for effect, no Bonferroni-type adjustment of
\( \alpha \) levels is required (Tabachnick & Fiddell, 1989). All contrasts had \( df = (1, 42) \).

### 7.2.5.2 Principle components analysis

These data were also subjected to a principle components analysis. Subjects average ERPs were restricted to between 50 – 400 ms. This covered the period of peak latency for all components identified in previous studies using peak detection procedures. Each average waveform was reduced to 88 pts. Data for all subjects at each electrode (43 subjects x 19 sites = 817) and each variable (88 digitised points) were submitted to a covariance matrix principle components analysis. This was followed by a varimax rotation of unstandardised PCA components (see Kayser & Tenke, 2003; Rushby, Barry & Doherty, 2005). Factor scores were generated in SPSS statistical package v. 15. These represent the product of the factor coefficient matrix and point amplitude for each case. Factor scores are directly related to component amplitudes (Picton et al., 2000) and were therefore used in a topographic analysis of PCA derived factors. The same ANOVA and planned contrasts used for peak data were used to investigate the topographic distribution of the factor scores.

### 7.2.5.3 LORETA source analysis

As an exploratory analysis, PCA derived factor scores to seven ERP components (N100, N130/140, P200, N220, P250, P300, P350), from each electrode across the scalp, were entered into low resolution electromagnetic tomography analysis software (LORETA: Pascual-Marqui, Michel & Lehmann, 1994; Pascual-Marqui, 1999). LORETA allows for the approximate
determination of 3D source distributions derived from scalp recorded data (Pascual-Marqui et al., 1994). This process calculates the smoothest current density configurations, resulting in the linear weighted sum of scalp recorded potentials (Romanos, Ehlis, Baehne, Jacob, Renner, Storch, Briegel, Walitza, Lesch & Fallgatter, 2010). Generator sources for each ERP component were identified by taking the three best matching brain regions for each of seven maximal current source densities. Those sources that showed multiple correspondence for each component of interest are reported.

7.3 Results

7.3.1 Peak-picked ERP components

N100 had a mean latency of 106.3 ms (SD = 9.8). As is evident in figures 7.1 and 7.2, it had a fronto-central midline topography being larger at frontal than parietal sites, at central sites compared to the mean of frontal and parietal sites (F > P: F = 37.52, p < 0.001; C > F/P: F = 48.60, p < 0.001 respectively) and at the midline than in the hemispheres (M > L/R: F = 43.58, p < 0.001).

N140, mean latency 133.7 ms (SD = 10.7), was larger frontally (F > P: F = 22.65, p < 0.001) and centrally (C > F/P: F = 9.46, p < 0.005). This component also had an enhancement at right frontal (R > L x F > P: F = 6.86, p < 0.05) and left central regions (L > R x C > F/P: F = 7.51, p < 0.01).

The P200 component had a mean latency of 200.4 ms (SD = 13.1). It was larger centrally compared to the mean of frontal and parietal regions (C > F/P: F = 115.22, p < 0.001), and at the midline compared to the hemispheres (M > L/R: F = 51.12, p < 0.001). P200 was enhanced at the parietal midline (P > F
x M > L/R: F = 13.91, p < 0.005) and as is evident in figure 7.2, it was largest at the vertex (C > P/F x M > L/R: F = 29.38, p < 0.001).

The N220 was a negative-going wave with a mean latency of 224.9 ms (SD = 13.9). As is evident in figures 7.1 and 7.2, N220 did not have a negative amplitude. Nonetheless, the mean of negative going activity at frontal and parietal regions was larger than at central sites (F/P > C: F = 75.37, p < 0.001) and N220 was more negative (closer to zero) in the hemispheres than at the midline (L/R > M: F = 71.14, p < 0.001). The N220 was also comparatively smaller at parietal midline sites (P < F x M < L/R: F = 12.22, p < 0.005) and at the vertex (C < P/F x M < L/R: F = 8.15, p < 0.01).

P250 had a mean latency of 252.9 ms (SD = 15.3). It was larger at central sites (C > F/P: F = 40.83, p < 0.001) and at the midline (M > L/R: F = 98.85, p < 0.001). This was predominantly due to larger amplitudes at the vertex (C > P/F x M > L/R: F = 8.39, p < 0.01).

P300 had a mean latency of 302.7 ms (SD = 12.7). It was larger at parietal regions (P > F: F = 14.31, p < 0.001) and in the right compared to the left hemisphere (R > L: F = 9.25, p < 0.005). These effects were due to larger amplitudes at the parietal midline (P > F x M > L/R: F = 6.17, p < 0.05) and central right regions (R > L x C > F/P: F = 5.94, p < 0.05), and smaller amplitudes at the vertex (C < P/F x M < L/R: F = 13.56, p < 0.005).

P350 had a mean latency of 344.7 ms (SD = 14.8). The mean of activity at frontal and parietal sites was larger than centrally (F/P > C: F = 12.67, p < 0.005), and it was larger in the hemispheres than the midline (L/R > M: F =
11.33, p < 0.005). These effects were largely due to comparative reductions at the frontal midline (F < P x M < L/R: F = 7.66, p < 0.01) and the vertex (C < P/F x M < L/R: F = 26.56, p < 0.001).

7.3.2 Principle components analysis

The principle components analysis yielded nine factors which explained 95.57% of the variance within the data. The factor loadings for these factors are presented in the top left panel of figure 7.3. Subsequent panels represent the virtual ERPs for each factor extracted. Virtual ERPs were constructed in accordance with Dien (1998) and Dien and Frishkoff (2005), by taking the product of, 1) the standard deviation of the raw data across subjects (for each electrode site), 2) the factor scores of each component (extracted for each subject and each electrode site separately), and 3) the voltage-corrected factor loadings. Visual inspection of the latency and topography of the virtual ERPs was used to identify and label the ERP components that corresponded to the extracted factors.

Factor 1 (18.21 % variance explained) had a positive polarity and a mean latency of 194 ms. Topographic analysis indicated it was larger at central sites compared to the mean of frontal and parietal sites (C > F/P: F = 127.41, p < 0.001) and at the midline compared to the hemispheres (M > L/R: F = 14.70, p < 0.005). Factor 1 also showed a comparative enhancement at the parietal midline and was largest at the vertex (P > F x M > L/R: F = 14.02, p < 0.005; C > P/F x M > L/R: F = 11.82, p < 0.001 respectively). Factor 1 is consistent with the P200 component.
Factor 2 (18.88 % variance explained) was a positive component with a mean latency of 250 ms. It was larger centrally than the mean of frontal and posterior sites (C > F/P: F = 27.76, p < 0.001) and at the midline (M > L/R: F=57.15, p < 0.001). This factor also had comparatively reduced amplitudes at left frontal regions (L < R x F > P: F = 6.27, p < 0.05), a comparative enhancement at mid frontal sites (F > P x M > L/R: F = 8.41, p < 0.01) and at the vertex (C > P/F x M > L/R: F = 13.17, p < 0.005). Factor 2 is consistent with the P250/P3a component.

Factor 3 (13.24 % variance explained) had a positive polarity and mean latency of 302 ms. It was larger parietally than frontally (P > F: F = 18.70, p < 0.001) and in the hemispheres compared to the midline (LR > M: F = 5.18, p < 0.05). These effects were predominantly due to enhancements at the parietal midline (P > F x M > L/R: F = 6.98, p < 0.05) and right central regions (R > L x C > F/P: F = 8.81, p < 0.01) and a comparative decrement at the vertex (P/F > C x L/R > M: F = 31.58, p < 0.001). This factor corresponds to the P300 component.

Factor 4 (10.52 % variance explained) was a positive component with a mean latency of 346 ms. The mean of frontal and parietal regions was larger than at central sites (F/P > C: F = 16.98, p < 0.001) and in the hemispheres compared to the midline (L/R > M: F = 11.05, P = 0.005). Factor 4 also showed a comparative reduction at the vertex (P/F > C x L/R > M: F = 37.02, p < 0.001). This factor is consistent with the P350 component.
Figure 7.1 Grand average ERPs across the scalp to inter-modal oddball targets.
Figure 7.3 Virtual ERPs for PCA derived factor scores. The top panel depicts factor loadings of nine factors. Subsequent panels represent virtual ERPs for the extracted factors. The bottom represents the reconstruction of PCA data compared to raw ERPs at Fz and Pz.
Figure 7.4 Topographic distribution of mean activity across Sagittal - [F]rontal, [C]entral, [P]arietal and Lateral - [L]eft, [M]idline and [R]ight regions for PCA factor scores (left panel) and headmaps showing the distribution of PCA derived activity across the scalp (right panel). Positive activity is in red, negative activity is in blue. Note that the headmap for Factor 9 is displayed with both top and rear views. As can be seen, the predominance of activity for this component is distributed in left parietal regions.
Factor 5 (11.16 % variance explained) had a mean latency of 378 ms. It was larger in the midline than the hemispheres (M > L/R: F = 37.78, p < 0.001) and at the vertex (C > P/F x M > L/R: F = 27.15, p < 0.001). This factor does not represent a previously reported component.

Factor 6 (9.46 % variance explained) was a negative component with a mean latency of 142 ms. It was predominantly negative at frontal sites (F > P: F = 16.80, p < 0.001) and was largest at the right frontal region (R > L x F > P: F = 12.28, p < 0.005). Factor 6 showed smaller amplitude at the midline compared to the hemispheres (M < L/R: F = 27.34, p < 0.001) due primarily to comparatively smaller amplitudes at the parietal midline (P < F x M < L/R: F = 40.78, p < 0.001) and parietal right regions (R < L x P/F < C: F = 4.74, p < 0.05). This factor had a frontal topography with enhancement at right frontal regions. This is consistent with the N140 component.

Factor 7 (8.1 % variance explained) had a negative polarity and mean latency of 110 ms. It was larger at frontal sites (F > P: F = 17.27, p < 0.001) at central sites compared to the mean of frontal and parietal electrodes (C > F/P: F = 28.89, p < 0.001) and at the midline (M > L/R: F = 28.76, p < 0.001). This factor showed a small enhancement at left central sites (C > F/P x L > R: F = 11.65, p < 0.005). Factor 7 had a predominant fronto-central midline topography and is consistent with the N100 component.

Factor 8 (3.5 % variance explained) had a positive polarity and mean latency of 78 ms. It was larger at central sites (C > F/P: F = 5.26, p < 0.05) and the midline (M > L/R: F = 18.17, p < 0.001) due to an enhancement at the vertex (C > F/P x M > L/R: F = 17.98, p < 0.001). This does not represent a
component previously identified in the inter-modal oddball task but based on its polarity and latency it is indicative of the P100 component.

Factor 9 (2.49 % variance explained) had a mean latency of 218 ms. This factor showed predominant negative activity in parietal left regions \((P > F \times L > R: F = 4.83, p < 0.05; P > F \times L/R > M: F = 9.08, p < 0.005)\). Despite differences in topography, the latency and polarity of factor 9 suggests it is consistent with the N220 component.

### 7.3.2.1 LORETA source analysis

PCA factor scores at all electrode sites for the seven primary ERP components were submitted to LORETA source analysis. There were several evident sources for each component. The sources reported represent the most prominent regions identified by the LORETA software package.

The major sources of factor 1 (P200) were identified as the superior temporal/supramarginal gyrus (BA 22, 39, 40), the mid-frontal/ventral anterior cingulate cortex (BA 2, 4, 6) and the post-central gyrus/paracentral lobule (BA 5, 7, 31, 40).

Factor 2 (P250) had sources evident in the superior temporal gyrus (BA 21, 22, 42) and the ventral anterior cingulate cortex (BA 6, 24).

The major sources for factor 3 (P300) were evident in the superior temporal/supramarginal gyrus (BA 40, 41, 42) and the precuneus/paracentral lobule (BA 5, 7, 31).
Factor 4 (P350) had sources evident in the superior temporal/supramarginal gyrus (BA 22, 40, 41, 42) and the anterior cingulate cortex (BA 6, 24, 32).

Factor 6 (N140) had major sources evident in the superior temporal gyrus (BA 22, 41, 42) and pre-frontal/anterior cingulate cortex (BA 10, 11, 32).

The major sources for factor 7 (N100) were found in the primary auditory cortex particularly the superior temporal gyrus (BA 22, 41, 42), mid-frontal gyrus (BA 6) and post-central gyrus (BA 40).

Factor 9 (N220) had sources in superior temporal gyrus (BA 22, 41, 42), the anterior cingulate cortex (BA 10, 11, 32) and the associative visual cortex/fusiform gyrus (BA 19, 37).

7.3.3 Post hoc analysis

As is evident in figure 7.4, factor 6 showed activation at both frontal and temporal sites. A post hoc analysis was conducted to further investigate the topographic distribution for this factor comparing the outer hemispheric electrode sites (Outer left [OL] (F7, T3, T5) and Outer right [OR] (F8, T4, T6)) with the midline (Fz, Cz, Pz). These data showed that the mean of frontal sites were larger than parietal sites (F > P: F = 4.80, p > 0.05) and centrally than the mean of frontal and parietal regions (C > F/P: F = 14.96, p < 0.001). This was due to larger amplitudes in the outer hemispheres (OL/OR > M: F = 6.57, p < 0.05), the outer right frontal region (OR > OL x F > P: F = 12.83, p < 0.001) and smaller amplitudes at the parietal midline and vertex (P < F x M < OL/OR: F = 38.07, p < 0.001; C < F/P x M < L/R: F = 6.35, p < 0.05). Overall, this analysis
showed that factor 6 had a frontal and temporal topography, with an enhancement in the outer right frontal regions and decrement at the centro-parietal midline (see figure 7.5).

Figure 7.5 Depiction of PCA derived activity for Factor 6 (N140). This figure clearly demonstrates that this component had predominant activity at both frontal and temporal regions, with activity largest over the right hemisphere.

7.4 Discussion

The purpose of this study was to investigate ERP components produced by auditory targets in the inter-modal oddball task using both peak-picking and PCA quantification techniques. The peak-picking procedure identified seven components that were consistent with those reported in previous chapters. The principle components analysis identified nine factors of which seven corresponded to the peak-picked data. The following is a discussion of ERP components identified by both quantification methods and their relationship to earlier work. These will be undertaken concurrently in order to better illustrate and define the characteristics of these components.
Table 7.1 presents a summary of characteristics of the ERP components produced by inter-modal oddball targets. The first three rows of table 7.1 show topography, regional effects and latencies of inter-modal oddball ERP components produced by the peak-picking quantification method over nine electrode sites. It is clear that the ERPs from the present chapter (third row) demonstrate morphologies that are broadly consistent with those identified previously. Although, the N140, P200, N220 and P250 components showed some focal topographic differences across tasks (discussed further below). The last two rows of table 7.1 show a comparison of the peak-picked ERP components with corresponding factor scores identified using PCA within this study. As is evident, there is a substantial correspondence between the characteristics of ERP components produced by the two quantification methods. However, some topographic differences were evident, notably, for the N140 and N220 components (see below).

The PCA derived factor scores were also examined using LORETA source analysis. This exploratory investigation was done to identify potential generator sources to stimuli in inter-modal oddball conditions. It is noted that the use of PCA derived factor scores have been shown to provide a more accurate indication of generator sources than ERP amplitude measures (Carretié, Tapia, Mercado, Albert, López-Martín & de la Serna, 2004) and although LORETA represents an approximation of underlying cortical sources of the ERP, it shows significant correspondence to hemodynamic measures in several experimental paradigms (e.g. Dierks, Jelic, Pascual-Marqui, Wahlund, Julin, Linden, Maurer, Winblad & Nordberg, 2000; Vitacco, Brandeis, Pascual-Marqui & Martin, 2002; Mulert, Jäger, Schmitt, Bussfeld, Pogarell, Möller, Juckel & Hegerl, 2004;
Table 7.1. A summary of topographic distribution and latency of ERP components to inter-modal oddball target stimuli reported throughout this thesis. Notes: (1) the first three rows represent data produced by peak picking quantification methods. The last row represents topographic data of principle components reported in this chapter. (2) the symbols ↑ and ↓ represent reported enhancements or decrements at specific topographic locations.

<table>
<thead>
<tr>
<th>Chapter</th>
<th>N100</th>
<th>N130/140</th>
<th>P200</th>
<th>N220</th>
<th>P250</th>
<th>P300</th>
<th>P350</th>
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</thead>
<tbody>
<tr>
<td>Count task</td>
<td>FC – M</td>
<td>FC</td>
<td>C – M</td>
<td>N/A</td>
<td>FC – M</td>
<td>P</td>
<td>FP – LR</td>
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<td>N=20</td>
<td>102 ms</td>
<td>130 ms</td>
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<td>V↑</td>
<td>253 ms</td>
<td>303 ms</td>
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<td>Button press</td>
<td>Topography:</td>
<td>FC – M</td>
<td>F</td>
<td>CP – MR</td>
<td>F – L</td>
<td>CP – MR</td>
<td>P</td>
</tr>
<tr>
<td>N=17</td>
<td>Focal effects:</td>
<td>MF↑ V↑</td>
<td>F - MR↑</td>
<td>PM↑ V↑</td>
<td>PM↑ V↑</td>
<td>221 ms</td>
<td>PM↑ V↓</td>
</tr>
<tr>
<td>Latency:</td>
<td>140 ms</td>
<td>192 ms</td>
<td>250 ms</td>
<td></td>
<td></td>
<td></td>
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<td>FC – M</td>
<td>FC</td>
<td>C – M</td>
<td>F – LR</td>
<td>C – M</td>
<td>P</td>
</tr>
<tr>
<td>N=43</td>
<td>Focal effects:</td>
<td>RF↑ LC↑</td>
<td>RF↑</td>
<td>PM↑ V↑</td>
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<td>140 ms</td>
<td>140 ms</td>
<td>225 ms</td>
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<tr>
<td>PCA derived components</td>
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<td>FC – M</td>
<td>F</td>
<td>C – M</td>
<td>PL</td>
<td>C – M</td>
<td>P – LR</td>
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<td>RF↑</td>
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<td>PM↑ RC↑ V↑</td>
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<td>194 ms</td>
<td>Factor 7</td>
<td>Factor 6</td>
<td>Factor 1</td>
<td>Factor 3</td>
</tr>
</tbody>
</table>

| Chapter 7 | Topography: | FC – M | FC | C – M | PL | C – M | P – LR | FP – LR |
| PCA derived components | Focal effects: | RF↑ | RF↑ | PM↑ V↑ | 218 ms | MF↑ V↑ | PM↑ RC↑ V↑ | 346 ms |
| Latency: | LC↑ | Factor 7 | Factor 6 | Factor 1 | Factor 9 | Factor 2 | Factor 3 | Factor 4 |

Note: Consider the context and implications of the described ERP components and their topographic distributions for the inter-modal oddball target stimuli reported in different chapters and tasks. This data is crucial for understanding the neural responses associated with task performance and stimulus processing.
Table 7.2 depicts the reported generator sources of PCA derived factor scores produced by LORETA. As is evident in this table, four ERP components (N100, P200, P250, P300) produced to inter-modal oddball targets in the present study (left columns) had substantial similarities to the generator sources of equivalent components reported by other researchers (right columns). Furthermore, the N140 component shows generators that are broadly consistent with the T-complex – this will be discussed further below. Overall, it is suggested that the use of source analysis supports the characterisation of inter-modal oddball ERPs made throughout this dissertation and provides an additional layer of interpretation of inter-modal oddball componentology.

Taken together, the multi-faceted approach of comparing ERP activity using different quantification methods and the comparison with data produced in previous studies and by other researchers suggests that the attributes of ERP components identified in inter-modal oddball conditions have been reliably characterised and interpreted throughout this dissertation. Given that, the following will be a discussion of the characteristics of inter-modal oddball ERP components, as reported throughout this dissertation, aimed at confirming and extending the understanding of processes produced by this task.

The N100 component produced by the picking of peak amplitudes evinced a fronto-central midline topography with a mean latency of 110 ms. The PCA showed that factor 7, consistent with the N100, had equivalent latency and topography. The N100 has low inter-individual variability and high replicability (Foranova Key et al., 2005). As can be seen in Table 7.1, the N100 identified in
Table 7.2. Generator sources of ERP components in the inter-modal oddball task identified using LORETA and the reported sources of ERPs identified by other researchers.

<table>
<thead>
<tr>
<th>Component</th>
<th>Sources</th>
<th>Broadmans areas</th>
<th>Reported sources</th>
<th>References</th>
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<td><strong>N100</strong></td>
<td>STG†</td>
<td>22, 41, 42</td>
<td>Auditory Cx</td>
<td>Vaughan &amp; Ritter, 1970; Knight et al., 1988; Scherg et al., 1989; Giard et al., 1994</td>
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<td></td>
<td>MFG</td>
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<td></td>
<td>PCG</td>
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<td></td>
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<td>22, 41, 42</td>
<td>Auditory Assoc Cx</td>
<td>Cealesia, 1976; McCallum &amp; Curry, 1979; Scherg &amp; von Cramon, 1985, 1986; Giard et al., 1990</td>
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<td>Frontal Cx*</td>
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<td>Auditor Assoc Cx (area 22)</td>
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<tr>
<td></td>
<td>PCG</td>
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<tr>
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<td>Auditory Cx</td>
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</tbody>
</table>

† Represents the identified sources in the present data that are consistent with those reported in the literature.
* Sources represent those reported to the T-Complex. STG = Supra-temporal Gyrus; ACC = Anterior Cingulate Cortex; IPL = Inferior Parietal Lobule; SMG = Supramarginal Gyrus; MFG = Mid-frontal Gyrus; PCG = Post-central Gyrus; STP = Superior Temporal Plane.
both chapters 4 and 6 had latency and topography consistent with those presented in the present study. In addition, the N100 produced by targets in the three-stimulus oddball task presented in chapter 6 had equivalent attributes (see chapter 6 – figure 6.2). Thus, these data demonstrate that the N100 component produced over several different experimental conditions can be reliably reproduced.

The N140 component, the second early negativity, had a mean latency of 135 ms and fronto-central topography in the peak-picked data. The PCA identified an equivalent component (Factor 6) that evinced a predominant frontal topography and had enhancements in the right hemisphere. Thus, the different quantification methods produced variations in the purported topography of this component. The difference in topography suggests a concern with the reliability of quantifying this component. This is further demonstrated by the data presented in previous chapters that also showed topographic differences. In chapter 4 the N140, which peaked marginally earlier (~ 130 ms) had a fronto-central topography, whereas in chapter 6 the N140 was only clearly evident at frontal sites. In chapter 6 this component was more pronounced than that seen in either chapter 4 or the present data (i.e. it had larger amplitudes and was relatively larger than N100 in that study). It is argued that this may be a result of the greater task demands imposed by the experimental paradigm in chapter 6 – namely the requirement for a motor response. If increased task demands produce an enhancement of this component then it may be assumed that the resultant activity is a better representation of the characteristics of this component. Furthermore, if we assume that the PCA procedure is effective in demonstrating the underlying
nature of ERP components, then taken together, these data provide strong
evidence for N140 having a predominantly frontal topography with a right frontal
enhancement. It may also be suggested that activation in central regions, seen
in peak-picked data in chapter 4 and in this study, might be an artefactual
consequence of activation in other regions (e.g. temporal sites – see below) and
by overlap of other components (e.g. N100).

Throughout this dissertation the N140 component has been investigated
at nine electrode sites or a subset thereof. This regimen has allowed the
characteristics of this component to be described and discussed, but it has not
been possible to reconcile it with descriptions of any of the six N1 components
described in the literature (i.e. Näätänen & Picton, 1987). The N140 did not
meet the formal criteria for any of the three ‘true’ N1 components. In chapter 6 it
was experimentally dissociated from component I (N100); its frontal or fronto-
central topography meant that it was unable to be reconciled with component II
(T-complex) which is described as having a temporal topography; and in
chapter 4 its latency, topography and eliciting factors meant that the N140 was
not consistent with the non-specific vertex component III. Furthermore, it is not
indicative of any of the endogenous N1 components (IV – VI: mismatch
negativity, early and late processing negativities) which are elicited by the
mismatch of the stimulus from the preceding stimulus and during selective
attention respectively. Therefore, based on the analyses presented thus far the
providence of this component remains elusive.

It is argued that in order to characterise the N140 component an
examination of PCA derived activity (i.e. not restricted to the central nine sites)
is warranted. As is evident in figures 7.4 and 7.5, the N140 had both frontal and broad temporal activation, with activity apparently largest in right temporal regions. The post hoc analysis for this component, conducted on outer hemispheric regions compared with the midline, confirmed the validity of this topographic distribution. It is noted that the T-complex is typically described as having a temporal topography with larger activity over the right than left temporal hemisphere regardless of ear of stimulation (Wolpaw & Penry, 1975; Näätänen & Picton, 1987; Näätänen, 1992; Woods et al., 1992). Furthermore, the LORETA source analysis of N140 suggested sources evident in the auditory association cortex, prefrontal and anterior cingulate regions. The T-complex has been described as having generators in the auditory association cortex possibly linking to poly-modal and prefrontal cortical regions (Näätänen & Picton, 1987). Taken together, it is argued that the attributes of the N140 are broadly consistent with the T-complex, or component II in Näätänen and Picton’s (1987) nomenclature.

These data suggest that the N140 component is indicative of the T-complex. Thus, a conceptualization of this component may be preferred by the comparison of its characteristics, with both T-complex attributes and those of other ERP components. Näätänen and Picton (1987) distinguished between the T-complex and the N1. The N1 was described as a sensory component representing the coding of physical characteristics such as tonal frequency and spatial location. In contrast, they argued that the T-complex reflected a different type of auditory information processing, which represented coding mechanisms other than sense memory. In chapter 6, both the N140 and P250/P3a components had frontal enhancements to target stimuli in the three-stimulus
version of the inter-modal oddball task. The modulation of both these components was due to either stimulus discrimination processes or differences in probability between tasks – that is, they were modulated by task related rather than sensory processes. The P3a has been described as representing a top-down cortical process, related to working memory and mediated by frontal attentional systems, particularly in the ACC (Polich, 2003, 2007). The sources of the N140 in the present data are broadly consistent with those of the P250/P3a (see table 7.2). Given the similarity in cortical activity and that these components have been shown to be mediated by similar experimental manipulations, it can be argued that the N140 may represent activation of similar systems. That is, N140 might, in part, represent a task-related, top-down cortical process mediated by frontal attentional systems.

The auditory targets produced a large P200 component that evinced a central and midline topography with parietal-midline enhancement and vertex maxima in the peak-picked data. Factor 1 had a topography and latency that was consistent with this component. As is evident in Table 7.1, the topography (including the vertex maxima) and approximate latency (200 ms) of P200 is entirely consistent with that seen in chapter 4. The tasks used in this study and chapter 4 required target stimuli to be counted. In both cases, the P200 had maximal amplitude at the vertex and was distributed symmetrically between the hemispheres. The P200 in these inter-modal oddball tasks were the largest positive component, having a mean amplitude that was greater than any of the subsequent positive peaks (i.e. P250, P300 or P350: see figures 7.1 and 7.2. See also figures 4.1 and 4.2 in chapter 4). The consistency of this component
across studies provides confidence in the ascription of P200 characteristics described in the count version of the inter-modal oddball task.

The morphology of P200 in the present data was somewhat different to that seen in chapter 6. In contrast with the present data, the P200 component in that chapter showed lateralisation to the right hemisphere (see Table 7.1). The two-stimulus task used in chapter 6 was identical to the task used in the present study. However, it required participants to make an overt motor response to targets rather than count them. The hemispheric asymmetry, as discussed in the last chapter, was most likely a result of overlapping negative motor and readiness potentials in the hemisphere contra-lateral to hand of response (Looren De Jong et al., 1989). Thus, as the majority of participants were right handed in that study, the P200 showed greater positive activity in the right hemisphere. The P200 also had a centro-parietal topography in the previous chapter as opposed to the central and midline topography seen in the current data. This comparative posteriorisation was most likely also due to the motor response requirement. It is noted that later positive components in chapter 6 (P250 and P300) had larger mean amplitudes than P200\textsuperscript{13} - which is opposite to the effects seen in the present data. These late positivities, particularly the P300, are modulated by task demands. Thus, the inclusion of the button press requirement potentially increased the difficulty of that task, which enhanced later components. It is argued that in contrast with the present data, the general enhancement of positive activity, produced by the motor response requirement,

\textsuperscript{13} This is somewhat different to the present data that show larger P200 amplitudes.
overlapped the P200 shifting its topography posteriorly. Taken together, it can be suggested that the difference between the present data and those in chapter 6 demonstrates a response mode effect on the topography of the P200 component in inter-modal oddball conditions.

In between the P200 and P250 components was a small negative deflection (N220). This peak was a negative going wave that did not evince negative amplitude at any site analysed. N220 was more negative (closer to zero) at frontal/parietal sites and in the hemispheres. This was largely due to smaller midline activity particularly at the vertex – arguably the effect of overlapping activity produced by the surrounding large positive vertex components (P200 and P250). It is noted that the topographic distribution of the N220 was substantially different to topographies derived by PCA. This will be discussed further below. The peak-picked N220 seen in the present data is broadly consistent with that identified in chapter 6\textsuperscript{14}. In that chapter, the N220 was considered representative of the omission of an expected visual stimulus. The present data is consistent with this interpretation. However, it is noted that the topography of N220 produced by peak-picking in the inter-modal oddball task, both in chapter 6 and the present study, is somewhat different to the emitted stimulus negativity produced by visual omission paradigms, which is described as having a parieto-occipital topography (Barlow et al., 1967; Simson et al., 1976; Renault & Le Serve, 1978; Renault et al., 1982; Renault, 1983).

\textsuperscript{14} This chapter provided the first evidence of this small negative going wave.
The PCA data showed a different topographic distribution for the N220 component (factor 9) than that produced by peak-picking. This component had an approximate mean latency of 218 ms, with focal enhancements at parietal left and central left electrode sites as opposed to the frontal/parietal and hemispheric activity seen in the peak-picked data. Thus, the PCA, which was considered over nine electrode sites in the main analysis, indicate that the N220 may be characterised as evincing a posterior left topography. This topography is more consistent with an interpretation of an omitted stimulus response (see Renault et al., 1982). That being said, an examination of the N220 derived by PCA suggests that analysis restricted to nine sites may be inadequate to properly characterise this component. As is evident in figure 7.4 (bottom right panel), the N220 showed apparent maximal activity at occipital and temporal-parietal regions – particularly in the left hemisphere – a topography that would be entirely consistent with an interpretation of a visual omission component (Barlow et al., 1967; Simson et al., 1976; Renault & Le Serve, 1978; Renault et al., 1982; Renault, 1983). Furthermore, the source data showed generators of this component in both visual and auditory cortices. Activation of the visual cortex is consistent with an interpretation of processes related to visual stimulation, which lends support to the conclusions drawn above. Activation of the auditory cortex in the present data is some what more equivocal. It can be speculated that it is indicative of cross-modal processes – noting that visual stimuli in cross-modal conditions can activate auditory cortical regions (c.f. chapter 3). Alternatively, the N220, which was a small component that was embedded amidst other large positivities, might indicate activity in the auditory cortex that is due to overlap by other components rather than a distinct process.
Given the difference evident in N220 topography, it is suggested that further investigation is required to comprehensively characterise this component.

These data produced a positive component (P250) which has been interpreted in previous chapters as consistent with the P3a. This component evinced a central-midline topography with enhancement at the vertex. This was consistent in both peak-picked and PCA data. A vertex topography for P3a has been reported previously (Rushby et al., 2005; Conroy & Polich, 2007, Polich, 2007). However, the P3a is known to be dependant on generators in the frontal lobes and areas such as the anterior cingulate cortex (ACC) (Knight, 1984; Ebmeier et al., 1995; Knight, Grabowecky & Scabini, 1995; Kirino et al., 2000; Friedman et al., 2001; Polich, 2007). The PCA data presented in this study showed that the P250/P3a had focal enhancement at frontal midline regions; activity that was not identified in the peak-picked data. It also showed sources evident in the ACC. It is argued that this focal activity may represent specific activation of frontal generator systems, notably the ACC.

The inter-modal oddball targets in this study produced a P250 component that had a topography that was somewhat different to that seen in previous chapters. In chapter 4, the topography of P250 was anterior (fronto-central) to that seen presently (see table 7.1). This difference was most likely a result of the smaller sample size used in that study. In chapter 6, the P250 evinced a centro-parietal rather than vertex topography. It was argued in that chapter that the posteriorisation of the P3a was indicative of overlapping positive activity produced in active oddball conditions (e.g. Squires et al., 1975; see also Friedman et al., 2001). It is suggested that the comparison of P250
activity from the 3 two-stimulus inter-modal oddball studies presented in this
dissertation seem to support this contention. In this chapter and chapter 4, the
largest positive component was the vertex maximal P200. In both these studies,
the subsequent P250 peak had a topography that was somewhat similar to
P200. In contrast, in chapter 6 the largest positive component was the parietal
P300. In that study, both P200 and P250 components had topographies that
were posterior to that seen in the present data – arguably a reflection of
overlapping activity produced by the large parietal P300. Taken together, this
suggests that the ostensible topography of P250, in inter-modal oddball
conditions, is somewhat reliant on the extent of overlapping activity produced by
adjacent positive components\textsuperscript{15}.

The P300 component in the peak-picked data had a predominant parietal
topography with enhancements at the parietal midline, in the right hemisphere –
specifically right central regions – and a comparative decrement at the vertex.
An examination of factor 3 derived through PCA indicates a latency and
topography that is broadly consistent with the P300. The comparison of P300 in
the current study with that produced in previous chapters indicates a common
parietal and parieto-midline topography and vertex decrement – suggesting that
this topography is indicative of this component. However, the present data also
show a bias to the right hemisphere for this component, an effect that has not

\textsuperscript{15} It is noted that the P250 in the three-stimulus version of the inter-modal oddball presented in
chapter 6 showed evident enhancements at frontal sites, which is consistent with an
interpretation of this component having generators in the frontal lobes.
been previously identified. It is argued that the previous studies may not have been sensitive enough to identify this effect due to the small sample sizes used.

The P300 is produced by auditory targets presented amidst visual standards in inter-modal oddball conditions (cf. chapters 5 and 6). In chapter 6, the ERP produced by targets in a two stimulus version of the inter-modal oddball was compared with those from a three-stimulus version of this task. The P300 in the three-stimulus task showed a comparative enhancement in the right parietal regions. It was argued that the less probable target stimuli in that task produced activation of supra-modal processing regions located in temporal-parietal areas of the right hemisphere. The larger sample size and the use of PCA in the present study arguably provides a more reliable and sensitive measure of P300 topography. These data show that P300 had a parietal topography with activity that extended through to right central regions (see figure 7.4). It could be argued that, consistent with the interpretation in chapter 6, the right hemisphere enhancement seen to inter-modal oddball targets in this study, is indicative of the activation of supra-modal processing regions.

The P350 was the third positive component produced by the inter-modal oddball targets. It was mostly evident at frontal regions and in the hemispheres, and showed a distinct reduction at the vertex. These characteristics were consistent in both the peak-picked and PCA (factor 4) data. Furthermore, this morphology was broadly consistent with the P350 component produced by targets in the inter-modal oddball tasks presented in both chapters 4 and 6. A definitive characterisation of the P350 is difficult as it is not entirely consistent with previous literature and it has not been experimentally manipulated in the
studies presented in this dissertation. However, it can be argued that it is not consistent with the positivity produced by the omission of an expected (visual) stimulus, which has been described as having parietal topography consistent with the P3b (Simson et al., 1976). It is also noted that this component differs in topography from both the P350 produced by auditory oddball targets (c.f. chapter 4 and 5) and from that produced by non-targets in the three-stimulus task (c.f. chapter 6). Thus, it appears to reflect a specific aspect of target processing within the inter-modal oddball task – a process that requires further investigation.

The PCA identified two additional factors representing ERP components that were not identified by the peak-picking procedure and have not been considered previously. Factor 5 was a late negativity that most likely represents the ascending arm of negative activity that peaked around 400 ms post-stimulus (see figure 7.1). Factor 8 was a small positivity (mean latency 78 ms) consistent with P100. Both of these components should be investigated in subsequent studies but as they are outside the scope of this dissertation are not considered further.

This chapter investigated ERPs to auditory targets in an inter-modal oddball task. In order to better define the characteristics of these ERP components, this study used a larger sample of participants than previous chapters, two quantification techniques and considered the relation of these data with that presented in other chapters. The peak-picking and PCA procedures identified seven common ERP components with similar morphologies. These ERPs were broadly consistent with those seen in other
chapters. Overall, the consistency of findings throughout this dissertation suggests that the interpretations reliably represent the activity evident in this task. The present data furthered the understanding of inter-modal target processing by: 1) demonstrating the reliability of N100 and P200 attributes across tasks, 2) confirming maximal vertex activity of P200 and showing that its topography is affected by response mode, 3) identifying a right frontal and temporal topography for N140, which indicated that it was consistent with the T-complex, 4) noting the ostensible topography of the P250/P3a component varied as a function of the task parameters, 5) suggesting that the P300/P3b may include supra-modal activity, 6) showing the P350 had a consistent topography in different chapters, which potentially represented a process specifically related to inter-modal oddball processing and, 7) finding supporting evidence for the N220 representing the omission of the visual standard stimulus. Taken together, the data presented in this chapter provides a clearer understanding of the processes evident in inter-modal oddball conditions and given the consistency with data presented in previous chapters provides support for the conclusions that have been reported throughout this dissertation.
8. General Discussion and Conclusions
8.1 General Discussion

The experiments contained within this dissertation investigated auditory processing in an inter-modal oddball task. This course of investigation was undertaken as it was recognised that ERPs to inter-modal oddball stimuli in clinical studies were somewhat inconsistent with previous research and a search of the literature indicated that no analysis of inter-modal oddball processes had been conducted. The aims of these studies were to: 1) identify ERP components produced by auditory targets in the inter-modal oddball task, 2) describe and characterise their functions, and 3) determine how these ERPs related to previous research. The four analyses presented within this dissertation represent a systematic approach to understanding processes evident in this task.

8.1.1 Study 1

The initial experiment, presented in chapter 4, had several aims. The primary aim was to characterise the ERP components produced by auditory target stimuli presented amidst frequent visual standard stimuli in the inter-modal oddball task. These data indicated that there were three early (N100, N130 and P200) and three late (P250, P300 and P350) ERP components produced by auditory target stimuli in this study. These components were compared to ERPs produced by an equivalent target stimulus in an auditory oddball task and when presented alone. This was done to answer three critical questions about the processes that occur in inter-modal oddball conditions.
The first was whether the processes evident in the inter-modal oddball task were equivalent to those seen in more commonly used tasks (i.e. the auditory oddball task). The results indicated that the early ERP components to targets in the inter-modal oddball task were unaffected by being presented amidst visual standards. That is, they did not differ from those evident to tones presented in the absence of standard stimuli (i.e. single tone condition). In contrast, the early components produced by the auditory oddball task differed markedly. The N100 and N130 components were comparatively smaller. It was argued that the attenuation of the N100 reflected refractory period effects produced by the close temporal proximity of the auditory standard stimuli in that task. The P200 was smaller, earlier and had a more posterior topography. It was argued that this was largely due to overlap by a subsequent N200 component – a component not evident in the inter-modal oddball task. Taken together, this suggested that differences in the comparison between early ERP components in the inter-modal and auditory oddball tasks were primarily due to intra-modal processes occurring in the later task. That is, they represented the effect that auditory standards had on the processing of auditory target stimuli. The later components to inter-modal oddball targets (P250, P300 and P350) also differed from activity produced in auditory oddball conditions. It was suggested that these differences reflected the context within which the targets were presented. One key finding (discussed further below) was that the inter-modal oddball targets produced a parietal P3 component that was earlier than that to auditory oddball targets. This was initially thought to be a reflection of a delay in processing in the auditory oddball condition. However, this conclusion was confounded by subsequent experiments.
The second question addressed by this study was whether the visual stimulus affected auditory ERP components or whether, as was posited by Brown et al. (2005), they may have been processed independently. It was assumed that if the auditory targets were processed independently from the visual standards then a comparison of inter-modal oddball target ERPs with those to targets presented alone (i.e. single tone condition) should show no differential activity. The early ERP components in these tasks were equivalent and this was interpreted as an indication of independent processing. However, the later ERP components to inter-modal oddball targets showed comparative differences in morphology being larger and having distinct scalp topography. This suggested that the visual standard stimuli affected later cognitive processes. These differences, along with those discussed above, indicated that the inter-modal oddball targets were processed in a task specific manner. Thus, the late ERP components reflected the stimulus context within which targets were presented. Taken together, it was concluded from these data that inter-modal oddball targets were processed in two stages, an early stimulus specific stage and a later context dependant stage.

The third question that this study aimed to answer was whether ERPs in the inter-modal oddball task demonstrated attributes that were similar to other inter-modal attention studies. It was noted that inter-modal selective attention effects were typically seen in early N1/Nd and P2/Pd components. The results of study 1 were inconsistent with these effects, showing that the early components were unaffected by the inclusion of the visual standard stimulus. Thus, it was concluded that processes evident in the inter-modal oddball task, a
one-channel sustained attention task, differed from those produced by inter-modal selective attention.

A further conclusion was drawn from these data. In the inter-modal oddball condition, only later ERPs were modulated. In contrast, auditory oddball ERPs differed at both early and late processing stages. This suggested that in traditional auditory oddball conditions all ERP components were affected by the proximity of the (auditory) standard stimuli. That is, they were modulated by intra-modal processes.

8.1.2 Study 2

The second study in this dissertation compared the ERPs produced by an auditory-visual oddball task with those from the auditory oddball task. The former task included a frequent visual standard stimulus that was paired with auditory standards. Both tasks in this study induced intra-modal effects. That is, the auditory standard stimuli modulated auditory target ERPs, consistent with the effects demonstrated in study 1. As the auditory stimuli in both tasks were equivalent, it was argued that differences in ERPs between tasks would represent processes produced by the inclusion of the visual standard stimulus in the auditory-visual oddball condition. The primary aim of this study was to determine how visual standard stimuli affected the ERP to auditory targets in an otherwise intra-modal task.

There were two main outcomes from this study. The first was confirmation that the inclusion of a visual standard stimulus did not affect early auditory ERP components. This effect was evident for the N100 and P200
components but was extended to include the N200 that also did not differ between tasks. This study demonstrated the independence of processing of early components and provided support for the findings outlined in study 1. It also suggested that, despite the early ERPs being modulated by intra-modal processes, as well as some evidence of MSI effects within the auditory-visual standards, early target ERPs were produced independently of the visual standard stimulus.

The second main outcome of study 2 was that late ERP components were modulated by the inclusion of visual standards, with each of the late positive components (P250, P300, P350) demonstrating greater activity in the auditory-visual oddball condition. A key finding from this study was evidence for two separate P3 components. There was an earlier centro-parietal P300 and a later parietal P350 component evident in the auditory-visual oddball, with only the later being consistent with activity seen in the auditory oddball condition. This led to the conclusion that these late positivities potentially represented two separate processes – an earlier inter-modal process (target detection amidst visual standards) and a later intra-modal process (target detection amidst auditory standards). In study 1, it was speculated that the respective P300 and P350 components to inter-modal oddball and auditory oddball targets represented a delay in processing. The data presented in study 2 suggested that, rather than a delay in processing, these components represented distinct processes. Overall, the difference between early and late effects further supported a two-stage theory of stimulus processing.
8.1.3 Study 3

The first two experiments in this dissertation illustrated how visual standard stimuli affected ERPs to auditory target stimuli. Study 3 used a variant of the inter-modal oddball task to investigate how modulation of infrequent stimulus parameters affected the ERP. This study compared ERPs in a two-stimulus and a three-stimulus version of the inter-modal oddball task. It also compared ERPs to targets and non-targets in the three-stimulus condition. Thus, factors such as stimulus discrimination, the requirement to withhold a response to non-target deviant stimuli and the probability of target presentation were manipulated and investigated in this study.

The results showed that modulating the characteristics of the infrequent stimuli in the inter-modal oddball task affected all of the elicited ERP components. These data showed that early components (N100 and P200) were somewhat larger to non-target stimuli than to targets. This was interpreted as representing the difference in auditory frequencies of target and non-target stimuli and the requirement to withhold response to the non-targets respectively. The N140 component was larger to both targets and non-targets in the three-stimulus condition than to targets in the two-stimulus condition – an effect that was evident at frontal electrode sites. This suggested that task parameters – that is, the requirement to discriminate targets from non-targets or the difference in stimulus probability between tasks – modulated this component. As the factors that modulated N100 and N140 were different, these data also provided experimental evidence for a dissociation of these early negativities.
Study 3 also identified an additional early effect in these data. It showed that target and non-target stimuli produced a small negative going wave (N220) that had not been previously considered. This component did not differ between target and non-target stimuli, suggesting that it was not necessarily related to the processing of the infrequent stimuli. Although these data did not allow for a definitive characterisation of this component, it was argued that the N220 might be indicative of processes related to the omission of the ongoing visual standard stimulus.

The target stimuli in this study produced a centro-parietal P3a component. It was larger at frontal sites in the three-stimulus task, which was interpreted as a reflection of modulation by either target evaluation or probability effects. The modulation of P3a at frontal sites suggested that this component was sensitive to differential task requirements. It was also noted that this effect was similar to the task demands that modulated target and non-target N140 amplitudes at frontal sites.

Target stimuli also produced separate late positive components (P300 and P350). The P300 had a parietal topography which was indicative of an inter-modal P3b component. The P300 was largely consistent across tasks, although in the three-stimulus condition it showed a focal enhancement in right parietal regions. This enhancement was interpreted as potentially reflecting activation of supra-modal processing regions. The P350 component had a different topography depending on the eliciting task. In the two-stimulus task, P350 topography was broadly consistent with data presented in study 1, showing activation in frontal and hemispheric regions. In the three-stimulus
task, the target P350 had a predominantly parietal topography. It was argued that the three-stimulus target P350 component, which was produced in a task that used multiple auditory stimuli, was indicative of a second P3b component, and represented intra-modal processing. Taken together, these results provided further support for the contention raised in study 2, that there are separate P3b processes evident in the ERP; that is, an inter-modal and an intra-modal process respectively.

The non-target deviants in the three-stimulus inter-modal oddball task were also analysed in this study. The late non-target components demonstrated a morphology that was substantially different to that seen to the targets. These ERPs were characterised by a broad negativity, peaking around 285 ms post-stimulus and a late frontal P350 component. These were interpreted as being broadly consistent with a NoGo response to the non-target stimulus. It was noted that the N285 component was somewhat different to a typical NoGo N2. This may have been a reflection of both the infrequency of stimulus presentation and the inclusion of the visual standards. In contrast, the P350 was consistent with NoGo P3 components reported in other studies. This suggested that the P350 component may not have been substantially affected by inter-modal processes. Overall, the pattern of activation in late components to non-target stimuli suggested that this task may be useful in further investigating NoGo activity produced when withholding a response to auditory non-target stimuli.
8.1.4 Study 4

The final experimental chapter in this dissertation was a confirmatory analysis of inter-modal oddball target ERPs. It included a larger number of subjects and considered two quantification methods; peak-picking, the technique used throughout this dissertation, and PCA. The data showed substantial similarities in the attributes of ERP components produced by both quantification methods. These components were also largely consistent with inter-modal oddball activity that was reported in previous chapters. This demonstrated the reliability of the data presented, and provided support to the interpretations made throughout this dissertation.

The data presented in chapter 7 clarified activity occurring in inter-modal oddball conditions. They showed that the N140 component had both temporal and right frontal activation, leading to the conclusion that this component was consistent with the T-complex. These data showed that the N140/T-complex had activation in frontal regions, possibly produced by PFC and ACC sources, which are not typically reported in analyses of this complex. These data also suggested that analyses conducted over the nine central sites were inadequate to fully characterise the N140. This chapter showed that the P200 was a highly reliable large vertex component that had some hemispheric asymmetry produced by motor response requirements. There was support for the supposition that the N220 reflected the omission of the visual standard stimulus in this task. These data also indicated that the topography of the P250 differed as a function of the task used, suggesting that the ostensible topography of this component was affected by task demands and overlapping activity from
surrounding components. Overall, this study enhanced the understanding of inter-modal oddball processes and demonstrated the reliability of the findings that have been presented throughout this dissertation.

8.2 **Key Findings**

The entirety of research presented in this dissertation indicated that auditory targets in the inter-modal oddball task reliably produced seven ERP components. These were the N100, N130/140, P200, N220, P250/P3a, P300 and P350 (c.f. chapters 4, 6, & 7). These studies also showed that ERPs to target stimuli are processed in two stages. These were an early processing stage where early ERP components are dependent on the characteristics of the stimuli – that is, a stimulus dependent stage – and a late processing stage where late components were modulated by task demands – that is, a context dependent stage. Furthermore, these data showed that the auditory targets in the inter-modal oddball task did not elicit an N2b component – a component that is typically produced by deviant stimuli in oddball conditions. These components, their relationship to activity elicited by other experimental paradigms, and how these data can be interpreted to comprehensively characterise activity occurring in the inter-modal oddball task are discussed below.

8.2.1 **Early components**

8.2.1.1 **N100**

The N100 component was reliably produced in several iterations of the inter-modal oddball task. It had a fronto-central midline topography and mean
latency of approximately 100 ms in the experiments presented in chapters 4, 6 and 7. These characteristics were consistent in both peak-picked and PCA derived data (c.f. chapter 7). The N100 was modulated by the physical characteristics of the stimulus. In chapter 6, it was shown to be larger to non-target stimuli, which were of a lower auditory frequency, than targets. This suggested an apparent frequency effect for this component, an effect that is consistent with previous reports (e.g. Butler, 1968). Based on the latency and topography of the N100, its reliability across experimental conditions and the demonstration of frequency effects, it was concluded that this component was consistent with the traditional N1, or component I in Näätänen and Picton’s (1987) nomenclature.

The N100 to inter-modal oddball targets in chapter 4 did not differ from those to the targets presented alone, suggesting that the visual standard stimulus did not affect the generation of this component. In contrast, the N100 was markedly different in this task to that produced in the auditory oddball task. This indicated that other processes were occurring in the auditory oddball condition – namely, refractory intra-modal processes produced by the temporal proximity of auditory standards to the auditory target stimulus. In chapter 5, intra-modal effects were induced in both the auditory oddball and auditory-visual oddball tasks. Despite this, the amplitude, latency and topography of N100 did not differ. This further supported the claim that the inclusion of the visual standard stimulus did not affect the N100 component. Overall, the absence of N100 modulation by visual standards in inter-modal oddball conditions suggests that there was no evidence of inter-modality or inter-modal refractory effects on this component.
8.2.1.2 N130/N140

The N130/N140\textsuperscript{16} component was clearly evident to inter-modal oddball targets in three out of the four experiments in this dissertation. Chapter 4 produced the first evidence for this second early negativity, and showed that it was not affected by the visual standard stimuli as it did not differ from a comparable component produced by the single tone condition. Therefore, it can be suggested that this component was not related to inter-modal oddball processing, rather reflecting the processing of auditory stimulus attributes in this task. In chapter 4 the N130 was interpreted as indicative of the non-specific vertex component (component III). This conclusion was based on a small number of studies that had found similar results in conditions where ISIs were longer than 6 sec (i.e. Alcaini et al., 1994; Budd et al., 1998). However, as was noted in that chapter, this interpretation was somewhat problematic\textsuperscript{17}. In chapter 6 the N130/N140 had a different topography and latency to N100 and was experimentally dissociated from that component, confirming that they were distinct components. In chapter 7, the N140 evinced a predominant temporal and right-frontal topography. This led to the conclusion that the N140 was consistent with component II, the T-Complex, rather than being indicative of component III.

\textsuperscript{16}These components are considered to be the same despite small variations in their latencies. Thus, the labels N130 and N140 are used synonymously.

\textsuperscript{17}Problems noted in chapter 4 included that the stimuli used in these studies did not require a motor response, Budd et al. (1998) showed no evidence for this component producing an orienting response, and these data did not demonstrate inter-modal refractory effects – all factors related to the elicitation of component III.
The data presented in this dissertation indicated that the N140 component in inter-modal oddball conditions was equivalent to the T-Complex. This complex is described as a bi-modal peak evident at temporal electrode sites (e.g. Wolpaw & Penry, 1975). However, the present data suggest that this component showed activity in both temporal and frontal regions. Furthermore, these data have demonstrated that activity at frontal sites could be modulated by task related factors such as probability or stimulus evaluation (c.f. section 6.4.1). Evidence of frontal modulation of the T-complex is not common; noting that activity at frontal sites is not typically considered with reference to this component. It is suggested that the inter-modal oddball task may provide a novel means of investigating activity related to this complex.

As noted elsewhere, the N140 component has little precedent in the literature and is not typically identified or discussed within auditory attention studies. The data presented in this dissertation may provide some explanation for why this is the case. As was evident in chapter 4, both the N100 and N130 components in the auditory oddball task were comparatively small, with the frontal N130 component largely subsumed into the N100 peak (see chapter 4, figure 4.1). This attenuation was arguably the result of intra-modal activity, that is, modulation of the ERP by the close temporal proximity of auditory standards to the target stimuli. A similar effect is evident in other auditory oddball studies, which show a broad N1 component at frontal sites that has a different morphology to activity at other sites on the scalp (e.g. Cass & Polich, 1997; Zenker & Barajas, 1999). Based on the evidence presented in this dissertation, it is argued that the N1 component at frontal sites in other auditory studies might represent the overlap of both N100 and N140 activity. That is, both these
components are produced by auditory stimulation. However, in intra-modal conditions and where data is quantified using maximal peak amplitudes it may be difficult to dissociate these separate components at this latency range. It is conceivable that any activity that could be attributed to the N140 component in these tasks is most likely interpreted as a reflection of the modulation of the fronto-central N100. If this were the case, then it is not surprising that no evidence for this second negativity – in tasks with comparatively short ISIs – has been proffered. Furthermore, it can be suggested that there is potentially a large body of literature that has misattributed variations in early negative activity to processes other than N140 modulation. This concern requires further investigation and it is suggested that the use of a wide range of tasks, including inter-modal and auditory oddball tasks, would be useful in clarifying the evident processes.

Overall, the data presented in this dissertation has identified N130/N140 (T-complex) activity that has not been previously seen. Its clear elicitation and ability to be experimentally manipulated suggest that the inter-modal oddball task may be a valuable tool for investigating the processing of relevant auditory stimuli in the N1 latency range.

8.2.1.3 Multiple N1 components

These data suggest that there are two early N1 components evident in these studies (N100 and N140). These components had different amplitudes, latencies and topographies and were experimentally dissociated. It has been argued that the N100 and N140 components are consistent with components I and II based on Näätänen and Picton’s (1987) nomenclature. It is noted that
these data suggested no evidence for the third ‘true’ N1 component produced by auditory stimuli – the non-specific vertex component, which has been related to the facilitation of motor activity. Components I and II represent distinct processes. Näätänen and Picton (1987) describe these components as “… occurring at different cerebral locations and subserve different psychophysiological functions. They are distinguished by their characteristic electrical and/or magnetic fields and by their specific relationship to various experimental manipulations” (p. 411). Component I is a fronto-central component with peak latency at 100 ms. It has refractory periods of 4 s or more and generators in the STP of the primary auditory cortex. This component has several possible functions representing: a transient detector process calling attention to a stimulus; the initial readout of auditory information; or it may be related to sense memory and the establishment of a neuronal trace. Thus, it is potentially related to the coding of auditory stimulus attributes such as tonal frequency or spatial location. Consistent with this description, the N100 in the inter-modal oddball task showed sources in the primary auditory cortex (c.f. chapter 7), with maximal amplitude at fronto-central regions and had a relatively short refractory period – as seen in auditory oddball conditions. It was modulated by differences in tonal frequency and is therefore interpreted as being related to the coding of auditory stimulus attributes. Component II has a negative wave at approximately 150 ms that is probably generated on the STG most likely in auditory association areas, with projections from the primary auditory cortex and also possibly the thalamus. Component II represents a different coding mechanism to component I and is most likely related to information processing rather than sense memory. Consistent with this
description, N140 was a later negativity with peaks evident at temporal and frontal sites. It showed generator sources in auditory association areas, most likely had other generators in the PFC and ACC and was modulated at frontal sites by differences in task requirements rather than stimulus attributes. Therefore, the characteristics of N130/140 are consistent with an interpretation of this component representing some form of information processing other than sense memory. Thus, it is clear that the N100 and N140 components in this task represent the processing of stimulus attributes and the encoding of stimulus information respectively.

It is argued that the processes responsible for N140 activity in frontal regions represent the activation of frontal attentional mechanisms. Polich (2007) noted that the frontal lobe is sensitive to attentional demands related to the detection of rare or physically alerting stimuli. This interpretation was made with reference to processes responsible for the production of the P3a component (see below for a further discussion). However, given the similarity in cortical activation of the N130/N140 and P3a components and the similarity in frontal modulation that was produced by task demands in chapter 6, it is suggested that this second early negativity might reflect some aspect of frontal attentional system activation. Given the timing of this component and that it was shown to be affected by global rather than focal stimulus effects (c.f. chapter 6) these effects arguably represent a pre-cognitive activation of these frontal mechanisms.
8.2.1.4 P200

The P200 component was a large central and midline component with an amplitude that was maximal at the vertex. It was reliably produced in several versions of the inter-modal oddball task (c.f. chapters 4, 6, 7) and was shown to be unaffected by the presence of the visual standard stimulus. The amplitude, latency and topography of the P200 differed from that seen in the auditory oddball task (c.f. chapter 4). The smaller, earlier and more posterior topography in the auditory oddball condition was largely due to intra-modal effects overlapping this component – primarily related to the elicitation of an N200 in that task. It is suggested that the large vertex topography of the P200, seen in the inter-modal oddball task, represents an accurate portrayal of the activity produced when processing auditory stimuli. That is, it represents cortical activation that is unaffected by either visual standard stimulation or other overlapping processes.

Varying the response requirement produced differences in P200 topography. In chapters 4 and 7 subjects were required to count target stimuli. In chapter 6, a speeded button press to target presentation was required. In the count versions of the inter-modal oddball task, the P200 was the largest positive component produced. Where subjects were required to make a motor response to target stimuli (chapter 6) the P200, despite having substantially large amplitudes, was comparatively smaller than the P300. It also showed lateralisation to the right hemisphere and a more posterior topography. These P200 differences between tasks were considered a reflection of a response
mode effect evident in this component, which were due to both readiness potentials and overlap by the P300.

The P200 was also larger to non-target than target stimuli in the three-stimulus version of the inter-modal oddball task. This effect was consistent with previous reports, which have shown P200 to be larger to non-target stimuli – a reflection of the inhibition of processing an irrelevant stimulus (Alho et al., 1987; Hansen & Hillyard, 1988; Rif et al., 1991; Hegerl & Juckel, 1993). However, it is noted that in the inter-modal oddball task this effect was reasonably small. Overall, the demonstration of P200 amplitudes that are unaffected by overlapping inter- and intra-modal processes in inter-modal oddball conditions, as well as evidence for response mode and non-target effects seen in these experiments, suggest that the inter-modal oddball might be a useful tool to further understand processes related to this component (see section 8.6 for a further discussion).

The three factors described above provide a novel interpretation for the function of this component. The differences between target and non-target stimuli shown in chapter 6 are consistent with an interpretation of P200 representing stimulus identification and analysis (Picton et al., 1974), or the early inhibition of irrelevant information or other channels competing for attention (Hansen & Hillyard, 1988; Rif et al., 1991; Hegerl & Juckel, 1993). These studies indicated that the P200 is sensitive to response parameters imposed by task requirements, which suggests that it may have some role in the production or withholding of responses to stimuli. Furthermore, the P200 was a large component evident at the vertex and this activity is readily identified
in the ERP when there was no overlap by other processes (i.e. MMN, N2b, intra-modality). Cortical regions around the vertex are known to be responsible for the production of motor responses. Libet, Alberts, Wright, Lewis & Feinstein, (1975) showed that between 135 and 220 ms, activation of motor regions at the vertex had polarity inversion between surface and depth electrodes (negative and positive respectively). Thus, given the large activation of the P200 in these regions, this component potentially has links that project to areas known to facilitate motor activity. This does not imply that the P200 reflects motor activity – noting that similar P200s were produced in condition where both no motor response (chapters 4 and 7) as well as motor responses (chapter 6) were required. Taken together, it is argued that the P200 represents the transfer of stimulus information from auditory association areas to central regions for the evaluation of stimulus attributes and preparatory processes that facilitate response production; these are linked to but not responsible for motor activity.

8.2.1.5 N200

It was noted in chapter 4, and further shown in chapters 6 and 7, that N200 is not produced in inter-modal oddball conditions. Other auditory attention studies have shown that auditory target stimuli produce an N200 that comprises several subcomponents - the most commonly reported are the MMN and N2b. The MMN, a modality specific endogenous component, represents a mismatch between a presented stimulus and the neuronal trace produced by an established stimulus train. This is generally reported in auditory conditions, with the MMN in other modalities not reliably produced (Fabiani et al., 2000). It is assumed that no MMN might be produced in this mixed-modality paradigm, and
no evidence for it was presented in these studies (see also section 8.3). The N2b subcomponent is produced in typical oddball tasks by a deviation in an ongoing train of stimuli. It is elicited by stimuli in different sensory modalities (e.g. visual and auditory), and this has led to the claim that it is modality non-specific (Näätänen et al., 1982). Chapters 4 and 5 indicated that N2b was elicited when both targets and standards are of the same modality, but not in inter-modal oddball conditions. This suggests that the deviance detection processes related to the N2b are not evident in inter-modal oddball conditions. Thus, stimuli from different sensory modalities presented within an oddball task do not elicit the N2b; indicating it might not be entirely modality non-specific.

8.2.1.6 N220

As noted above, the inter-modal oddball task consistently failed to produce an N200 component to auditory targets. However, in between the early and late ERP components was a small negative going wave, the N220 (c.f. chapters 6 and 7). The N220, first identified in chapter 6, was considered a reflection of the omission of the visual standard stimulus. This speculation was supported by the topographic analysis of PCA data in chapter 7. Thus, it would appear that the ERPs to target stimuli include an additional small component that is not directly related to the processing of the auditory stimulus in this task.

8.2.2 Late components

8.2.2.1 P250/P3a

In each study there was evidence of a late positivity (P250) that was the first in a suite of positivities produced in inter-modal oddball conditions. The
P250 was readily evident and reliably produced in all studies and was interpreted as being indicative of the P3a. This component differed in topography between studies, being predominantly fronto-central, centro-parietal, centro-parietal and central in the four studies respectively. These differences led to the suggestion that the ostensible topography of the P250/P3a may vary as a function of the task in which it was elicited (c.f. chapter 7). The variation of P3a topography is arguably due to processes such as overlap by later parietal activity in active oddball tasks (Squires et al., 1975); particularly the larger P3b component (Polich, 2007) and may also be a result of stimulus categorisation (Friedman & Simpson, 1994; Friedman et al., 2001). P3a is thought to be produced by frontal generator systems (Knight, 1984). Despite the differences in the topography of P3a in this dissertation, evidence for frontal activity was demonstrated in these data. In chapter 6, the P3a to targets in both the two- and three-stimulus tasks had a predominant centro-parietal topography. This topography was arguably the result of overlap by the large parietal P300 component produced in these tasks. However, it showed modulation at frontal electrodes, being larger in the three-stimulus condition – arguably the task that that imposed greater cognitive demands on the participants. In chapter 7, the P250/P3a component, which had a central topography, showed generator sources in the frontal lobes – particularly the ACC. It is argued that despite the P3a having a central/posterior scalp distribution in these studies, an effect that is frequently seen in active oddball tasks, these data showed that activity in frontal regions can be identified and modulated in inter-modal oddball conditions. Given the fact that this component has been reliably identified in all studies in this dissertation, it may be further
suggested that the inter-modal oddball task might be a useful tool for investigating P3a activity in active oddball conditions.

8.2.2.2 P300

The P300 was a parietal midline component produced by auditory targets. The topography, latency and modulation by experimental parameters evident in the four experiments suggested that this component was indicative of the P3b produced by targets presented amidst visual standards – that is, an inter-modal P3b. This conclusion was supported by evidence of right central and parietal activity in chapters 6 and 7, which was interpreted as potentially reflecting activation of supra-modal processing regions.

8.2.2.3 P3a and P3b

The two positive components, P250 and P300, were broadly consistent with the description given by Polich’s (2003, 2007) integrative model of the P3. Within this framework the P3a and P3b components (consistent with P250 and P300 in the current paradigm) represent activity in frontal and temporal-parietal regions respectively. Polich (2007) argues that, in oddball conditions, stimuli initiate frontal lobe activity that is sensitive to rare or alerting stimuli. When attentional focus is engaged, frontal lobe memory processes elicit P3a. Subsequent activation of attentional resources promotes memory operations in temporal-parietal regions producing P3b. Both of these components are produced to relevant target stimuli. Polich (2007) further argues that these components represent separate top-down and bottom-up processes. The P3a represents a top-down process resulting from the evaluation of incoming stimuli
by frontal attention mechanisms and the P3b represents a bottom-up memory operation related to context-updating and subsequent memory storage.

It is argued that processes consistent with that reported by Polich (2007) are evident in the inter-modal oddball task. Frontal attentional systems are engaged by the auditory stimulus producing a P250 component that is evident in frontal regions demonstrating generators in the PFC and ACC. Subsequent activation of memory operations related to the processing of target stimuli produces a subsequent large parietal P300. Thus, auditory stimuli in inter-modal oddball conditions engages frontal attentional processes that are under top-down control, and produce subsequent bottom-up activation of parietal regions used to update memory in response to auditory targets that are presented amidst the visual standards.

The P3b component represents the updating of stimulus context. Within this framework, the P300 to inter-modal oddball targets represents a stimulus driven updating of auditory stimuli presented amidst ongoing visual activity. However, these data have also shown separate P3b activity produced by different task parameters (c.f. chapters 5 and 6). The P350 produced by auditory oddball, auditory-visual oddball and three-stimulus oddball targets represented an additional P3b component that was elicited by the processing of auditory targets presented amidst other auditory stimuli. Thus, these data suggest that there were separate memory updating functions occurring to target stimuli, which were indicative of the context within which they were presented. This finding supports the concept of a bottom-up memory updating processes occurring in parietal areas, which is related to individual stimulus contexts rather
than target characteristics per se. This suggests that presenting stimuli in multiple contexts (e.g. with complicated stimulus arrays) might produce multiple distinct P3b processes that represents separate cortical updating of relevant stimulus information.

8.2.2.4 P350

The inter-modal oddball P350 was an additional positive component that had frontal, parietal and hemispheric activity with sources evident in the auditory cortex and ACC. This component was only present in the two-stimulus version of this task (c.f. chapters 4, 6, 7). The inter-modal P350 was not consistent with positive activity produced at this latency by the other tasks in this dissertation, nor did it represent positive activity previously reported. This led to the suggestion that it might be specifically related to inter-modal oddball processing. It is noted that this component was not experimentally manipulated in the studies presented in this dissertation and therefore could not be definitively characterised, and further investigation of the characteristics of this component is required. However, the topographic distribution of this component and its relationship to inter-modal oddball processes allow for some speculative assumptions to be made. Firstly, the activation of frontal areas, including generator sources in the ACC, suggests that the topography of this component is broadly consistent with those of the N140 and P250 components discussed above. Thus, it is speculated that this component might represent the activation of attentional systems in the frontal cortex and it could be argued that it therefore represents a process that is under top-down control. Secondly, the inter-modal P350 had additional activation of sensory specific cortices. In
chapter 3 it was shown that cross-modal activity produces feedback to ostensible uni-sensory areas at late processing stages. Thus, it is argued that the P350 might represent activation of frontal attentional systems that feedback from poly-modal to sensory specific cortical areas. This is consistent with an interpretation of either cross-modal or inter-modal activation.

The other experimental paradigms used in this dissertation demonstrated positive activity around 350 ms that was markedly different from that to the two-stimulus inter-modal oddball task. In chapter 4, the auditory oddball task produced a P350 component that had a posterior topography somewhat similar to the inter-modal oddball P300. This component was interpreted as an auditory oddball P3b. This component was also seen in chapter 5 where a commensurate component was produced in the auditory-visual oddball task. This led to the conclusion that the P350 component in these tasks represented the processing of an auditory stimulus presented amidst auditory standards. This conclusion was further supported by data presented in chapter 6 which showed P350 to targets in the three-stimulus inter-modal oddball task also had a parietal topography. Taken together, these data suggest that the P350/P3b produced in auditory oddball, auditory-visual oddball and three-stimulus inter-modal oddball tasks represent an intra-modal positivity – that is, a component produced by auditory targets presented amidst other auditory stimuli.

8.3 The N140 and the Mismatch Negativity

It has been argued in this dissertation that the attributes of the N140 component are consistent with an interpretation of the T-complex. This was based on its latency, temporal topography and generator sources. However, it
could be argued that some attributes of the N140 are also consistent with another early negative component, the endogenous MMN - notably, activation of frontal regions (particularly in the right hemisphere) and sources in the auditory cortex and frontal lobe structures (Näätänen & Kähkönen, 2009). However, it is argued that based on both the characteristics of the inter-modal oddball task and the ERPs it produces there are several factors that preclude such an interpretation. Näätänen (Näätänen & Picton, 1987; Näätänen, 1992) identified several defining criteria of the MMN. These include: 1) that a different stimulus from the same modality is presented within a few seconds prior to the eliciting stimulus, 2) that when standard stimuli are omitted no MMN is produced, 3) that the MMN is a frontally distributed wave extending over 200 ms, 4) that the MMN is difficult to identify in attended oddball conditions as it is typically overlapped by the N200, and 5) that evidence of MMN activity is typically derived through the subtraction of target ERPs from those to standards. Given that, it is argued that the N140 produced in inter-modal oddball conditions does not meet the criteria required to be considered the MMN. Firstly, the inter-modal task presents auditory targets amidst visual standards, that is, different sensory modalities. Also, the timing of auditory stimuli, that is, the target to target interval, and the fact that all targets had the same physical characteristics should produce no auditory specific mismatch. Both of these factors violate criterion 1. Secondly, it is noted that inter-modal oddball and single tone ERPs identified in chapter 4 did not differ. This suggests that the N140 was not a specific inter-modal component, rather representing auditory processing. Given the similarity in activity of N140 in these tasks and that a single tone task does not produce an MMN (criterion 2), then it follows
that no MMN activity should be evident in inter-modal conditions either. Thirdly, the MMN extends over 200 ms (criterion 3) and is typically overlapped in attended oddball conditions by the N200 (criterion 4). The inter-modal oddball task did not produce an N200 component, nor did it evince any activity in this latency range that could be considered indicative of the MMN. Based on these factors it is concluded that no MMN activity is produced in inter-modal oddball conditions. One further consideration is that in this task, the elicitation of MMN would be difficult to observe. It would be problematic to produce the requisite difference wave (criterion 5) with target and standard stimuli when they were of different sensory modalities. Overall, it is strongly argued that the N140 does not meet several of the criteria required to be considered a MMN, and therefore, the present interpretation – that of the T-complex – represents the most parsimonious explanation for the data presented in this dissertation.

It has been argued that the inter-modal oddball task does not elicit a mismatch negativity, despite the similarities in topographic distribution of the N140 with this component. If it is assumed that the N140 represents activity that is produced by the processing of auditory stimuli – an assumption supported by the characteristics of the N140 in ST conditions – then activation in frontal regions of this component presents a concern for the interpretation of MMN activity produced in other auditory tasks (e.g. auditory oddball). Given the topographic overlap of these components and that the N140 has been shown to be affected by task requirements; in chapter 6 this represented either probability effects or mismatch processes, it is suggested that, in auditory tasks, early ERP activity potentially represents the overlap of both N140/T-complex and MMN activity. Although this concern can not be addressed within the current data, it is
clear that further investigation of the N140/T-complex and its relationship to the MMN is required. Without such, the interpretation of early negative activity might be confounded by distinct overlapping activity.

8.4 The Processes Involved in Auditory Target Processing

These data have provided systematic evidence of auditory processing in inter-modal oddball conditions. There were six key ERP components produced by auditory targets in the inter-modal oddball task (N100, N140, P200, P250, P300 & P350). It has been argued throughout this dissertation that these components represent a two-stage mode of auditory target processing (c.f. sections 4.4, 5.4, 6.4). That is, an early stimulus dependant and a late context dependant stage. However, an examination of these data suggests another interpretation for the processes elicited by auditory target stimuli. As can be seen in figure 8.1, the ERPs presented in this dissertation may be separated into processes that are under top-down control, mediated by the frontal lobe and those that represent stimulus-driven bottom-up activity. The N140 and P250 components were modulated differentially in frontal regions by the manipulation of task requirements (c.f. chapter 6). They also showed generator sources in frontal lobe structures – notably the ACC (c.f. chapter 7). The P350, arguably representing a separate process providing feedback to auditory cortices in inter-modal oddball conditions, also showed frontal activation and generators in frontal lobe regions. Thus, it is argued that these components

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18 N220 is not included here as it is considered a representation of the omission of visual stimuli rather than an auditory evoked component.
Figure 8.1 A representation of generator sources, topography and function of inter-modal oddball ERPs and their relationship to top-down and bottom-up processing.

(N140, P250 and P350) are most likely mediated by the activation of frontal lobe structures that are under top-down control. In contrast, the early exogenous components (N100 and P200) represent bottom-up processes modulated by the characteristics of the stimuli, whilst the P300 reflects a bottom-up process mediated by stimulus attributes that represents the updating of working memory.
(as per Polich, 2007). Taken together, it can be argued that, as well as separate early and late processes, the ERPs produced by auditory targets in inter-modal oddball conditions represent distinct top-down and bottom-up processes.

8.5 A Theoretical Interpretation of the Processing of Auditory Stimuli in the Inter-modal Oddball Task

It has been shown in these studies that there are seven primary ERP components produced by auditory stimuli in inter-modal oddball conditions. Of these, it has been suggested that the N220 represents a process related to visual stimulus omission, whilst the P350 component is most likely a representation of an inter-modal process. The remaining components (N100, N140, P200, P250, P300) represent the processing of auditory stimulus attributes within this task. It is argued that, despite these components being produced in the inter-modal oddball context, they are largely representative of auditory stimulus processing common to all tasks that require auditory targets to be identified. Based on the time course, topography and generator sources of the inter-modal oddball ERPs presented herein it is argued that each component represents a specific cortical process within which a theoretical model of auditory processing can be formulated.

It is firstly noted that the ERPs elicited in this task provide a more parsimonious explanation for underlying auditory activity than may be evident in other auditory tasks. The N100 in this task is produced without identifiable refractory effects. This means that the ERP clearly portrays the registration of stimulus attributes within the cortex. Furthermore, the comparison of inter-modal oddball ERPs with those from the auditory oddball task indicates a more
discreet set of processes. In traditional auditory oddball conditions, the ERP includes an additional process related to the detection of deviance from an ongoing stimulus train. This process is responsible for the elicitation of the N2b. In the inter-modal oddball task the process of deviance detection is not apparent, noting that no N2b component was evident. By removing deviance detection processes, the characteristics of auditory ERPs are more clearly identifiable – notably with reference to the N140 and P200 components. These early components represent specific processes that have not been clearly outlined in other studies. In addition, the inter-modal oddball task data has demonstrated that P3a and P3b activity is consistent with previous conceptualisations. Thus, it is argued that the ERPs produced in this task present a clearer representation of auditory target stimulus processing, without confounds related to intra-modality or component overlap.

Figure 8.2 A representation of a theoretical model of auditory processing showing how auditory ERP activity is transferred between different cortical regions. Top down (blue arrows) and bottom-up (red arrows) processes are represented separately.
These data suggest that auditory stimuli activate primary auditory cortices sensitive to stimulus characteristics (N100). Subsequent activation of auditory association areas produces activity representing the initial registration of auditory stimulus characteristics in frontal lobe structures (N140) and processes responsible for response preparation (P200). Frontal lobe systems act to compare inputs from association areas with the contents of working memory held in frontal attentional systems (P250). Subsequent transfer of information to parietal working memory structures occurs in response to relevant target stimuli (P300).

The ERPs in this task demonstrate several distinct processes which can be interpreted to form a theoretical model of the processes involved in auditory target processing. This model posits that after target stimulus information reaches the sensory receptors it is transferred to primary auditory cortices. This activates cortical structures that are sensitive to stimulus characteristics. The activation of areas within the primary auditory cortex transfers activity to fronto-central regions and this is responsible for the production of the N100 (c.f. sections 2.3.1, 8.2.1.1, 8.2.1.3). Subsequently, auditory association areas are activated by inputs from both sub-cortical structures and projections from the primary auditory cortex. Auditory association areas produce both the N140 and P200 components (c.f. sections 2.3.1, 2.3.2, 8.2.1.2, 8.2.1.3). The areas responsible for the elicitation of the N140 component transfer information to the frontal lobe. This represents the initial encoding of an incoming stimulus in frontal lobe structures (c.f. section 8.2.1.3). The areas responsible for the production of P200 project to central midline regions – reflecting preparation for the production or withholding of a response to a stimulus (c.f. section 8.2.1.4).
The processes related to these components are clearly evident in the absence of N2b overlap. Subsequent activation of frontal lobe structures, related to attention and memory processes, produce the P250/P3a component – the first in a suite of positive activity. It is suggested that these processes are functionally linked to the N140 which represents the initial encoding of stimulus information. N140 processes occur irrespective of stimulus meaning, that is, they are blind to stimulus relevance – this is suggested by the absence of differences between target and non-target N140 seen in chapter 6. Thus, the N140 represents the pre-cognitive input of auditory stimulus information. The P250 represents the comparison of these inputs with a neuronal trace held within frontal memory systems (c.f. sections 2.3.5, 8.2.2.1, 8.2.2.3). When a stimulus requires subsequent processing (i.e. targets), information is transferred to temporo-parietal regions responsible for the updating of working memory and this produces the P300. From this theoretical perspective, each of the ERP components represents a specific process related to the stimulus. It is argued that the processes identified in this dissertation, reflecting activation and transfer between cortical regions, are indicative of the way auditory target stimuli are typically processed in auditory tasks. By removing the effect of confounding activity seen in other tasks, it is suggested that the inter-modal oddball task represents a more prudent means by which auditory target processing can be identified and interpreted.

8.6 Limitations and Future Research

The studies in this dissertation represent a systematic investigation of inter-modal oddball processes. The task parameters used within were
equivalent to those used in previous clinical studies (i.e. Brown et al., 2005; Barry et al., 2006, 2009a, 2009b). Thus, the scope was limited to effects produced by auditory targets presented amidst visual standards. This means that an investigation of inter-modal oddball processes using different combinations of multi-modal stimuli still awaits consideration (e.g. visual targets with auditory standards or incorporating somatosensory stimuli in the paradigm). There were several further limitations in the inter-modal oddball task presented. This task used a fixed ISI, a constant standard-target probability and did not substantially alter auditory and visual stimulus characteristics (i.e. the 2000 Hz tone was presented amidst visual checkerboard stimuli across studies). Furthermore, these studies limited their analyses predominantly to effects of target stimulus activity. From this, there are several experimental investigations that were not considered in this thesis that could be suggested. No investigation was conducted into the differences that may be apparent to the visual standard stimuli. Understanding of these processes and how they relate to target processes is warranted. An investigation of variations to stimulus characteristics, such as those to the spatial frequency of checks to see if they alter target response, the use of a visual stimuli other than a counter-phasing checkerboard (e.g. flash stimulus, varying in aspects such as luminosity, colour, position) and differences in the frequency, intensity, probability and duration of auditory targets should all be considered. A variation in the inter-stimulus interval, such as presenting stimuli with a shorter or longer fixed ISI or presenting stimuli with a variable ISI could also be looked at. Furthermore, the effect of modulating task difficulty, either by increasing overall task demands or the difficulty of target stimulus discrimination should also be studied. These
studies were also limited to an investigation of effects in adult subjects. Given that a clinical investigation in children was the initial impetus for this study, the effect of this task in children requires consideration. It is argued that the inter-modal oddball task could incorporate many of the processes that have been investigated using traditional oddball methodologies. Given the differences between these data and those produced in traditional oddball conditions, application of previously used techniques might prove useful in further understanding the processing of auditory stimuli.

The present study represents the first attempt understand activity in the inter-modal oddball task. It has described several processes evident in this task. However, there are a number of unaddressed questions resulting from these studies that require further investigation. There were several effects seen in the N140 component whose attributes were beyond the scope of the present research project. This component was an additional early negativity evident in the ERP. The present data led to the conclusion that this component was consistent with the T-complex. However, a clearer understanding of the relationship between N140 and previous reports of the T-complex is needed. An investigation into the effects of stimulus modulation on the N140 and how this relates to the current understanding of T-complex activity also await clarification. Furthermore, the relationship between temporal and frontal activity in the N140 needs to be better understood. Areas of concern include the factors that modulate N140, particularly at frontal sites (e.g. whether probability or discrimination processes were responsible for modulation as discussed in chapter 6), the relationship of these factors with modulation of the P250 component and the relationship of frontal modulation of N140 with MMN activity.
produced in intra-modal tasks. Thus, there are several areas in which this component should be studied, and given the demonstration of activity and modulation of this component in inter-modal oddball conditions, this task is an ideal means to do so.

These data suggest the N220 component represents activity related to the omission of the visual standard stimulus. The effect that the omission of the standard stimulus has on target ERPs and whether there is evidence of omission related positive activity, possibly obscured by target processes, in these data should be investigated.

The P300 represents the processing of the auditory target stimulus presented amidst visual standards in the inter-modal oddball task. This component demonstrated several attributes consistent with the P3b. However, the factors that affect P300 elicitation were not extensively studied in this series of experiments and should be comprehensively investigated. A thorough understanding of P300 activity requires the determination of whether this component is modulated by stimulus parameters in a way that is consistent with other reports of P3b activity. That is, does the P300 respond to variations in factors such as probability, intensity and significance in a way that is consistent with reports of P3b activation in other studies? Furthermore, the data presented in chapters 5 and 6 suggested that there were separate P3b components produced by the auditory target in conditions where visual standards and an additional auditory stimulus was presented. The relationship between these components and how they respond to the modulation of task parameters – particularly, whether they respond in a similar way to P3 modulating factors –
needs clarification. This should help strengthen the certainty of the claims made in this dissertation and potentially could also be used to improve understanding of P3b processes. Furthermore, the P300 showed activity indicative of activation of supra-modal processing regions. This requires further clarification. It is suggested that a comprehensive examination of the processes related to the P300 component could enhance understanding of cortical activation, inter-modal processes and activity related to the P3b.

The inter-modal oddball targets produced a late positive component, the P350. This component had a topography that was different from positive components, evident at the same approximate latency, produced by other experimental paradigms. The P350 was also not consistent with other late positive components reported elsewhere in the literature. The P350 was interpreted as a reflection of processes related to target processing in inter-modal oddball conditions. An investigation of factors that might modulate the amplitude, latency and topography of this component should be conducted in order to clarify the nature of this component. The P350 demonstrated activity in frontal cortical regions and also indicated that it had generator sources in frontal and ACC regions. Whether this activity relates to other frontal processes (e.g. novelty processing or orienting) and the relationship between the frontal activity of this component and other components reported in this series of studies (i.e. N140 and P250) awaits further investigation.

An advantage of the oddball task is that it directs attention to the stimulus and allows for attentional processes to be manipulated. As was evident in chapters 4 and 5, the traditional two-tone oddball task produces ERPs that
incorporate intra-modal effects. The inter-modal oddball task requires attention to be directed to all stimuli, thus attention effects can also be manipulated in this task. However, as was demonstrated in the current set of studies, early components are not affected by standard stimulus attributes. It is these aspects of the inter-modal oddball task that suggest it could be useful in an investigation of the effects of the stimulus registration processes that are indicative of N1 and P2 activity. The amplitude of both these components represented maximal activation to the target stimulus, unaffected by the visual standards. Thus, differences in the characteristics of these components should arguably represent the effect of auditory target processing on the ERP. In the three-stimulus oddball condition N100 and P200 were modulated by the inclusion of the non-target deviant stimulus – an effect interpreted as a reflecting frequency differences and early stimulus discrimination processes related to the target and non-target stimuli respectively. It is suggested that the use of the three-stimulus inter-modal oddball task might be valuable in understanding these auditory effects. For example, an examination of the N100 in three-stimulus oddball conditions, where the characteristics of target and non-target stimuli were systematically counterbalanced, would provide a simple means of studying the effects of frequency differences in this task. Furthermore, by systematically varying the amount of frequency separation between targets and non-targets, a comprehensive understanding of frequency effects on this component, in attended conditions, and without the intra-modal confounds produced by a frequently presented auditory standard stimuli, should be possible. This would arguably enhance the understanding of these effects on the tonotopically arranged regions of the auditory cortex. Similarly, varying the stimulus attributes
of target and non-target stimuli would also improve the understanding of response related processes evident in the P200 component.

Finally, the data presented in this dissertation may be useful in the investigation of processing deficits in clinical populations. It has been shown that a range of clinical disorders produce aberrant ERP activity. For example, there is evidence for smaller P200s in patients with schizophrenia (Shenton, Faux, McCarley, Ballinger, Coleman & Duffy, 1989), P200 and N200 differences in clinical depression (Roth, Pfefferbaum, Kelly, Berger & Kopell, 1981; Ogura, Nageishi, Omura, Fukao, Ohta, Kishimoto & Matsubayashi, 1993; Vandoolaeghe, van Hunsel, Nuyten & Maes, 1998) and differential P2 activity in children with AD/HD (Satterfield et al., 1994; Kemner et al., 1996; Oades et al., 1996). Given that the current data have shown that P200 and N200 components have overlapping activity in traditional auditory oddball tasks, the reported deficits in these components might be a reflection of differences in one of these components that is overlapped upon the other. For example, deficits in P200 activity in a clinical population would arguably result in both smaller P200 amplitudes and ostensibly larger N200 activity. In this case, the N200 differences might be an artefact of overlapping P200 activity rather than a specific N200 augmentation. It is argued that the clear elicitation of the P200 without confounding overlapping activity in inter-modal oddball conditions could be useful in identifying specific P200 processing deficits. If the extent of P200 processing deficits can be identified, then it should also be possible to identify the contribution of N200 deficits in the ERP when considered in auditory oddball conditions. Furthermore, the study by Brown et al. (2005), which was important in the establishment of the current series of experiments, suggested that the P2
component in inter-modal oddball conditions was not consistent with previously reported activity in a sub-set of AD/HD subjects. The use of combination of inter-modal and auditory-oddball tasks might be useful in understanding why these differences occurred.

8.7 Summary

The studies presented in this dissertation investigated the processing of auditory target stimuli presented amidst visual standards in an inter-modal oddball task. The data showed that the target stimuli in this task produced seven ERP components. These were broadly consistent with auditory ERPs produced in other experimental paradigms. However, the inter-modal oddball task produced modulation of these components in a task specific way. The data suggested that the stimuli were processed in two stages – representing stimulus dependant and context dependant activity. They showed that the ERPs elicited by auditory target stimuli represented processes different to those seen in auditory oddball tasks. They also showed that the inter-modal oddball, as a sustained attention task, did not modulate ERPs in a similar way as seen in inter-modal selective attention tasks. Overall, the inter-modal oddball task presented in this dissertation represents a new and novel means of investigating auditory processing. Further experimentation with this task and in conjunction with activity that has been identified in other experimental paradigms should prove useful in the understanding of cortical activity that occurs whilst processing relevant, attended auditory stimuli.
9. References


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counterpart: Implications for their neural generation.

*Electroencephalography and Clinical Neurophysiology, 54*, 561-569.


configurations of the vertex components of the human auditory evoked
response: A reinterpretation. *Electroencephalography and Clinical
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organization in human auditory cortex revealed by positron emission

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between audition and touch in covert endogenous spatial attention.
*Perception and Psychophysics, 65*(6), 901-924.

probability and motor response in young and old adults: an ERP study.


10. Appendix A

See attached files for statistical data for each study.
Study 1 – Inter-modal oddball, Auditory oddball and Single tone data

Amplitude and Topographic analysis

P350 topography – inter-modal oddball amplitudes

<table>
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<th>N</th>
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<td>4.193</td>
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** ** ** * A n a l y s i s o f V a r i a n c e -- d e s i g n 1 ** ** **

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<th>Hypoth. MS</th>
<th>Error MS</th>
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<th>Sig. of F</th>
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T2   .25707  112.32850   .25707    5.91203    .04348       .837
T3    26.53388  60.42043  26.53388    3.18002    8.34393       .009

---

EFFECT .. LATERAL (Cont.)
Univariate F-tests with (1,19) D. F.

Variable   Hypoth. SS   Error SS Hypoth. MS   Error MS          F  Sig. of F
T4             .36186   64.55851     .36186    3.39782     .10650       .748
T5           11.09425   37.63745   11.09425    1.98092    5.60056       .029

---

EFFECT .. FRTOPOS BY LATERAL (Cont.)
Univariate F-tests with (1,19) D. F.

Variable   Hypoth. SS   Error SS Hypoth. MS   Error MS          F  Sig. of F
T6             .50032   14.13765     .50032     .74409     .67239       .422
T7             .38377    9.94402     .38377     .52337     .73327       .402
T8             .42810   12.09831     .42810     .63675     .67232       .422
T9           11.65167    9.90520   11.65167     .52133   22.35004       .000

---

P300 topography – inter-modal oddball amplitudes

---

Cell Means and Standard Deviations
Variable .. F3P3B1
Mean  Std. Dev.          N
For entire sample                          3.604      3.618         20

---

Variable .. FZP3B1
Mean  Std. Dev.          N
For entire sample                          3.692      4.256         20

---

Variable .. F4P3B1
Mean  Std. Dev.          N
For entire sample                          3.624      3.553         20

---

Variable .. C3P3B1
Mean  Std. Dev.          N
For entire sample                          3.896      2.896         20

---

Variable .. CZP3B1
Mean  Std. Dev.          N
For entire sample                          3.831      3.806         20

---

Variable .. C4P3B1
Mean  Std. Dev.          N
For entire sample                          4.236      2.758         20

---

* * * * * A n a l y s i s   o f   V a r i a n c e -- design 1 * * * * *

Cell Means and Standard Deviations (Cont.)
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<th>N</th>
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Variable .. PZP3B1

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Variable .. P4P3B1

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EFFECT .. FRTOPOS (Cont.)
Univariate F-tests with (1,19) D. F.

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<th>Hypoth. MS</th>
<th>Error MS</th>
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<td>61.25576</td>
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<td>.216</td>
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EFFECT .. LATERAL (Cont.)
Univariate F-tests with (1,19) D. F.

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<tr>
<th>Variable</th>
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<th>Error SS</th>
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<th>Error MS</th>
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<th>Sig. of F</th>
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<tr>
<td>T4</td>
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<td>19.34053</td>
<td>.80497</td>
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<td>.56194</td>
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EFFECT .. FRTOPOS BY LATERAL (Cont.)
Univariate F-tests with (1,19) D. F.

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P250 topography – inter-modal oddball amplitudes

Cell Means and Standard Deviations

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Variable .. F4P3A1

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<tbody>
<tr>
<td>For entire sample</td>
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</table>

Variable .. C3P3A1
For entire sample                          6.560      4.689         20
- - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - -
Variable .. CZP3A1
Mean Std. Dev. N
For entire sample                          8.832      5.382         20
- - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - -
Variable .. C4P3A1
Mean Std. Dev. N
For entire sample                          7.035      4.568         20
- - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - -
Variable .. P3P3A1
Mean Std. Dev. N
For entire sample                          5.275      4.216         20
- - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - -
Variable .. PZP3A1
Mean Std. Dev. N
For entire sample                          6.366      4.363         20
- - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - -
Variable .. P4P3A1
Mean Std. Dev. N
For entire sample                          5.531      3.957         20
- - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - -
- - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - -
** * * * * * A n a l y s i s o f V a r i a n c e -- design 1 * * * * * **

Cell Means and Standard Deviations (Cont.)
Variable .. P3P3A1
Mean Std. Dev. N
For entire sample                          5.275      4.216         20
- - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - -
Variable .. P2P3A1
Mean Std. Dev. N
For entire sample                          6.366      4.363         20
- - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - -
Variable .. P4P3A1
Mean Std. Dev. N
For entire sample                          5.531      3.957         20
- - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - -
EFFECT .. FRTOPOS (Cont.)
Univariate F-tests with (1,19) D. F.
Variable Hypoth. SS Error SS Hypoth. MS Error MS F Sig. of F
T2 34.24855 103.88121 34.24855 5.46743 6.26410 .022
T3 59.28471 41.62185 59.28471 2.19062 27.06294 .000
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EFFECT .. LATERAL (Cont.)
Univariate F-tests with (1,19) D. F.
Variable Hypoth. SS Error SS Hypoth. MS Error MS F Sig. of F
T4 4.39524 59.55231 4.39524 3.13433 1.40229 .251
T5 84.75306 36.51176 84.75306 1.92167 44.10382 .000
- - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - -
EFFECT .. FRTOPOS BY LATERAL (Cont.)
Univariate F-tests with (1,19) D. F.
Variable Hypoth. SS Error SS Hypoth. MS Error MS F Sig. of F
T6 .12976 13.77632 .12976 .72507 .17896 .677
T7 1.10458 14.10388 1.10458 .74231 1.48803 .237
T8 .12621 7.97641 .12621 .41981 .30064 .590
T9 6.71549 6.83262 6.71549 .35961 18.67429 .000
- - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - -

P200 topography – inter-modal oddball amplitudes
**Cell Means and Standard Deviations**

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<tbody>
<tr>
<td>For entire sample</td>
<td>8.087</td>
<td>4.020</td>
</tr>
</tbody>
</table>

**Analysis of Variance -- design 1**

**Cell Means and Standard Deviations (Cont.)**

<table>
<thead>
<tr>
<th>Variable ..</th>
<th>Mean</th>
<th>Std. Dev.</th>
<th>N</th>
</tr>
</thead>
<tbody>
<tr>
<td>For entire sample</td>
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</table>

**Variable .. F2P21**

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**Variable .. F4P21**

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<td>5.665</td>
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</table>

**Effect .. FRTOPOS (Cont.)**

Univariate F-tests with (1,19) D. F.

<table>
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<tr>
<th>Variable</th>
<th>Hypoth. SS</th>
<th>Error SS</th>
<th>Hypoth. MS</th>
<th>Error MS</th>
<th>F</th>
<th>Sig. of F</th>
</tr>
</thead>
<tbody>
<tr>
<td>T2</td>
<td>1.42221</td>
<td>267.73662</td>
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<td>14.09140</td>
<td>.10093</td>
<td>.754</td>
</tr>
<tr>
<td>T3</td>
<td>300.44362</td>
<td>113.52552</td>
<td>300.44362</td>
<td>3.27045</td>
<td>17.80054</td>
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</table>

**Effect .. LATERAL (Cont.)**

Univariate F-tests with (1,19) D. F.

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<th>Hypoth. SS</th>
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<th>Hypoth. MS</th>
<th>Error MS</th>
<th>F</th>
<th>Sig. of F</th>
</tr>
</thead>
<tbody>
<tr>
<td>T4</td>
<td>2.19784</td>
<td>42.49176</td>
<td>2.19784</td>
<td>2.23641</td>
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<td>T5</td>
<td>58.21586</td>
<td>62.13864</td>
<td>58.21586</td>
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<td>.000</td>
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</table>
**EFFECT .. FRTOPOS BY LATERAL (Cont.)**

Univariate F-tests with (1,19) D. F.

<table>
<thead>
<tr>
<th>Variable</th>
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<th>Error SS</th>
<th>Hypoth. MS</th>
<th>Error MS</th>
<th>F</th>
<th>Sig. of F</th>
</tr>
</thead>
<tbody>
<tr>
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<tr>
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<td>15.22416</td>
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<td>.41357</td>
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**N130 topography – inter-modal oddball amplitudes**

Cell Means and Standard Deviations

<table>
<thead>
<tr>
<th>Variable .. F3N1T1</th>
<th>Mean</th>
<th>Std. Dev.</th>
<th>N</th>
</tr>
</thead>
<tbody>
<tr>
<td>For entire sample</td>
<td>-4.449</td>
<td>4.114</td>
<td>20</td>
</tr>
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</table>

<table>
<thead>
<tr>
<th>Variable .. F2N1T1</th>
<th>Mean</th>
<th>Std. Dev.</th>
<th>N</th>
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</thead>
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<table>
<thead>
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<th>Std. Dev.</th>
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<th>Std. Dev.</th>
<th>N</th>
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<thead>
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<th>Mean</th>
<th>Std. Dev.</th>
<th>N</th>
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<tbody>
<tr>
<td>For entire sample</td>
<td>-4.469</td>
<td>4.269</td>
<td>20</td>
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</tbody>
</table>

* * * * * Analysis of Variance -- design 1 * * * * *

Cell Means and Standard Deviations (Cont.)

<table>
<thead>
<tr>
<th>Variable .. F3N1T1</th>
<th>Mean</th>
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<th>N</th>
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<tbody>
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<td>-3.474</td>
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<thead>
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<tbody>
<tr>
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<table>
<thead>
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<th>Std. Dev.</th>
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### EFFECT .. FRTOPOS (Cont.)

Univariate F-tests with (1, 19) D. F.

<table>
<thead>
<tr>
<th>Variable</th>
<th>Hypoth. SS</th>
<th>Error SS</th>
<th>Hypoth. MS</th>
<th>Error MS</th>
<th>F</th>
<th>Sig. of F</th>
</tr>
</thead>
<tbody>
<tr>
<td>T2</td>
<td>41.43893</td>
<td>186.85746</td>
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<td>9.83460</td>
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<tr>
<td>T3</td>
<td>33.22859</td>
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<td>10.08421</td>
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### EFFECT .. LATERAL (Cont.)

Univariate F-tests with (1, 19) D. F.

<table>
<thead>
<tr>
<th>Variable</th>
<th>Hypoth. SS</th>
<th>Error SS</th>
<th>Hypoth. MS</th>
<th>Error MS</th>
<th>F</th>
<th>Sig. of F</th>
</tr>
</thead>
<tbody>
<tr>
<td>T4</td>
<td>1.70173</td>
<td>41.01802</td>
<td>1.70173</td>
<td>2.15884</td>
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<td>T5</td>
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<td>.96277</td>
<td>0.60128</td>
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### EFFECT .. FRTOPOS BY LATERAL (Cont.)

Univariate F-tests with (1, 19) D. F.

<table>
<thead>
<tr>
<th>Variable</th>
<th>Hypoth. SS</th>
<th>Error SS</th>
<th>Hypoth. MS</th>
<th>Error MS</th>
<th>F</th>
<th>Sig. of F</th>
</tr>
</thead>
<tbody>
<tr>
<td>T6</td>
<td>1.55127</td>
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<td>0.65858</td>
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<td>.49027</td>
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<td>.67639</td>
<td>4.58433</td>
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<td>.24128</td>
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<td>.110</td>
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<td>1.00654</td>
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<td>1.00654</td>
<td>1.10015</td>
<td>0.91491</td>
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</table>

### N100 topography – inter-modal oddball amplitudes

#### Cell Means and Standard Deviations

**Variable .. F3N1V1**

<table>
<thead>
<tr>
<th>Mean</th>
<th>Std. Dev.</th>
<th>N</th>
</tr>
</thead>
<tbody>
<tr>
<td>-5.083</td>
<td>2.469</td>
<td>20</td>
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</tbody>
</table>

**Variable .. F2N1V1**

<table>
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**Variable .. F4N1V1**

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**Variable .. C3N1V1**

<table>
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**Variable .. C2N1V1**

<table>
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<th>Std. Dev.</th>
<th>N</th>
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<tr>
<td>-5.618</td>
<td>2.972</td>
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**Variable .. C4N1V1**

<table>
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<th>Std. Dev.</th>
<th>N</th>
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</thead>
<tbody>
<tr>
<td>-4.762</td>
<td>3.134</td>
<td>20</td>
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</tbody>
</table>
**Analysis of Variance -- design 1**

**Cell Means and Standard Deviations (Cont.)**

Variable .. P3N1V1

<table>
<thead>
<tr>
<th>Mean</th>
<th>Std. Dev.</th>
<th>N</th>
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</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>For entire sample</td>
<td>-2.467</td>
<td>1.744</td>
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Variable .. P2N1V1

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<th>Mean</th>
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<th>N</th>
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</thead>
<tbody>
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<tr>
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Variable .. P4N1V1

<table>
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<th>Std. Dev.</th>
<th>N</th>
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</thead>
<tbody>
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<td></td>
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<tr>
<td>For entire sample</td>
<td>-2.905</td>
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</table>

**EFFECT .. FRTOPOS (Cont.)**

Univariate F-tests with (1,19) D. F.

<table>
<thead>
<tr>
<th>Variable</th>
<th>Hypoth. SS</th>
<th>Error SS</th>
<th>Hypoth. MS</th>
<th>Error MS</th>
<th>F</th>
<th>Sig. of F</th>
</tr>
</thead>
<tbody>
<tr>
<td>T2</td>
<td>187.60571</td>
<td>187.49292</td>
<td>187.60571</td>
<td>9.86805</td>
<td>19.01143</td>
<td>.000</td>
</tr>
<tr>
<td>T3</td>
<td>28.46890</td>
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<td>28.46890</td>
<td>2.20130</td>
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**EFFECT .. LATERAL (Cont.)**

Univariate F-tests with (1,19) D. F.

<table>
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<tr>
<th>Variable</th>
<th>Hypoth. SS</th>
<th>Error SS</th>
<th>Hypoth. MS</th>
<th>Error MS</th>
<th>F</th>
<th>Sig. of F</th>
</tr>
</thead>
<tbody>
<tr>
<td>T4</td>
<td>2.82523</td>
<td>53.52407</td>
<td>2.82523</td>
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<td>1.00290</td>
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<td>T5</td>
<td>18.65846</td>
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**EFFECT .. FRTOPOS BY LATERAL (Cont.)**

Univariate F-tests with (1,19) D. F.

<table>
<thead>
<tr>
<th>Variable</th>
<th>Hypoth. SS</th>
<th>Error SS</th>
<th>Hypoth. MS</th>
<th>Error MS</th>
<th>F</th>
<th>Sig. of F</th>
</tr>
</thead>
<tbody>
<tr>
<td>T6</td>
<td>.50778</td>
<td>12.82977</td>
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<td>.67525</td>
<td>.75198</td>
<td>.397</td>
</tr>
<tr>
<td>T7</td>
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<td>.11587</td>
<td>.22210</td>
<td>.52171</td>
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<tr>
<td>T8</td>
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<td>.04590</td>
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<td>.697</td>
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<td>.88114</td>
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**Comparisons**

**P350 Inter-modal vs. Single tone**

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</tr>
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<tbody>
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<td></td>
<td></td>
</tr>
<tr>
<td>For entire sample</td>
<td>3.123</td>
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<table>
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</thead>
<tbody>
<tr>
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<td></td>
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<td>Variable ..</td>
<td>F4PNC1</td>
<td>Mean</td>
</tr>
<tr>
<td>------------</td>
<td>--------</td>
<td>-------</td>
</tr>
<tr>
<td>For entire sample</td>
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<td></td>
<td>C3PNC1</td>
<td>Mean</td>
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<td>Mean</td>
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<tr>
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<td>Mean</td>
</tr>
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<td>2.708</td>
<td>4.254</td>
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</table>

** * * * * * * A n a l y s i s   o f   V a r i a n c e -- design 1 * * * * * * **

Cell Means and Standard Deviations (Cont.)

<table>
<thead>
<tr>
<th>Variable ..</th>
<th>P3PNC1</th>
<th>Mean</th>
<th>Std. Dev.</th>
<th>N</th>
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</thead>
<tbody>
<tr>
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<tr>
<td></td>
<td>P2PNC1</td>
<td>Mean</td>
<td>Std. Dev.</td>
<td>N</td>
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<tr>
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<td>3.947</td>
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<td></td>
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<tr>
<td></td>
<td>P4PNC1</td>
<td>Mean</td>
<td>Std. Dev.</td>
<td>N</td>
</tr>
<tr>
<td>For entire sample</td>
<td>2.941</td>
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<td></td>
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<tr>
<td></td>
<td>F3PNC3</td>
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</tr>
<tr>
<td></td>
<td>F2PNC3</td>
<td>Mean</td>
<td>Std. Dev.</td>
<td>N</td>
</tr>
<tr>
<td>For entire sample</td>
<td>-0.391</td>
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</tr>
<tr>
<td></td>
<td>F4PNC3</td>
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<tr>
<td>For entire sample</td>
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<td>Std. Dev.</td>
<td>N</td>
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</table>
**Analysis of Variance -- design 1**

Cell Means and Standard Deviations (Cont.)

<table>
<thead>
<tr>
<th>Variable ..</th>
<th>Mean</th>
<th>Std. Dev.</th>
<th>N</th>
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</thead>
<tbody>
<tr>
<td>C4PNC3</td>
<td>-1.018</td>
<td>2.506</td>
<td>20</td>
</tr>
<tr>
<td>P3PNC3</td>
<td>-1.158</td>
<td>2.558</td>
<td>20</td>
</tr>
<tr>
<td>P2PNC3</td>
<td>-1.403</td>
<td>2.845</td>
<td>20</td>
</tr>
<tr>
<td>P4PNC3</td>
<td>-1.349</td>
<td>2.450</td>
<td>20</td>
</tr>
</tbody>
</table>

Tests involving 'TASK' Within-Subject Effect.

Tests of Significance for T2 using UNIQUE sums of squares

<table>
<thead>
<tr>
<th>Source of Variation</th>
<th>SS</th>
<th>DF</th>
<th>MS</th>
<th>F</th>
<th>Sig of F</th>
</tr>
</thead>
<tbody>
<tr>
<td>WITHIN CELLS</td>
<td>722.59</td>
<td>19</td>
<td>38.03</td>
<td></td>
<td></td>
</tr>
<tr>
<td>TASK</td>
<td>885.67</td>
<td>1</td>
<td>885.67</td>
<td>23.29</td>
<td>.000</td>
</tr>
</tbody>
</table>

EFFECT .. TASK BY FRTOPOS (Cont.)

Univariate F-tests with (1,19) D. F.

<table>
<thead>
<tr>
<th>Variable</th>
<th>Hypoth. SS</th>
<th>Error SS</th>
<th>Hypoth. MS</th>
<th>Error MS</th>
<th>F</th>
<th>Sig. of F</th>
</tr>
</thead>
<tbody>
<tr>
<td>T7</td>
<td>6.94182</td>
<td>156.10430</td>
<td>6.94182</td>
<td>8.21602</td>
<td>.84491</td>
<td>.370</td>
</tr>
<tr>
<td>T8</td>
<td>.75491</td>
<td>30.78984</td>
<td>.75491</td>
<td>1.62052</td>
<td>.46585</td>
<td>.503</td>
</tr>
</tbody>
</table>

EFFECT .. TASK BY LATERAL (Cont.)

Univariate F-tests with (1,19) D. F.

<table>
<thead>
<tr>
<th>Variable</th>
<th>Hypoth. SS</th>
<th>Error SS</th>
<th>Hypoth. MS</th>
<th>Error MS</th>
<th>F</th>
<th>Sig. of F</th>
</tr>
</thead>
<tbody>
<tr>
<td>T9</td>
<td>3.49791</td>
<td>38.75414</td>
<td>3.49791</td>
<td>2.03969</td>
<td>1.71492</td>
<td>.206</td>
</tr>
<tr>
<td>T10</td>
<td>1.05490</td>
<td>10.25964</td>
<td>1.05490</td>
<td>.53998</td>
<td>1.95359</td>
<td>.178</td>
</tr>
</tbody>
</table>

EFFECT .. TASK BY FTROPOS BY LATERAL (Cont.)

Univariate F-tests with (1,19) D. F.

<table>
<thead>
<tr>
<th>Variable</th>
<th>Hypoth. SS</th>
<th>Error SS</th>
<th>Hypoth. MS</th>
<th>Error MS</th>
<th>F</th>
<th>Sig. of F</th>
</tr>
</thead>
<tbody>
<tr>
<td>T15</td>
<td>2.38058</td>
<td>12.42564</td>
<td>2.38058</td>
<td>.65398</td>
<td>3.64014</td>
<td>.072</td>
</tr>
<tr>
<td>T16</td>
<td>1.29573</td>
<td>11.19656</td>
<td>1.29573</td>
<td>.58929</td>
<td>2.19879</td>
<td>.155</td>
</tr>
<tr>
<td>T17</td>
<td>.73669</td>
<td>10.94790</td>
<td>.73669</td>
<td>.57621</td>
<td>1.27817</td>
<td>.272</td>
</tr>
<tr>
<td>T18</td>
<td>1.69873</td>
<td>17.70759</td>
<td>1.69873</td>
<td>.93198</td>
<td>1.82271</td>
<td>.193</td>
</tr>
</tbody>
</table>

**P300 Inter-modal vs. Single tone**
<table>
<thead>
<tr>
<th>Variable ..</th>
<th>Mean</th>
<th>Std. Dev.</th>
<th>N</th>
</tr>
</thead>
<tbody>
<tr>
<td>F3P3B1</td>
<td>3.604</td>
<td>3.618</td>
<td>20</td>
</tr>
<tr>
<td>F2P3B1</td>
<td>3.692</td>
<td>4.256</td>
<td>20</td>
</tr>
<tr>
<td>F4P3B1</td>
<td>3.624</td>
<td>3.553</td>
<td>20</td>
</tr>
<tr>
<td>C3P3B1</td>
<td>3.896</td>
<td>2.896</td>
<td>20</td>
</tr>
<tr>
<td>CZP3B1</td>
<td>3.831</td>
<td>3.806</td>
<td>20</td>
</tr>
<tr>
<td>C4P3B1</td>
<td>4.236</td>
<td>2.758</td>
<td>20</td>
</tr>
</tbody>
</table>

**Analysis of Variance -- design 1**

<table>
<thead>
<tr>
<th>Variable ..</th>
<th>Mean</th>
<th>Std. Dev.</th>
<th>N</th>
</tr>
</thead>
<tbody>
<tr>
<td>P3P3B1</td>
<td>4.832</td>
<td>2.922</td>
<td>20</td>
</tr>
<tr>
<td>P2P3B1</td>
<td>5.410</td>
<td>2.994</td>
<td>20</td>
</tr>
<tr>
<td>P4P3B1</td>
<td>4.964</td>
<td>2.688</td>
<td>20</td>
</tr>
<tr>
<td>F3P3B3</td>
<td>1.081</td>
<td>2.300</td>
<td>20</td>
</tr>
<tr>
<td>F2P3B3</td>
<td>.002</td>
<td>3.218</td>
<td>20</td>
</tr>
<tr>
<td>F4P3B3</td>
<td>Mean</td>
<td>Std. Dev.</td>
<td>N</td>
</tr>
</tbody>
</table>
For entire sample                           .699      2.302         20

Variable .. C3P3B3
Mean  Std. Dev.          N
For entire sample                          1.301      2.289         20

Variable .. C2P3B3
Mean  Std. Dev.          N
For entire sample                          -.039      3.268         20

* * * * * * Analysis of Variance -- design 1 * * * * * *

Cell Means and Standard Deviations (Cont.)
Variable .. C4P3B3
Mean  Std. Dev.          N
For entire sample                          1.474      2.418         20

Variable .. P3P3B3
Mean  Std. Dev.          N
For entire sample                          2.195      2.464         20

Variable .. P2P3B3
Mean  Std. Dev.          N
For entire sample                          2.276      2.889         20

Variable .. P4P3B3
Mean  Std. Dev.          N
For entire sample                          2.613      2.755         20

* * * * * * Analysis of Variance -- design 1 * * * * * *
Tests involving 'TASK' Within-Subject Effect.

Tests of Significance for T2 using UNIQUE sums of squares
Source of Variation          SS      DF        MS         F  Sig of F
WITHIN CELLS             735.10      19     38.69
TASK                     779.51       1    779.51     20.15      .000

----- EFFECT .. TASK BY FRTOPOS (Cont.)-----
Univariate F-tests with (1,19) D. F.
Variable   Hypoth. SS   Error SS Hypoth. MS   Error MS          F  Sig. of F
T7            1.71759  261.79999    1.71759   13.77895     .12465       .728
T8             .78725   37.82335     .78725    1.99070     .39546       .537

----- EFFECT .. TASK BY LATERAL (Cont.)-----
Univariate F-tests with (1,19) D. F.
Variable   Hypoth. SS   Error SS Hypoth. MS   Error MS          F  Sig. of F
T9             .13408   45.22981     .13408    2.38052     .05632       .815
T10           17.39587   19.88814   17.39587    1.04674   16.61903       .001

----- EFFECT .. TASK BY FRTOPOS BY LATERAL (Cont.)-----
Univariate F-tests with (1,19) D. F.

<table>
<thead>
<tr>
<th>Variable</th>
<th>Hypoth. SS</th>
<th>Error SS</th>
<th>Hypoth. MS</th>
<th>Error MS</th>
<th>F</th>
<th>Sig. of F</th>
</tr>
</thead>
<tbody>
<tr>
<td>T15</td>
<td>1.18443</td>
<td>18.90305</td>
<td>1.18443</td>
<td>.99490</td>
<td>1.19050</td>
<td>.289</td>
</tr>
<tr>
<td>T16</td>
<td>.35364</td>
<td>14.22729</td>
<td>.35364</td>
<td>.74880</td>
<td>.47227</td>
<td>.500</td>
</tr>
<tr>
<td>T17</td>
<td>.03943</td>
<td>11.20111</td>
<td>.03943</td>
<td>.58953</td>
<td>.06688</td>
<td>.799</td>
</tr>
<tr>
<td>T18</td>
<td>.66781</td>
<td>10.64770</td>
<td>.66781</td>
<td>.56041</td>
<td>1.19165</td>
<td>.289</td>
</tr>
</tbody>
</table>

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**P250 Inter-modal vs. Single tone**

---

Cell Means and Standard Deviations
Variable .. F3P3A1

<table>
<thead>
<tr>
<th>Mean</th>
<th>Std. Dev.</th>
<th>N</th>
</tr>
</thead>
<tbody>
<tr>
<td>6.127</td>
<td>4.008</td>
<td>20</td>
</tr>
</tbody>
</table>

Variable .. F2P3A1

<table>
<thead>
<tr>
<th>Mean</th>
<th>Std. Dev.</th>
<th>N</th>
</tr>
</thead>
<tbody>
<tr>
<td>7.705</td>
<td>4.799</td>
<td>20</td>
</tr>
</tbody>
</table>

Variable .. F4P3A1

<table>
<thead>
<tr>
<th>Mean</th>
<th>Std. Dev.</th>
<th>N</th>
</tr>
</thead>
<tbody>
<tr>
<td>6.545</td>
<td>3.993</td>
<td>20</td>
</tr>
</tbody>
</table>

Variable .. C3P3A1

<table>
<thead>
<tr>
<th>Mean</th>
<th>Std. Dev.</th>
<th>N</th>
</tr>
</thead>
<tbody>
<tr>
<td>6.560</td>
<td>4.689</td>
<td>20</td>
</tr>
</tbody>
</table>

Variable .. C2P3A1

<table>
<thead>
<tr>
<th>Mean</th>
<th>Std. Dev.</th>
<th>N</th>
</tr>
</thead>
<tbody>
<tr>
<td>8.832</td>
<td>5.382</td>
<td>20</td>
</tr>
</tbody>
</table>

Variable .. C4P3A1

<table>
<thead>
<tr>
<th>Mean</th>
<th>Std. Dev.</th>
<th>N</th>
</tr>
</thead>
<tbody>
<tr>
<td>7.035</td>
<td>4.568</td>
<td>20</td>
</tr>
</tbody>
</table>

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** *** *** Analysis of Variance -- design 1 *** ***

Cell Means and Standard Deviations (Cont.)
Variable .. F3P3A1

<table>
<thead>
<tr>
<th>Mean</th>
<th>Std. Dev.</th>
<th>N</th>
</tr>
</thead>
<tbody>
<tr>
<td>5.275</td>
<td>4.216</td>
<td>20</td>
</tr>
</tbody>
</table>

Variable .. F2P3A1

<table>
<thead>
<tr>
<th>Mean</th>
<th>Std. Dev.</th>
<th>N</th>
</tr>
</thead>
<tbody>
<tr>
<td>6.366</td>
<td>4.363</td>
<td>20</td>
</tr>
</tbody>
</table>

Variable .. F4P3A1

<table>
<thead>
<tr>
<th>Mean</th>
<th>Std. Dev.</th>
<th>N</th>
</tr>
</thead>
<tbody>
<tr>
<td>5.531</td>
<td>3.957</td>
<td>20</td>
</tr>
<tr>
<td>Variable .. F3P3A3</td>
<td>Mean</td>
<td>Std. Dev.</td>
</tr>
<tr>
<td>--------------------</td>
<td>------</td>
<td>-----------</td>
</tr>
<tr>
<td>For entire sample</td>
<td>4.153</td>
<td>2.909</td>
</tr>
<tr>
<td>Variable .. F2P3A3</td>
<td>Mean</td>
<td>Std. Dev.</td>
</tr>
<tr>
<td>For entire sample</td>
<td>4.960</td>
<td>3.570</td>
</tr>
<tr>
<td>Variable .. F4P3A3</td>
<td>Mean</td>
<td>Std. Dev.</td>
</tr>
<tr>
<td>For entire sample</td>
<td>4.073</td>
<td>3.165</td>
</tr>
<tr>
<td>Variable .. C3P3A3</td>
<td>Mean</td>
<td>Std. Dev.</td>
</tr>
<tr>
<td>For entire sample</td>
<td>4.516</td>
<td>3.413</td>
</tr>
<tr>
<td>Variable .. CZP3A3</td>
<td>Mean</td>
<td>Std. Dev.</td>
</tr>
<tr>
<td>For entire sample</td>
<td>5.452</td>
<td>4.846</td>
</tr>
</tbody>
</table>

**Analysis of Variance -- design 1***

Cell Means and Standard Deviations (Cont.)

<table>
<thead>
<tr>
<th>Variable .. C4P3A3</th>
<th>Mean</th>
<th>Std. Dev.</th>
<th>N</th>
</tr>
</thead>
<tbody>
<tr>
<td>For entire sample</td>
<td>4.743</td>
<td>3.734</td>
<td>20</td>
</tr>
<tr>
<td>Variable .. P3P3A3</td>
<td>Mean</td>
<td>Std. Dev.</td>
<td>N</td>
</tr>
<tr>
<td>For entire sample</td>
<td>3.408</td>
<td>3.693</td>
<td>20</td>
</tr>
<tr>
<td>Variable .. P2P3A3</td>
<td>Mean</td>
<td>Std. Dev.</td>
<td>N</td>
</tr>
<tr>
<td>For entire sample</td>
<td>3.697</td>
<td>3.976</td>
<td>20</td>
</tr>
<tr>
<td>Variable .. P4P3A3</td>
<td>Mean</td>
<td>Std. Dev.</td>
<td>N</td>
</tr>
<tr>
<td>For entire sample</td>
<td>3.428</td>
<td>3.637</td>
<td>20</td>
</tr>
</tbody>
</table>

**Tests involving 'TASK' Within-Subject Effect.**

Tests of Significance for T2 using UNIQUE sums of squares

<table>
<thead>
<tr>
<th>Source of Variation</th>
<th>SS</th>
<th>DF</th>
<th>MS</th>
<th>F</th>
<th>Sig of F</th>
</tr>
</thead>
<tbody>
<tr>
<td>WITHIN CELLS</td>
<td>1083.64</td>
<td>19</td>
<td>57.03</td>
<td></td>
<td></td>
</tr>
<tr>
<td>TASK</td>
<td>515.80</td>
<td>1</td>
<td>515.80</td>
<td>9.04</td>
<td>.007</td>
</tr>
</tbody>
</table>

**Tests involving 'TASK' Within-Subject Effect.**

EFFECT .. TASK BY FRTOPOS

Multivariate Tests of Significance (S = 1, M = 0, N = 8 )

<table>
<thead>
<tr>
<th>Test Name</th>
<th>Value</th>
<th>Exact F Hypoth. DF</th>
<th>Error DF</th>
<th>Sig. of F</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pillais</td>
<td>.04086</td>
<td>.38341</td>
<td>2.00</td>
<td>18.00</td>
</tr>
<tr>
<td>Hotellings</td>
<td>.04260</td>
<td>.38341</td>
<td>2.00</td>
<td>18.00</td>
</tr>
</tbody>
</table>
**EFFECT .. TASK BY FRTOPOS (Cont.)**

Univariate F-tests with (1,19) D. F.

<table>
<thead>
<tr>
<th>Variable</th>
<th>Hypoth. SS</th>
<th>Error SS</th>
<th>Hypoth. MS</th>
<th>Error MS</th>
<th>F</th>
<th>Sig. of F</th>
</tr>
</thead>
<tbody>
<tr>
<td>T7</td>
<td>.51082</td>
<td>97.20641</td>
<td>.51082</td>
<td>.51163</td>
<td>.09984</td>
<td>.755</td>
</tr>
<tr>
<td>T8</td>
<td>1.42897</td>
<td>33.92745</td>
<td>1.42897</td>
<td>1.78566</td>
<td>.80025</td>
<td>.382</td>
</tr>
</tbody>
</table>

**EFFECT .. TASK BY LATERAL (Cont.)**

Univariate F-tests with (1,19) D. F.

<table>
<thead>
<tr>
<th>Variable</th>
<th>Hypoth. SS</th>
<th>Error SS</th>
<th>Hypoth. MS</th>
<th>Error MS</th>
<th>F</th>
<th>Sig. of F</th>
</tr>
</thead>
<tbody>
<tr>
<td>T9</td>
<td>1.60357</td>
<td>25.89130</td>
<td>1.60357</td>
<td>1.36270</td>
<td>1.17676</td>
<td>.292</td>
</tr>
<tr>
<td>T10</td>
<td>12.99489</td>
<td>37.01043</td>
<td>12.99489</td>
<td>1.94792</td>
<td>6.67117</td>
<td>.018</td>
</tr>
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</table>

**EFFECT .. TASK BY FRTOPOS BY LATERAL (Cont.)**

Univariate F-tests with (1,19) D. F.

<table>
<thead>
<tr>
<th>Variable</th>
<th>Hypoth. SS</th>
<th>Error SS</th>
<th>Hypoth. MS</th>
<th>Error MS</th>
<th>F</th>
<th>Sig. of F</th>
</tr>
</thead>
<tbody>
<tr>
<td>T15</td>
<td>.17075</td>
<td>7.53326</td>
<td>.17075</td>
<td>.39649</td>
<td>.43066</td>
<td>.520</td>
</tr>
<tr>
<td>T16</td>
<td>.08696</td>
<td>11.88429</td>
<td>.08696</td>
<td>.62549</td>
<td>.13902</td>
<td>.713</td>
</tr>
<tr>
<td>T17</td>
<td>.04837</td>
<td>6.84719</td>
<td>.04837</td>
<td>.36038</td>
<td>.13421</td>
<td>.718</td>
</tr>
<tr>
<td>T18</td>
<td>1.65547</td>
<td>12.58208</td>
<td>1.65547</td>
<td>.66221</td>
<td>2.49990</td>
<td>.130</td>
</tr>
</tbody>
</table>

**P200 Inter-modal vs. Single tone**

Cell Means and Standard Deviations

<table>
<thead>
<tr>
<th>Variable</th>
<th>Mean</th>
<th>Std. Dev.</th>
<th>N</th>
</tr>
</thead>
<tbody>
<tr>
<td>For entire sample</td>
<td>5.534</td>
<td>3.433</td>
<td>20</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Variable</th>
<th>Mean</th>
<th>Std. Dev.</th>
<th>N</th>
</tr>
</thead>
<tbody>
<tr>
<td>For entire sample</td>
<td>5.951</td>
<td>4.274</td>
<td>20</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Variable</th>
<th>Mean</th>
<th>Std. Dev.</th>
<th>N</th>
</tr>
</thead>
<tbody>
<tr>
<td>For entire sample</td>
<td>5.759</td>
<td>3.359</td>
<td>20</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Variable</th>
<th>Mean</th>
<th>Std. Dev.</th>
<th>N</th>
</tr>
</thead>
<tbody>
<tr>
<td>For entire sample</td>
<td>7.837</td>
<td>3.740</td>
<td>20</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Variable</th>
<th>Mean</th>
<th>Std. Dev.</th>
<th>N</th>
</tr>
</thead>
<tbody>
<tr>
<td>For entire sample</td>
<td>9.868</td>
<td>5.304</td>
<td>20</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Variable</th>
<th>Mean</th>
<th>Std. Dev.</th>
<th>N</th>
</tr>
</thead>
<tbody>
<tr>
<td>For entire sample</td>
<td>Mean</td>
<td>Std. Dev.</td>
<td>N</td>
</tr>
</tbody>
</table>
For entire sample                          8.087      4.020         20

** * * * * * A n a l y s i s o f V a r i a n c e -- d e s i g n 1 * * * * * **

Cell Means and Standard Deviations (Cont.)

<table>
<thead>
<tr>
<th>Variable</th>
<th>Mean</th>
<th>Std. Dev.</th>
<th>N</th>
</tr>
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<tbody>
<tr>
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<td>PZP21</td>
<td>6.905</td>
<td>4.051</td>
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<td>P4P21</td>
<td>5.665</td>
<td>3.394</td>
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<td>F3P23</td>
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<td>CZP23</td>
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<td>P3P23</td>
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</table>
Variable .. P4P23
For entire sample  5.560  3.466  20

* * * * * Analysis of Variance -- design 1 * * * * *

Tests involving 'TASK' Within-Subject Effect.
Tests of Significance for T2 using UNIQUE sums of squares

<table>
<thead>
<tr>
<th>Source of Variation</th>
<th>SS</th>
<th>DF</th>
<th>MS</th>
<th>F</th>
<th>Sig of F</th>
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<tbody>
<tr>
<td>WITHIN CELLS</td>
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<td>1.71</td>
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EFFECT .. TASK BY FRTOPOS (Cont.)
Univariate F-tests with (1,19) D. F.

<table>
<thead>
<tr>
<th>Variable</th>
<th>Hypoth. SS</th>
<th>Error SS</th>
<th>Hypoth. MS</th>
<th>Error MS</th>
<th>F</th>
<th>Sig. of F</th>
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</thead>
<tbody>
<tr>
<td>T7</td>
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EFFECT .. TASK BY LATERAL (Cont.)
Univariate F-tests with (1,19) D. F.

<table>
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<th>Error SS</th>
<th>Hypoth. MS</th>
<th>Error MS</th>
<th>F</th>
<th>Sig. of F</th>
</tr>
</thead>
<tbody>
<tr>
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EFFECT .. TASK BY FRTOPOS BY LATERAL (Cont.)
Univariate F-tests with (1,19) D. F.

<table>
<thead>
<tr>
<th>Variable</th>
<th>Hypoth. SS</th>
<th>Error SS</th>
<th>Hypoth. MS</th>
<th>Error MS</th>
<th>F</th>
<th>Sig. of F</th>
</tr>
</thead>
<tbody>
<tr>
<td>T15</td>
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<td>6.63130</td>
<td>.12002</td>
<td>.34902</td>
<td>.34388</td>
<td>.565</td>
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<tr>
<td>T16</td>
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<td>8.02146</td>
<td>.04123</td>
<td>.42218</td>
<td>.09767</td>
<td>.758</td>
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<tr>
<td>T17</td>
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<td>.15026</td>
<td>.23427</td>
<td>.64139</td>
<td>.433</td>
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<tr>
<td>T18</td>
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N130 Inter-modal vs. Single tone

Cell Means and Standard Deviations

<table>
<thead>
<tr>
<th>Variable .. F3N1T1</th>
<th>Mean</th>
<th>Std. Dev.</th>
<th>N</th>
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</thead>
<tbody>
<tr>
<td>For entire sample</td>
<td>-4.449</td>
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<table>
<thead>
<tr>
<th>Variable .. F2N1T1</th>
<th>Mean</th>
<th>Std. Dev.</th>
<th>N</th>
</tr>
</thead>
<tbody>
<tr>
<td>For entire sample</td>
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<table>
<thead>
<tr>
<th>Variable .. F4N1T1</th>
<th>Mean</th>
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<table>
<thead>
<tr>
<th>Variable .. C3N1T1</th>
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<th>Std. Dev.</th>
<th>N</th>
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</thead>
<tbody>
<tr>
<td>For entire sample</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Variable .. CZN1T1
Mean  Std. Dev.          N
For entire sample                         -5.039      4.824         20

Variable .. C4N1T1
Mean  Std. Dev.          N
For entire sample                         -4.469      4.269         20

Cell Means and Standard Deviations (Cont.)
Variable .. P3N1T1
Mean  Std. Dev.          N
For entire sample                         -3.474      2.694         20

Variable .. P2N1T1
Mean  Std. Dev.          N
For entire sample                         -3.394      3.113         20

Variable .. P4N1T1
Mean  Std. Dev.          N
For entire sample                         -3.063      3.277         20

Variable .. F3N1T3
Mean  Std. Dev.          N
For entire sample                         -4.831      2.954         20

Variable .. F2N1T3
Mean  Std. Dev.          N
For entire sample                         -5.127      3.289         20

Variable .. F4N1T3
Mean  Std. Dev.          N
For entire sample                         -4.870      2.919         20

Variable .. C3N1T3
Mean  Std. Dev.          N
For entire sample                         -5.578      3.323         20

Variable .. C2N1T3
Mean  Std. Dev.          N
For entire sample                         -6.058      3.674         20

* * * * * A n a l y s i s   o f   V a r i a n c e -- design 1 * * * * *
Variable .. P3N1T3
For entire sample  -3.919  2.153  20

Variable .. P2N1T3
For entire sample  -3.920  2.713  20

Variable .. P4N1T3
For entire sample  -3.428  1.881  20

** * * * * * Analysis of Variance -- design 1 * * * * * **

Tests involving 'TASK' Within-Subject Effect.

Tests of Significance for T2 using UNIQUE sums of squares

<table>
<thead>
<tr>
<th>Source of Variation</th>
<th>SS</th>
<th>DF</th>
<th>MS</th>
<th>F</th>
<th>Sig of F</th>
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<tbody>
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</table>

** EFFECT .. TASK BY FRTOPOS (Cont.)**

Univariate F-tests with (1,19) D. F.

<table>
<thead>
<tr>
<th>Variable</th>
<th>Hypoth. SS</th>
<th>Error SS</th>
<th>Hypoth. MS</th>
<th>Error MS</th>
<th>F</th>
<th>Sig. of F</th>
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</thead>
<tbody>
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<td>.00025</td>
<td>.987</td>
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<td>T8</td>
<td>1.86910</td>
<td>35.46884</td>
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** EFFECT .. TASK BY LATERAL (Cont.)**

Univariate F-tests with (1,19) D. F.

<table>
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<tr>
<th>Variable</th>
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<th>Error SS</th>
<th>Hypoth. MS</th>
<th>Error MS</th>
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<th>Sig. of F</th>
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<tbody>
<tr>
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<td>1.79799</td>
<td>10.22811</td>
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<td>1.79799</td>
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** EFFECT .. TASK BY FRTOPOS BY LATERAL (Cont.)**

Univariate F-tests with (1,19) D. F.

<table>
<thead>
<tr>
<th>Variable</th>
<th>Hypoth. SS</th>
<th>Error SS</th>
<th>Hypoth. MS</th>
<th>Error MS</th>
<th>F</th>
<th>Sig. of F</th>
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</thead>
<tbody>
<tr>
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<td>.00178</td>
<td>.967</td>
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<tr>
<td>T16</td>
<td>.23209</td>
<td>18.37224</td>
<td>.23209</td>
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<td>.24002</td>
<td>.630</td>
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<td>.00316</td>
<td>7.40146</td>
<td>.00316</td>
<td>.38955</td>
<td>.00812</td>
<td>.929</td>
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<td>.720</td>
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**N100 Inter-modal vs. Single tone**

Cell Means and Standard Deviations

<table>
<thead>
<tr>
<th>Variable .. F3N1V1</th>
<th>Mean</th>
<th>Std. Dev.</th>
<th>N</th>
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<tbody>
<tr>
<td>Variable</td>
<td>Mean</td>
<td>Std. Dev.</td>
<td>N</td>
</tr>
<tr>
<td>----------</td>
<td>------</td>
<td>-----------</td>
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<tr>
<td>FZN1V1</td>
<td>-5.083</td>
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<tr>
<td>C4N1V1</td>
<td>-4.762</td>
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<tr>
<td>P3N1V1</td>
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<td>P4N1V1</td>
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<td>F3N1V3</td>
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<tr>
<td>FZN1V3</td>
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<tr>
<td>C3N1V3</td>
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**Analysis of Variance -- design 1**

Cell Means and Standard Deviations (Cont.)

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<tr>
<th>Variable</th>
<th>Mean</th>
<th>Std. Dev.</th>
<th>N</th>
</tr>
</thead>
<tbody>
<tr>
<td>C2N1V3</td>
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<td>P3N1V3</td>
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<tr>
<td>P4N1V3</td>
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</table>

**Analysis of Variance -- design 1**

Tests involving 'TASK' Within-Subject Effect.

Tests of Significance for T2 using UNIQUE sums of squares

<table>
<thead>
<tr>
<th>Source of Variation</th>
<th>SS</th>
<th>DF</th>
<th>MS</th>
<th>F</th>
<th>Sig of F</th>
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<tbody>
<tr>
<td>WITHIN CELLS</td>
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**Analysis of Variance -- design 1**

Tests involving 'TASK' Within-Subject Effect.

Univariate F-tests with (1,19) D. F.

<table>
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<tr>
<th>Variable</th>
<th>Hypoth. SS</th>
<th>Error SS</th>
<th>Hypoth. MS</th>
<th>Error MS</th>
<th>F</th>
<th>Sig. of F</th>
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</thead>
<tbody>
<tr>
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<td>185.99246</td>
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**Analysis of Variance -- design 1**

Tests involving 'TASK' Within-Subject Effect.

Univariate F-tests with (1,19) D. F.

<table>
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<tr>
<th>Variable</th>
<th>Hypoth. SS</th>
<th>Error SS</th>
<th>Hypoth. MS</th>
<th>Error MS</th>
<th>F</th>
<th>Sig. of F</th>
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<tbody>
<tr>
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<td>45.33341</td>
<td>1.72191</td>
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**Analysis of Variance -- design 1**

Tests involving 'TASK' Within-Subject Effect.

Univariate F-tests with (1,19) D. F.

<table>
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<tr>
<th>Variable</th>
<th>Hypoth. SS</th>
<th>Error SS</th>
<th>Hypoth. MS</th>
<th>Error MS</th>
<th>F</th>
<th>Sig. of F</th>
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<tbody>
<tr>
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<td>.103</td>
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</table>
### P350 Inter-modal vs. Auditory oddball

#### Cell Means and Standard Deviations

<table>
<thead>
<tr>
<th>Variable</th>
<th>Mean</th>
<th>Std. Dev.</th>
<th>N</th>
</tr>
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<tbody>
<tr>
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</tr>
<tr>
<td>FZPNC1</td>
<td>2.840</td>
<td>4.514</td>
<td>20</td>
</tr>
<tr>
<td>F4PNC1</td>
<td>3.087</td>
<td>4.069</td>
<td>20</td>
</tr>
<tr>
<td>C3PNC1</td>
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<td>4.136</td>
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</tr>
<tr>
<td>CZPNC1</td>
<td>1.388</td>
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<tr>
<td>C4PNC1</td>
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</table>

<table>
<thead>
<tr>
<th>Variable</th>
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<th>Std. Dev.</th>
<th>N</th>
</tr>
</thead>
<tbody>
<tr>
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<tr>
<td>PZPNC1</td>
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<tr>
<td>P4PNC1</td>
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</table>
### Analysis of Variance -- design 1

**Mean & Standard Deviation**

<table>
<thead>
<tr>
<th>Variable</th>
<th>Mean</th>
<th>Std. Dev.</th>
<th>N</th>
</tr>
</thead>
<tbody>
<tr>
<td>F4PNC2</td>
<td>2.133</td>
<td>5.278</td>
<td>20</td>
</tr>
<tr>
<td>C3PNC2</td>
<td>2.157</td>
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<td>20</td>
</tr>
<tr>
<td>CZPNC2</td>
<td>2.939</td>
<td>3.692</td>
<td>20</td>
</tr>
<tr>
<td>C4PNC2</td>
<td>1.956</td>
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<tr>
<td>P3PNC2</td>
<td>3.109</td>
<td>4.613</td>
<td>20</td>
</tr>
<tr>
<td>PZPNC2</td>
<td>4.497</td>
<td>3.180</td>
<td>20</td>
</tr>
<tr>
<td>P4PNC2</td>
<td>4.140</td>
<td>3.765</td>
<td>20</td>
</tr>
</tbody>
</table>

### Analysis of Variance -- design 1

#### Cell Means and Standard Deviations (Cont.)

<table>
<thead>
<tr>
<th>Variable</th>
<th>Mean</th>
<th>Std. Dev.</th>
<th>N</th>
</tr>
</thead>
<tbody>
<tr>
<td>C4PNC2</td>
<td>3.109</td>
<td>4.613</td>
<td>20</td>
</tr>
<tr>
<td>P3PNC2</td>
<td>4.497</td>
<td>3.180</td>
<td>20</td>
</tr>
<tr>
<td>P2PNC2</td>
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<td>20</td>
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<td>P4PNC2</td>
<td>4.364</td>
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### Analysis of Variance -- design 1

#### Tests involving 'TASK' Within-Subject Effect.

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<th>DF</th>
<th>MS</th>
<th>F</th>
<th>Sig. of F</th>
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<tbody>
<tr>
<td>WITHIN CELLS</td>
<td>981.77</td>
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<td>51.67</td>
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<td>1</td>
<td>6.24</td>
<td>.12</td>
<td>.732</td>
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### Effect TASK BY FRTOPOS (Cont.)

<table>
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<tr>
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<th>Error SS</th>
<th>Hypoth. MS</th>
<th>Error MS</th>
<th>F</th>
<th>Sig. of F</th>
</tr>
</thead>
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### Effect TASK BY LATERAL (Cont.)

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<th>Error SS</th>
<th>Hypoth. MS</th>
<th>Error MS</th>
<th>F</th>
<th>Sig. of F</th>
</tr>
</thead>
</table>
Univariate F-tests with (1,19) D. F.

<table>
<thead>
<tr>
<th>Variable</th>
<th>Hypoth. SS</th>
<th>Error SS</th>
<th>Hypoth. MS</th>
<th>Error MS</th>
<th>F</th>
<th>Sig. of F</th>
</tr>
</thead>
<tbody>
<tr>
<td>T15</td>
<td>.12209</td>
<td>7.46714</td>
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<td>.43703</td>
<td>1.80629</td>
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**P300 Inter-modal vs. Auditory oddball**

---

Cell Means and Standard Deviations

<table>
<thead>
<tr>
<th>Variable</th>
<th>F3P3B1</th>
<th>F2P3B1</th>
<th>F4P3B1</th>
<th>C3P3B1</th>
<th>C2P3B1</th>
<th>C4P3B1</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mean</td>
<td>3.604</td>
<td>3.692</td>
<td>3.624</td>
<td>3.896</td>
<td>3.831</td>
<td>4.236</td>
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<tr>
<td>Std. Dev.</td>
<td>3.618</td>
<td>4.256</td>
<td>3.553</td>
<td>2.896</td>
<td>3.806</td>
<td>2.758</td>
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<tr>
<td>N</td>
<td>20</td>
<td>20</td>
<td>20</td>
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<td>20</td>
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* * * * * Analysis of Variance -- design 1 * * * * *

Cell Means and Standard Deviations (Cont.)

<table>
<thead>
<tr>
<th>Variable</th>
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<th>F2P3B1</th>
<th>F4P3B1</th>
<th>C3P3B1</th>
<th>C2P3B1</th>
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</thead>
<tbody>
<tr>
<td>Mean</td>
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</tr>
<tr>
<td>Std. Dev.</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>N</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
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</tr>
</tbody>
</table>
Variable .. P4P3B1
Mean Std. Dev. N
For entire sample 4.964 2.688 20

Variable .. F3P3B2
Mean Std. Dev. N
For entire sample 5.037 2.545 20

Variable .. F2P3B2
Mean Std. Dev. N
For entire sample 5.964 2.720 20

Variable .. F4P3B2
Mean Std. Dev. N
For entire sample 5.560 2.660 20

Variable .. C3P3B2
Mean Std. Dev. N
For entire sample 4.768 3.132 20

Variable .. CZP3B2
Mean Std. Dev. N
For entire sample 4.768 3.132 20

Variable .. P3P3B2
Mean Std. Dev. N
For entire sample 4.808 3.541 20

Variable .. PZP3B2
Mean Std. Dev. N
For entire sample 5.064 3.525 20

Variable .. P4P3B2
Mean Std. Dev. N
For entire sample 5.054 2.904 20

* * * * * * Analysis of Variance -- design 1 * * * * *

Cell Means and Standard Deviations (Cont.)
Variable .. C4P3B2
Mean Std. Dev. N
For entire sample 5.347 2.831 20

Variable .. P3P3B2
Mean Std. Dev. N
For entire sample 4.808 3.541 20

Variable .. P2P3B2
Mean Std. Dev. N
For entire sample 5.064 3.525 20

Variable .. P4P3B2
Mean Std. Dev. N
For entire sample 5.054 2.904 20

* * * * * * Analysis of Variance -- design 1 * * * * *

Tests involving 'TASK' Within-Subject Effect.

Tests of Significance for T2 using UNIQUE sums of squares

<table>
<thead>
<tr>
<th>Source of Variation</th>
<th>SS</th>
<th>DF</th>
<th>MS</th>
<th>F</th>
<th>Sig of F</th>
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<tbody>
<tr>
<td>WITHIN CELLS</td>
<td>810.91</td>
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<td>TASK</td>
<td>81.85</td>
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<td>81.85</td>
<td>1.92</td>
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EFFECT .. TASK BY FRTOPOS (Cont.)
### Univariate F-tests with (1,19) D. F.

<table>
<thead>
<tr>
<th>Variable</th>
<th>Hypoth. SS</th>
<th>Error SS</th>
<th>Hypoth. MS</th>
<th>Error MS</th>
<th>F</th>
<th>Sig. of F</th>
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</thead>
<tbody>
<tr>
<td>T7</td>
<td>58.43593</td>
<td>216.95523</td>
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<td>11.41870</td>
<td>5.11757</td>
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<tr>
<td>T8</td>
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<td>21.98941</td>
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</table>

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### EFFECT .. TASK BY LATERAL (Cont.)

### Univariate F-tests with (1,19) D. F.

<table>
<thead>
<tr>
<th>Variable</th>
<th>Hypoth. SS</th>
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<th>Hypoth. MS</th>
<th>Error MS</th>
<th>F</th>
<th>Sig. of F</th>
</tr>
</thead>
<tbody>
<tr>
<td>T9</td>
<td>1.22037</td>
<td>37.30458</td>
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<td>1.96340</td>
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<td>.90377</td>
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### EFFECT .. TASK BY PROTOPOS BY LATERAL (Cont.)

### Univariate F-tests with (1,19) D. F.

<table>
<thead>
<tr>
<th>Variable</th>
<th>Hypoth. SS</th>
<th>Error SS</th>
<th>Hypoth. MS</th>
<th>Error MS</th>
<th>F</th>
<th>Sig. of F</th>
</tr>
</thead>
<tbody>
<tr>
<td>T15</td>
<td>.37757</td>
<td>10.87876</td>
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<td>3.11466</td>
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<td>.19563</td>
<td>15.92129</td>
<td>.001</td>
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<tr>
<td>T17</td>
<td>.01555</td>
<td>8.19550</td>
<td>.01555</td>
<td>.43134</td>
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<td>.851</td>
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<td>T18</td>
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<td>.08992</td>
<td>.30731</td>
<td>.29260</td>
<td>.595</td>
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</tbody>
</table>

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### P250 Inter-modal vs. Auditory oddball

#### Cell Means and Standard Deviations

<table>
<thead>
<tr>
<th>Variable .. F3P3A1</th>
<th>Mean</th>
<th>Std. Dev.</th>
<th>N</th>
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<tbody>
<tr>
<td>For entire sample</td>
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<table>
<thead>
<tr>
<th>Variable .. F2P3A1</th>
<th>Mean</th>
<th>Std. Dev.</th>
<th>N</th>
</tr>
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<tbody>
<tr>
<td>For entire sample</td>
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<table>
<thead>
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<th>Mean</th>
<th>Std. Dev.</th>
<th>N</th>
</tr>
</thead>
<tbody>
<tr>
<td>For entire sample</td>
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<table>
<thead>
<tr>
<th>Variable .. C3P3A1</th>
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<th>Std. Dev.</th>
<th>N</th>
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<table>
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<th>Mean</th>
<th>Std. Dev.</th>
<th>N</th>
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<table>
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**Analysis of Variance -- design 1**

Cell Means and Standard Deviations (Cont.)

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<tbody>
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<td>P4P3A1</td>
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<td>F3P3A2</td>
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<tr>
<td>F4P3A2</td>
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<td>C2P3A2</td>
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<tr>
<td>P2P3A2</td>
<td>5.303</td>
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<td>P4P3A2</td>
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</table>
**Analysis of Variance -- design 1**

Tests involving 'TASK' Within-Subject Effect.

Tests of Significance for T2 using UNIQUE sums of squares

<table>
<thead>
<tr>
<th>Source of Variation</th>
<th>SS</th>
<th>DF</th>
<th>MS</th>
<th>F</th>
<th>Sig of F</th>
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</thead>
<tbody>
<tr>
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EFFECT .. TASK BY FRTOPOS (Cont.)

Univariate F-tests with (1,19) D. F.

<table>
<thead>
<tr>
<th>Variable</th>
<th>Hypoth. SS</th>
<th>Error SS</th>
<th>Hypoth. MS</th>
<th>Error MS</th>
<th>F</th>
<th>Sig. of F</th>
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<tbody>
<tr>
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<td>83.67993</td>
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EFFECT .. TASK BY FRTOPOS BY LATERAL (Cont.)

Univariate F-tests with (1,19) D. F.

<table>
<thead>
<tr>
<th>Variable</th>
<th>Hypoth. SS</th>
<th>Error SS</th>
<th>Hypoth. MS</th>
<th>Error MS</th>
<th>F</th>
<th>Sig. of F</th>
</tr>
</thead>
<tbody>
<tr>
<td>T15</td>
<td>1.19245</td>
<td>9.83693</td>
<td>1.19245</td>
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<td>.05344</td>
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<td>T17</td>
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**P200 Inter-modal vs. Auditory oddball**

Cell Means and Standard Deviations

<table>
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<tr>
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<th>Mean</th>
<th>Std. Dev.</th>
<th>N</th>
</tr>
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<tbody>
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<td></td>
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<table>
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<tbody>
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<table>
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<th>N</th>
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<tbody>
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<table>
<thead>
<tr>
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<th>Std. Dev.</th>
<th>N</th>
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</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
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</table>

<table>
<thead>
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<th>N</th>
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</thead>
<tbody>
<tr>
<td></td>
<td></td>
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<tr>
<td>For entire sample</td>
<td>9.868</td>
<td>5.304</td>
<td>20</td>
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</table>

<table>
<thead>
<tr>
<th>Variable</th>
<th>Mean</th>
<th>Std. Dev.</th>
<th>N</th>
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<tbody>
<tr>
<td></td>
<td></td>
<td></td>
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</tr>
<tr>
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<td>5.304</td>
<td>20</td>
</tr>
<tr>
<td>Variable ..</td>
<td>Mean</td>
<td>Std. Dev.</td>
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<td>--------------</td>
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<tr>
<td>F2P22</td>
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<td>3.102</td>
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<tr>
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<tr>
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**Analysis of Variance -- design 1**

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<th>N</th>
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### Analysis of Variance -- Design 1

#### Tests involving 'TASK' Within-Subject Effect.

Tests of Significance for T2 using UNIQUE sums of squares

<table>
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<tr>
<th>Source of Variation</th>
<th>SS</th>
<th>DF</th>
<th>MS</th>
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<th>Sig of F</th>
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**EFFECT .. TASK BY FRTOPOS (Cont.)**

Univariate F-tests with (1,19) D. F.

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<tr>
<th>Variable</th>
<th>Hypoth. SS</th>
<th>Error SS</th>
<th>Hypoth. MS</th>
<th>Error MS</th>
<th>F</th>
<th>Sig. of F</th>
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**EFFECT .. TASK BY LATERAL (Cont.)**

Univariate F-tests with (1,19) D. F.

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<th>Hypoth. MS</th>
<th>Error MS</th>
<th>F</th>
<th>Sig. of F</th>
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</thead>
<tbody>
<tr>
<td>T9</td>
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**EFFECT .. TASK BY FRTOPOS BY LATERAL (Cont.)**

Univariate F-tests with (1,19) D. F.

<table>
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<tr>
<th>Variable</th>
<th>Hypoth. SS</th>
<th>Error SS</th>
<th>Hypoth. MS</th>
<th>Error MS</th>
<th>F</th>
<th>Sig. of F</th>
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<tbody>
<tr>
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<td>.29373</td>
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### N130 Inter-modal vs. Auditory oddball

#### Cell Means and Standard Deviations

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<thead>
<tr>
<th>Variable .. F3N1T1</th>
<th>Mean</th>
<th>Std. Dev.</th>
<th>N</th>
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<tbody>
<tr>
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<tr>
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<th>Std. Dev.</th>
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<tbody>
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<td>Variable</td>
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<td>Std. Dev.</td>
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<tr>
<td>------------</td>
<td>------</td>
<td>-----------</td>
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<tr>
<td>For entire sample</td>
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<tr>
<td>C3N1T1</td>
<td>-4.920</td>
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<td>CZN1T1</td>
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**Analysis of Variance -- design 1**

Cell Means and Standard Deviations (Cont.)

<table>
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<th>Variable</th>
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<tr>
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<table>
<thead>
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<table>
<thead>
<tr>
<th>Variable</th>
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<tr>
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<table>
<thead>
<tr>
<th>Variable</th>
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<th>Std. Dev.</th>
<th>N</th>
</tr>
</thead>
<tbody>
<tr>
<td>For entire sample</td>
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<tr>
<td>C4N1T2</td>
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### Variable .. P3N1T2

Mean  Std. Dev.  N
For entire sample  -.748  1.786  20

### Variable .. PZN1T2

Mean  Std. Dev.  N
For entire sample  -.532  1.588  20

### Variable .. P4N1T2

Mean  Std. Dev.  N
For entire sample  -.635  1.407  20

---

**Analysis of Variance -- design 1**

Tests involving 'TASK' Within-Subject Effect.

Tests of Significance for T2 using UNIQUE sums of squares

<table>
<thead>
<tr>
<th>Source of Variation</th>
<th>SS</th>
<th>DF</th>
<th>MS</th>
<th>F</th>
<th>Sig of F</th>
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**EFFECT .. TASK BY FRTOPOS (Cont.)**

Univariate F-tests with (1,19) D. F.

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<th>Hypoth. SS</th>
<th>Error SS</th>
<th>Hypoth. MS</th>
<th>Error MS</th>
<th>F</th>
<th>Sig. of F</th>
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**EFFECT .. TASK BY LATERAL (Cont.)**

Univariate F-tests with (1,19) D. F.

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<th>Variable</th>
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<th>Error SS</th>
<th>Hypoth. MS</th>
<th>Error MS</th>
<th>F</th>
<th>Sig. of F</th>
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<tbody>
<tr>
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**EFFECT .. TASK BY FRTOPOS BY LATERAL (Cont.)**

Univariate F-tests with (1,19) D. F.

<table>
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<tr>
<th>Variable</th>
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<th>Hypoth. MS</th>
<th>Error MS</th>
<th>F</th>
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**N100 Inter-modal vs. Auditory oddball**

---

Cell Means and Standard Deviations

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<th>Mean</th>
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<tr>
<td>Variable</td>
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<td>Std. Dev.</td>
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<td>F4N1V1</td>
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**Analysis of Variance -- design 1**

Cell Means and Standard Deviations (Cont.)

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<th>Std. Dev.</th>
<th>N</th>
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<table>
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<tr>
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<th>Std. Dev.</th>
<th>N</th>
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<table>
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</tr>
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</table>

**Analysis of Variance -- design 1**

Tests involving 'TASK' Within-Subject Effect.

Tests of Significance for T2 using UNIQUE sums of squares

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<thead>
<tr>
<th>Source of Variation</th>
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<th>DF</th>
<th>MS</th>
<th>F</th>
<th>Sig of F</th>
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<tbody>
<tr>
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EFFECT .. TASK BY FRTOPOS (Cont.)

Univariate F-tests with (1,19) D. F.

<table>
<thead>
<tr>
<th>Variable</th>
<th>Hypoth. SS</th>
<th>Error SS</th>
<th>Hypoth. MS</th>
<th>Error MS</th>
<th>F</th>
<th>Sig. of F</th>
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<tbody>
<tr>
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EFFECT .. TASK BY LATERAL (Cont.)

Univariate F-tests with (1,19) D. F.

<table>
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<tr>
<th>Variable</th>
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<th>Hypoth. MS</th>
<th>Error MS</th>
<th>F</th>
<th>Sig. of F</th>
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EFFECT .. TASK BY FRTOPOS BY LATERAL (Cont.)

Univariate F-tests with (1,19) D. F.

<table>
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<tr>
<th>Variable</th>
<th>Hypoth. SS</th>
<th>Error SS</th>
<th>Hypoth. MS</th>
<th>Error MS</th>
<th>F</th>
<th>Sig. of F</th>
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<tbody>
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<td>T15</td>
<td>.04585</td>
<td>8.33341</td>
<td>.04585</td>
<td>.10453</td>
<td>.750</td>
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<tr>
<td>T16</td>
<td>.79707</td>
<td>2.17565</td>
<td>.79707</td>
<td>6.96082</td>
<td>.016</td>
<td></td>
</tr>
<tr>
<td>T17</td>
<td>.06306</td>
<td>3.37234</td>
<td>.06306</td>
<td>.35526</td>
<td>.558</td>
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<tr>
<td>T18</td>
<td>1.09011</td>
<td>8.70707</td>
<td>1.09011</td>
<td>2.37877</td>
<td>.139</td>
<td></td>
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</table>
### P350 Inter-modal vs. Single tone

<table>
<thead>
<tr>
<th>Variable ..</th>
<th>Mean</th>
<th>Std. Dev.</th>
<th>N</th>
</tr>
</thead>
<tbody>
<tr>
<td>F3PNC1</td>
<td>1.099</td>
<td>1.476</td>
<td>20</td>
</tr>
<tr>
<td>FZPNC1</td>
<td>.999</td>
<td>1.588</td>
<td>20</td>
</tr>
<tr>
<td>F4PNC1</td>
<td>1.086</td>
<td>1.432</td>
<td>20</td>
</tr>
<tr>
<td>C3PNC1</td>
<td>.932</td>
<td>1.455</td>
<td>20</td>
</tr>
<tr>
<td>CZPNC1</td>
<td>.489</td>
<td>1.787</td>
<td>20</td>
</tr>
<tr>
<td>C4PNC1</td>
<td>.953</td>
<td>1.497</td>
<td>20</td>
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</table>

**Analysis of Variance -- design 1**

<table>
<thead>
<tr>
<th>Variable ..</th>
<th>Mean</th>
<th>Std. Dev.</th>
<th>N</th>
</tr>
</thead>
<tbody>
<tr>
<td>P3PNC1</td>
<td>1.159</td>
<td>1.190</td>
<td>20</td>
</tr>
<tr>
<td>PZPNC1</td>
<td>1.088</td>
<td>1.389</td>
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</tbody>
</table>
### Variable .. P4PNC1

<table>
<thead>
<tr>
<th>Mean</th>
<th>Std. Dev.</th>
<th>N</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.035</td>
<td>1.214</td>
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</table>

### Variable .. F3PNC3

<table>
<thead>
<tr>
<th>Mean</th>
<th>Std. Dev.</th>
<th>N</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.305</td>
<td>4.502</td>
<td>20</td>
</tr>
</tbody>
</table>

### Variable .. F2PNC3

<table>
<thead>
<tr>
<th>Mean</th>
<th>Std. Dev.</th>
<th>N</th>
</tr>
</thead>
<tbody>
<tr>
<td>-0.487</td>
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<td>20</td>
</tr>
</tbody>
</table>

### Variable .. F4PNC3

<table>
<thead>
<tr>
<th>Mean</th>
<th>Std. Dev.</th>
<th>N</th>
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</thead>
<tbody>
<tr>
<td>0.245</td>
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<td>20</td>
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</table>

### Variable .. C3PNC3

<table>
<thead>
<tr>
<th>Mean</th>
<th>Std. Dev.</th>
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</thead>
<tbody>
<tr>
<td>-0.349</td>
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</table>

### Variable .. CZPNC3

<table>
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<th>N</th>
</tr>
</thead>
<tbody>
<tr>
<td>-2.189</td>
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</tbody>
</table>

### Variable .. C4PNC3

<table>
<thead>
<tr>
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<th>Std. Dev.</th>
<th>N</th>
</tr>
</thead>
<tbody>
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<td>-1.268</td>
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### Variable .. P3PNC3

<table>
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<th>N</th>
</tr>
</thead>
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<td>-0.197</td>
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### Variable .. PZPNC3

<table>
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<th>Std. Dev.</th>
<th>N</th>
</tr>
</thead>
<tbody>
<tr>
<td>-0.502</td>
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</tbody>
</table>

### Analysis of Variance -- design 1

**Tests involving 'TASK' Within-Subject Effect.**

<table>
<thead>
<tr>
<th>Source of Variation</th>
<th>SS</th>
<th>DF</th>
<th>MS</th>
<th>F</th>
<th>Sig of F</th>
</tr>
</thead>
<tbody>
<tr>
<td>WITHIN CELLS</td>
<td>574.73</td>
<td>19</td>
<td>30.25</td>
<td></td>
<td></td>
</tr>
<tr>
<td>TASK</td>
<td>179.69</td>
<td>1</td>
<td>179.69</td>
<td>5.94</td>
<td>.025</td>
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**Tests involving 'TASK' By FRTOPOS (Cont.)**

Univariate F-tests with (1,19) D. F.
<table>
<thead>
<tr>
<th>Variable</th>
<th>Hypoth. SS</th>
<th>Error SS</th>
<th>Hypoth. MS</th>
<th>Error MS</th>
<th>F</th>
<th>Sig. of F</th>
</tr>
</thead>
<tbody>
<tr>
<td>T7</td>
<td>8.77709</td>
<td>239.79830</td>
<td>8.77709</td>
<td>12.62096</td>
<td>.69544</td>
<td>.415</td>
</tr>
<tr>
<td>T8</td>
<td>18.83444</td>
<td>25.48830</td>
<td>18.83444</td>
<td>1.34149</td>
<td>14.03994</td>
<td>.001</td>
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**EFFECT .. TASK BY LATERAL (Cont.)**

Univariate F-tests with (1,19) D. F.

<table>
<thead>
<tr>
<th>Variable</th>
<th>Hypoth. SS</th>
<th>Error SS</th>
<th>Hypoth. MS</th>
<th>Error MS</th>
<th>F</th>
<th>Sig. of F</th>
</tr>
</thead>
<tbody>
<tr>
<td>T9</td>
<td>7.34933</td>
<td>14.97469</td>
<td>7.34933</td>
<td>.78814</td>
<td>9.32489</td>
<td>.007</td>
</tr>
<tr>
<td>T10</td>
<td>11.46511</td>
<td>12.20232</td>
<td>11.46511</td>
<td>.64223</td>
<td>17.85211</td>
<td>.000</td>
</tr>
</tbody>
</table>

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**EFFECT .. TASK BY FRTOPOS BY LATERAL (Cont.)**

Univariate F-tests with (1,19) D. F.

<table>
<thead>
<tr>
<th>Variable</th>
<th>Hypoth. SS</th>
<th>Error SS</th>
<th>Hypoth. MS</th>
<th>Error MS</th>
<th>F</th>
<th>Sig. of F</th>
</tr>
</thead>
<tbody>
<tr>
<td>T15</td>
<td>2.17682</td>
<td>6.53984</td>
<td>2.17682</td>
<td>.34420</td>
<td>6.32425</td>
<td>.021</td>
</tr>
<tr>
<td>T16</td>
<td>3.27677</td>
<td>8.28728</td>
<td>3.27677</td>
<td>.43617</td>
<td>7.51254</td>
<td>.013</td>
</tr>
<tr>
<td>T17</td>
<td>.42992</td>
<td>7.85161</td>
<td>.42992</td>
<td>.41324</td>
<td>1.04036</td>
<td>.321</td>
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<tr>
<td>T18</td>
<td>.28544</td>
<td>14.09357</td>
<td>.28544</td>
<td>.74177</td>
<td>.38481</td>
<td>.542</td>
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</tbody>
</table>

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**P300 Inter-modal vs. Single tone**

---

Cell Means and Standard Deviations

<table>
<thead>
<tr>
<th>Variable .. F3P3B1</th>
<th>Mean</th>
<th>Std. Dev.</th>
<th>N</th>
</tr>
</thead>
<tbody>
<tr>
<td>For entire sample</td>
<td>.842</td>
<td>.846</td>
<td>20</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Variable .. F2P3B1</th>
<th>Mean</th>
<th>Std. Dev.</th>
<th>N</th>
</tr>
</thead>
<tbody>
<tr>
<td>For entire sample</td>
<td>.863</td>
<td>.995</td>
<td>20</td>
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<table>
<thead>
<tr>
<th>Variable .. F4P3B1</th>
<th>Mean</th>
<th>Std. Dev.</th>
<th>N</th>
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</thead>
<tbody>
<tr>
<td>For entire sample</td>
<td>.847</td>
<td>.830</td>
<td>20</td>
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</table>

<table>
<thead>
<tr>
<th>Variable .. C3P3B1</th>
<th>Mean</th>
<th>Std. Dev.</th>
<th>N</th>
</tr>
</thead>
<tbody>
<tr>
<td>For entire sample</td>
<td>.910</td>
<td>.677</td>
<td>20</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Variable .. C2P3B1</th>
<th>Mean</th>
<th>Std. Dev.</th>
<th>N</th>
</tr>
</thead>
<tbody>
<tr>
<td>For entire sample</td>
<td>.895</td>
<td>.889</td>
<td>20</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Variable .. C4P3B1</th>
<th>Mean</th>
<th>Std. Dev.</th>
<th>N</th>
</tr>
</thead>
<tbody>
<tr>
<td>For entire sample</td>
<td>.990</td>
<td>.644</td>
<td>20</td>
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</tbody>
</table>

* * * * * Analysis of Variance -- design 1 * * * * *
### Cell Means and Standard Deviations (Cont.)

#### Variable .. P3P3B1

<table>
<thead>
<tr>
<th>Mean</th>
<th>Std. Dev.</th>
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</thead>
<tbody>
<tr>
<td>1.129</td>
<td>.683</td>
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</tbody>
</table>

#### Variable .. P2P3B1

<table>
<thead>
<tr>
<th>Mean</th>
<th>Std. Dev.</th>
<th>N</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.264</td>
<td>.700</td>
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</tbody>
</table>

#### Variable .. P4P3B1

<table>
<thead>
<tr>
<th>Mean</th>
<th>Std. Dev.</th>
<th>N</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.160</td>
<td>.628</td>
<td>20</td>
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</tbody>
</table>

#### Variable .. F3P3B3

<table>
<thead>
<tr>
<th>Mean</th>
<th>Std. Dev.</th>
<th>N</th>
</tr>
</thead>
<tbody>
<tr>
<td>.686</td>
<td>1.459</td>
<td>20</td>
</tr>
</tbody>
</table>

#### Variable .. FZP3B3

<table>
<thead>
<tr>
<th>Mean</th>
<th>Std. Dev.</th>
<th>N</th>
</tr>
</thead>
<tbody>
<tr>
<td>.001</td>
<td>2.042</td>
<td>20</td>
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</table>

#### Variable .. F4P3B3

<table>
<thead>
<tr>
<th>Mean</th>
<th>Std. Dev.</th>
<th>N</th>
</tr>
</thead>
<tbody>
<tr>
<td>.443</td>
<td>1.461</td>
<td>20</td>
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</tbody>
</table>

#### Variable .. C3P3B3

<table>
<thead>
<tr>
<th>Mean</th>
<th>Std. Dev.</th>
<th>N</th>
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</thead>
<tbody>
<tr>
<td>.826</td>
<td>1.452</td>
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#### Variable .. CZP3B3

<table>
<thead>
<tr>
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<th>N</th>
</tr>
</thead>
<tbody>
<tr>
<td>-.024</td>
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</table>

* * * * * * * Analysis of Variance -- design 1 * * * * *

Cell Means and Standard Deviations (Cont.)

#### Variable .. C4P3B3

<table>
<thead>
<tr>
<th>Mean</th>
<th>Std. Dev.</th>
<th>N</th>
</tr>
</thead>
<tbody>
<tr>
<td>.935</td>
<td>1.534</td>
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#### Variable .. P3P3B3

<table>
<thead>
<tr>
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<th>N</th>
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<tbody>
<tr>
<td>1.393</td>
<td>1.564</td>
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#### Variable .. P2P3B3

<table>
<thead>
<tr>
<th>Mean</th>
<th>Std. Dev.</th>
<th>N</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.494</td>
<td>1.834</td>
<td>20</td>
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</table>

#### Variable .. P4P3B3

<table>
<thead>
<tr>
<th>Mean</th>
<th>Std. Dev.</th>
<th>N</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.658</td>
<td>1.748</td>
<td>20</td>
</tr>
</tbody>
</table>

* * * * * * * Analysis of Variance -- design 1 * * * * *

Tests involving 'TASK' Within-Subject Effect.
Tests of Significance for T2 using UNIQUE sums of squares
Source of Variation | SS   | DF  | MS   | F   | Sig of F
---------------------|------|-----|------|-----|----------
WITHIN CELLS         | 133.41| 19  | 7.02 |    |          
TASK                 | 2.63 | 1   | 2.63 | .37 | .548     

EFFECT .. TASK BY FRTOPOS (Cont.)
Univariate F-tests with (1,19) D. F.
<table>
<thead>
<tr>
<th>Variable</th>
<th>Hypoth. SS</th>
<th>Error SS</th>
<th>Hypoth. MS</th>
<th>Error MS</th>
<th>F</th>
<th>Sig. of F</th>
</tr>
</thead>
<tbody>
<tr>
<td>T7</td>
<td>9.30672</td>
<td>60.92889</td>
<td>9.30672</td>
<td>3.20678</td>
<td>2.90220</td>
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<tr>
<td>T8</td>
<td>1.49072</td>
<td>11.90499</td>
<td>1.49072</td>
<td>.62658</td>
<td>2.37915</td>
<td>.139</td>
</tr>
</tbody>
</table>

EFFECT .. TASK BY LATERAL (Cont.)
Univariate F-tests with (1,19) D. F.
<table>
<thead>
<tr>
<th>Variable</th>
<th>Hypoth. SS</th>
<th>Error SS</th>
<th>Hypoth. MS</th>
<th>Error MS</th>
<th>F</th>
<th>Sig. of F</th>
</tr>
</thead>
<tbody>
<tr>
<td>T9</td>
<td>.00048</td>
<td>11.98459</td>
<td>.00048</td>
<td>.63077</td>
<td>.00077</td>
<td>.978</td>
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</table>

EFFECT .. TASK BY FRTOPOS BY LATERAL (Cont.)
Univariate F-tests with (1,19) D. F.
<table>
<thead>
<tr>
<th>Variable</th>
<th>Hypoth. SS</th>
<th>Error SS</th>
<th>Hypoth. MS</th>
<th>Error MS</th>
<th>F</th>
<th>Sig. of F</th>
</tr>
</thead>
<tbody>
<tr>
<td>T15</td>
<td>.57963</td>
<td>3.35246</td>
<td>.57963</td>
<td>.17645</td>
<td>3.28501</td>
<td>.086</td>
</tr>
<tr>
<td>T16</td>
<td>.48348</td>
<td>3.55112</td>
<td>.48348</td>
<td>.18690</td>
<td>2.58683</td>
<td>.124</td>
</tr>
<tr>
<td>T17</td>
<td>.00451</td>
<td>2.47467</td>
<td>.00451</td>
<td>.13025</td>
<td>.03460</td>
<td>.854</td>
</tr>
<tr>
<td>T18</td>
<td>.93466</td>
<td>2.66431</td>
<td>.93466</td>
<td>.14023</td>
<td>6.66534</td>
<td>.018</td>
</tr>
</tbody>
</table>

P250 Inter-modal vs. Single tone

Cell Means and Standard Deviations
<table>
<thead>
<tr>
<th>Variable</th>
<th>Mean</th>
<th>Std. Dev.</th>
<th>N</th>
</tr>
</thead>
<tbody>
<tr>
<td>F3P3A1</td>
<td>.909</td>
<td>.594</td>
<td>20</td>
</tr>
<tr>
<td>FZP3A1</td>
<td>1.143</td>
<td>.712</td>
<td>20</td>
</tr>
<tr>
<td>F4P3A1</td>
<td>.971</td>
<td>.592</td>
<td>20</td>
</tr>
<tr>
<td>C3P3A1</td>
<td>.973</td>
<td>.695</td>
<td>20</td>
</tr>
<tr>
<td>CZP3A1</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Variable</td>
<td>Mean</td>
<td>Std. Dev.</td>
<td>N</td>
</tr>
<tr>
<td>---------------</td>
<td>-------</td>
<td>-----------</td>
<td>----</td>
</tr>
<tr>
<td>C4P3A1</td>
<td>1.310</td>
<td>.798</td>
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</table>

**Analysis of Variance -- design 1**

Cell Means and Standard Deviations (Cont.)

<table>
<thead>
<tr>
<th>Variable</th>
<th>Mean</th>
<th>Std. Dev.</th>
<th>N</th>
</tr>
</thead>
<tbody>
<tr>
<td>P3P3A1</td>
<td>1.043</td>
<td>.677</td>
<td>20</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Variable</th>
<th>Mean</th>
<th>Std. Dev.</th>
<th>N</th>
</tr>
</thead>
<tbody>
<tr>
<td>P2P3A1</td>
<td>.782</td>
<td>.625</td>
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<table>
<thead>
<tr>
<th>Variable</th>
<th>Mean</th>
<th>Std. Dev.</th>
<th>N</th>
</tr>
</thead>
<tbody>
<tr>
<td>P4P3A1</td>
<td>.944</td>
<td>.647</td>
<td>20</td>
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</tbody>
</table>

<table>
<thead>
<tr>
<th>Variable</th>
<th>Mean</th>
<th>Std. Dev.</th>
<th>N</th>
</tr>
</thead>
<tbody>
<tr>
<td>F3P3A1</td>
<td>.820</td>
<td>.587</td>
<td>20</td>
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</table>

<table>
<thead>
<tr>
<th>Variable</th>
<th>Mean</th>
<th>Std. Dev.</th>
<th>N</th>
</tr>
</thead>
<tbody>
<tr>
<td>F2P3A1</td>
<td>.961</td>
<td>.673</td>
<td>20</td>
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</tbody>
</table>

<table>
<thead>
<tr>
<th>Variable</th>
<th>Mean</th>
<th>Std. Dev.</th>
<th>N</th>
</tr>
</thead>
<tbody>
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<td>1.148</td>
<td>.826</td>
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<table>
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<th>Std. Dev.</th>
<th>N</th>
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<tbody>
<tr>
<td>C3P3A3</td>
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<table>
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<th>Variable</th>
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<tbody>
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**Analysis of Variance -- design 1**

Cell Means and Standard Deviations (Cont.)

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<tr>
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<tr>
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**Analysis of Variance -- design 1**

Tests involving 'TASK' Within-Subject Effect.

Tests of Significance for T2 using UNIQUE sums of squares

<table>
<thead>
<tr>
<th>Source of Variation</th>
<th>SS</th>
<th>DF</th>
<th>MS</th>
<th>F</th>
<th>Sig of F</th>
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<tbody>
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**EFFECT .. TASK BY FRTOPOS (Cont.)**

Univariate F-tests with (1,19) D. F.

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<th>Variable</th>
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<th>Error SS</th>
<th>Hypoth. MS</th>
<th>Error MS</th>
<th>F</th>
<th>Sig. of F</th>
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</thead>
<tbody>
<tr>
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**EFFECT .. TASK BY LATERAL (Cont.)**

Univariate F-tests with (1,19) D. F.

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<th>Hypoth. MS</th>
<th>Error MS</th>
<th>F</th>
<th>Sig. of F</th>
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<tbody>
<tr>
<td>T9</td>
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**EFFECT .. TASK BY FRTOPOS BY LATERAL (Cont.)**

Univariate F-tests with (1,19) D. F.

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<tr>
<th>Variable</th>
<th>Hypoth. SS</th>
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<th>Hypoth. MS</th>
<th>Error MS</th>
<th>F</th>
<th>Sig. of F</th>
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<tbody>
<tr>
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<tr>
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**P200 Inter-modal vs. Single tone**

Cell Means and Standard Deviations

<table>
<thead>
<tr>
<th>Variable</th>
<th>F3P21</th>
<th>Mean</th>
<th>Std. Dev.</th>
<th>N</th>
</tr>
</thead>
<tbody>
<tr>
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<table>
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<th>Mean</th>
<th>Std. Dev.</th>
<th>N</th>
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<tr>
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<table>
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<th>Std. Dev.</th>
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<tr>
<td>Variable</td>
<td>Mean</td>
<td>Std. Dev.</td>
<td>N</td>
<td></td>
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<tr>
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<tr>
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<td>.434</td>
<td>20</td>
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<tr>
<td>PZP21</td>
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<td>.585</td>
<td>20</td>
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<tr>
<td>P4P21</td>
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<td>.490</td>
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<td>F3P23</td>
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** Analysis of Variance -- design 1 **

Cell Means and Standard Deviations (Cont.)
<table>
<thead>
<tr>
<th>Variable</th>
<th>Mean</th>
<th>Std. Dev.</th>
<th>N</th>
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<tbody>
<tr>
<td>F3P21</td>
<td>.769</td>
<td>.434</td>
<td>20</td>
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<tr>
<td>F2P21</td>
<td>.997</td>
<td>.585</td>
<td>20</td>
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<td>F4P21</td>
<td>.818</td>
<td>.490</td>
<td>20</td>
</tr>
<tr>
<td>F3P23</td>
<td>.756</td>
<td>.431</td>
<td>20</td>
</tr>
<tr>
<td>F2P23</td>
<td>.856</td>
<td>.530</td>
<td>20</td>
</tr>
<tr>
<td>F4P23</td>
<td>.793</td>
<td>.400</td>
<td>20</td>
</tr>
</tbody>
</table>

** Analysis of Variance -- design 1 **
Variable .. P3P23
For entire sample
Mean  Std. Dev.          N
.794       .447         20

Variable .. P2P23
For entire sample
Mean  Std. Dev.          N
1.033       .584         20

Variable .. P4P23
For entire sample
Mean  Std. Dev.          N
.816       .509         20

** Analysis of Variance -- design 1 **

Tests involving 'TASK' Within-Subject Effect.
Tests of Significance for T2 using UNIQUE sums of squares

<table>
<thead>
<tr>
<th>Source of Variation</th>
<th>SS</th>
<th>DF</th>
<th>MS</th>
<th>F</th>
<th>Sig of F</th>
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<tbody>
<tr>
<td>WITHIN CELLS</td>
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EFFECT .. TASK BY FRTOPOS (Cont.)
Univariate F-tests with (1,19) D. F.

<table>
<thead>
<tr>
<th>Variable</th>
<th>Hypoth. SS</th>
<th>Error SS</th>
<th>Hypoth. MS</th>
<th>Error MS</th>
<th>F</th>
<th>Sig. of F</th>
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<tbody>
<tr>
<td>T7</td>
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<td>.14626</td>
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EFFECT .. TASK BY LATERAL (Cont.)
Univariate F-tests with (1,19) D. F.

<table>
<thead>
<tr>
<th>Variable</th>
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<th>Error SS</th>
<th>Hypoth. MS</th>
<th>Error MS</th>
<th>F</th>
<th>Sig. of F</th>
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<tbody>
<tr>
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<td>.52470</td>
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EFFECT .. TASK BY FRTOPOS BY LATERAL (Cont.)
Univariate F-tests with (1,19) D. F.

<table>
<thead>
<tr>
<th>Variable</th>
<th>Hypoth. SS</th>
<th>Error SS</th>
<th>Hypoth. MS</th>
<th>Error MS</th>
<th>F</th>
<th>Sig. of F</th>
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** N130 Inter-modal vs. Single tone **

Cell Means and Standard Deviations
Variable .. F3N1T1
For entire sample
Mean  Std. Dev.          N
-1.046       .967         20
<table>
<thead>
<tr>
<th>Variable ..</th>
<th>Mean</th>
<th>Std. Dev.</th>
<th>N</th>
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<tbody>
<tr>
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<tr>
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<td>C3N1T1</td>
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<tr>
<td>CZN1T1</td>
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<td>1.134</td>
<td>20</td>
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<tr>
<td>C4N1T1</td>
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<td>1.003</td>
<td>20</td>
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<tr>
<td>P3N1T1</td>
<td>-.816</td>
<td>.633</td>
<td>20</td>
</tr>
<tr>
<td>PZN1T1</td>
<td>-.798</td>
<td>.732</td>
<td>20</td>
</tr>
<tr>
<td>P4N1T1</td>
<td>-.720</td>
<td>.770</td>
<td>20</td>
</tr>
<tr>
<td>F3N1T3</td>
<td>-1.002</td>
<td>.613</td>
<td>20</td>
</tr>
<tr>
<td>FZN1T3</td>
<td>-1.063</td>
<td>.682</td>
<td>20</td>
</tr>
<tr>
<td>F4N1T3</td>
<td>-1.010</td>
<td>.605</td>
<td>20</td>
</tr>
<tr>
<td>C3N1T3</td>
<td>-1.157</td>
<td>.689</td>
<td>20</td>
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<tr>
<td>CZN1T3</td>
<td>-1.184</td>
<td>1.134</td>
<td>20</td>
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**Analysis of Variance -- design 1**

Cell Means and Standard Deviations (Cont.)

<table>
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<tr>
<th>Variable ..</th>
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<th>Std. Dev.</th>
<th>N</th>
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</thead>
<tbody>
<tr>
<td>F3N1T1</td>
<td>-.816</td>
<td>.633</td>
<td>20</td>
</tr>
<tr>
<td>P2N1T1</td>
<td>-.798</td>
<td>.732</td>
<td>20</td>
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<tr>
<td>P4N1T1</td>
<td>-.720</td>
<td>.770</td>
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<td>F3N1T3</td>
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<td>F2N1T3</td>
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**Analysis of Variance -- design 1**

### Cell Means and Standard Deviations (Cont.)

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<th>Std. Dev.</th>
<th>N</th>
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</thead>
<tbody>
<tr>
<td>For entire sample</td>
<td>-1.050</td>
<td>.625</td>
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<table>
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<th>Std. Dev.</th>
<th>N</th>
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<tbody>
<tr>
<td>For entire sample</td>
<td>-1.050</td>
<td>.625</td>
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<table>
<thead>
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<th>Std. Dev.</th>
<th>N</th>
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<tbody>
<tr>
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<td>-1.050</td>
<td>.625</td>
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**Tests involving 'TASK' Within-Subject Effect.**

<table>
<thead>
<tr>
<th>Source of Variation</th>
<th>SS</th>
<th>DF</th>
<th>MS</th>
<th>F</th>
<th>Sig of F</th>
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<tbody>
<tr>
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**EFFECT .. TASK BY FRTOPOS (Cont.)**

<table>
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<th>Error SS</th>
<th>Hypoth. MS</th>
<th>Error MS</th>
<th>F</th>
<th>Sig. of F</th>
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**EFFECT .. TASK BY LATERAL (Cont.)**

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<th>Error SS</th>
<th>Hypoth. MS</th>
<th>Error MS</th>
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<th>Sig. of F</th>
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**EFFECT .. TASK BY FRTOPOs BY LATERAL (Cont.)**

<table>
<thead>
<tr>
<th>Variable</th>
<th>Hypoth. SS</th>
<th>Error SS</th>
<th>Hypoth. MS</th>
<th>Error MS</th>
<th>F</th>
<th>Sig. of F</th>
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</thead>
<tbody>
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<tr>
<td>T16</td>
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<td>.01249</td>
<td>.04540</td>
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<tr>
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### N100 Inter-modal vs. Single tone

#### Cell Means and Standard Deviations

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<td>For entire sample</td>
<td>-1.055</td>
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* * * * * A n a l y s i s   o f   V a r i a n c e -- design 1 * * * * *

#### Cell Means and Standard Deviations (Cont.)

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<td>1.291</td>
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Variable .. F4N1V3
For entire sample
-1.124     .566        20

Variable .. C3N1V3
For entire sample
-1.089     .539        20

Variable .. CZN1V3
For entire sample
-1.135     .617        20

** ** ** ** Analysis of Variance -- design 1 ** ** ** **

Cell Means and Standard Deviations (Cont.)
Variable .. C4N1V3
For entire sample
-1.019     .517        20

Variable .. P3N1V3
For entire sample
-.557      .411        20

Variable .. P2N1V3
For entire sample
-.699      .424        20

Variable .. P4N1V3
For entire sample
-.645      .392        20

** ** ** ** Analysis of Variance -- design 1 ** ** ** **

Tests involving 'TASK' Within-Subject Effect.
Tests of Significance for T2 using UNIQUE sums of squares
Source of Variation          SS      DF        MS         F  Sig of F
WITHIN CELLS              14.69      19       .77
TASK                        .00       1       .00       .00      .983

Effect .. TASK BY FRTOPOS (Cont.)
Univariate F-tests with (1,19) D. F.
Variable   Hypoth. SS   Error SS Hypoth. MS   Error MS          F  Sig. of F
T7             .00027    7.93416     .00027     .41759     .00065       .980
T8             .00684    1.51185     .00684     .07957     .08602       .772

Effect .. TASK BY LATERAL (Cont.)
Univariate F-tests with (1,19) D. F.
Variable   Hypoth. SS   Error SS Hypoth. MS   Error MS          F  Sig. of F
T9             .08205    2.00066     .08205     .10530     .77925       .388
T10            .03532     .49162     .03532     .02587    1.36493       .257

Effect .. TASK BY FRTOPOS BY LATERAL (Cont.)
Univariate F-tests with (1,19) D. F.
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<th>Error SS</th>
<th>Hypoth. MS</th>
<th>Error MS</th>
<th>F</th>
<th>Sig. of F</th>
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**P350 Inter-modal vs. Auditory oddball**

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Variable .. F3PNC1

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Variable .. F2PNC1

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Variable .. C3PNC1

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Variable .. C2PNC1

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Variable .. C4PNC1

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* * * * * Analysis of Variance -- design 1 * * * * *

Variable .. F3PNC1

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Variable .. F2PNC1

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Variable .. F4PNC1

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### Analysis of Variance -- design 1

**Tests involving 'TASK' Within-Subject Effect.**

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**EFFECT .. TASK BY FRTOPOS (Cont.)**

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<th>Hypoth. MS</th>
<th>Error MS</th>
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**EFFECT .. TASK BY LATERAL (Cont.)**
Univariate F-tests with (1,19) D. F.

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<tr>
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<th>Error MS</th>
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EFFECT . TASK BY FRTOPOS BY LATERAL (Cont.)

Univariate F-tests with (1,19) D. F.

<table>
<thead>
<tr>
<th>Variable</th>
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P300 Inter-modal vs. Auditory oddball

- - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - -

Cell Means and Standard Deviations

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<th>Mean</th>
<th>Std. Dev.</th>
<th>N</th>
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<tbody>
<tr>
<td>For entire sample</td>
<td>.842</td>
<td>.846</td>
<td>20</td>
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<th>N</th>
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<tr>
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** * * * * * Analysis of Variance -- design 1 * * * * * **

Cell Means and Standard Deviations (Cont.)

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<th>Std. Dev.</th>
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- - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - -
Mean  Std. Dev.          N
For entire sample                          1.264       .700         20
                           - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - -
Variable .. P4P3B1  Mean Std. Dev.          N
For entire sample                          1.160       .628         20
                           - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - -
Variable .. F3P3B2  Mean Std. Dev.          N
For entire sample                           .969       .490         20
                           - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - -
Variable .. FZP3B2  Mean Std. Dev.          N
For entire sample                          1.147       .523         20
                           - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - -
Variable .. F4P3B2  Mean Std. Dev.          N
For entire sample                          1.070       .512         20
                           - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - -
Variable .. C3P3B2  Mean Std. Dev.          N
For entire sample                          1.029       .545         20
                           - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - -
Variable .. CZP3B2  Mean Std. Dev.          N
For entire sample                           .925       .681         20
                           - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - -
Variable .. P3P3B2  Mean Std. Dev.          N
For entire sample                          1.029       .545         20
                           - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - -
Variable .. PZP3B2  Mean Std. Dev.          N
For entire sample                          1.070       .512         20
                           - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - -
Variable .. P4P3B2  Mean Std. Dev.          N
For entire sample                           .925       .681         20
                           - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - -
* * * * * * A n a l y s i s   o f   V a r i a n c e -- design 1 * * * * * *

Cell Means and Standard Deviations (Cont.)
Variable .. C4P3B2  Mean Std. Dev.          N
For entire sample                          1.029       .545         20
                           - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - -
Variable .. P3P3B2  Mean Std. Dev.          N
For entire sample                           .925       .681         20
                           - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - -
Variable .. P2P3B2  Mean Std. Dev.          N
For entire sample                           .974       .678         20
                           - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - -
Variable .. P4P3B2  Mean Std. Dev.          N
For entire sample                          1.029       .545         20
                           - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - -
* * * * * * A n a l y s i s   o f   V a r i a n c e -- design 1 * * * * * *

Tests involving 'TASK' Within-Subject Effect.
Tests of Significance for T2 using UNIQUE sums of squares
Source of Variation  SS  DF  MS  F  Sig of F
WITHIN CELLS         38.17  19  2.01  -  -
TASK                 .01  1  .01  .00  .954
                           - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - -
EFFECT TASK BY FRTOPOS (Cont.)
Univariate F-tests with (1,19) D. F.

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<th>Error MS</th>
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EFFECT TASK BY LATERAL (Cont.)
Univariate F-tests with (1,19) D. F.

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EFFECT TASK BY FRTOPOS BY LATERAL (Cont.)
Univariate F-tests with (1,19) D. F.

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<th>Hypoth. MS</th>
<th>Error MS</th>
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<td>.01079</td>
<td>.01413</td>
<td>.76343</td>
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P250 Inter-modal vs. Auditory oddball

Cell Means and Standard Deviations

<table>
<thead>
<tr>
<th>Variable</th>
<th>Mean</th>
<th>Std. Dev.</th>
<th>N</th>
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<tbody>
<tr>
<td>F3P3A1</td>
<td>.909</td>
<td>.594</td>
<td>20</td>
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<tr>
<td>F2P3A1</td>
<td>1.143</td>
<td>.712</td>
<td>20</td>
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<tr>
<td>F4P3A1</td>
<td>.971</td>
<td>.592</td>
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<td>.677</td>
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<td>Std. Dev.</td>
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<tr>
<td>P2P3A1</td>
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<tr>
<td>P4P3A1</td>
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<td>F3P3A2</td>
<td>0.672</td>
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<td>FZP3A2</td>
<td>0.881</td>
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<td>F4P3A2</td>
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<td>PZP3A2</td>
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<td>0.529</td>
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<td>P4P3A2</td>
<td>0.938</td>
<td>0.505</td>
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</table>
### Analysis of Variance -- design 1

Tests involving 'TASK' Within-Subject Effect.

Tests of Significance for T2 using UNIQUE sums of squares

<table>
<thead>
<tr>
<th>Source of Variation</th>
<th>SS</th>
<th>DF</th>
<th>MS</th>
<th>F</th>
<th>Sig of F</th>
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EFFECT .. TASK BY FRTOPOS (Cont.)

Univariate F-tests with (1,19) D. F.

<table>
<thead>
<tr>
<th>Variable</th>
<th>Hypoth. SS</th>
<th>Error SS</th>
<th>Hypoth. MS</th>
<th>Error MS</th>
<th>F</th>
<th>Sig. of F</th>
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<tbody>
<tr>
<td>T7</td>
<td>2.49060</td>
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<td>.48519</td>
<td>.14362</td>
<td>.02553</td>
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EFFECT .. TASK BY LATERAL (Cont.)

Univariate F-tests with (1,19) D. F.

<table>
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<th>Hypoth. SS</th>
<th>Error SS</th>
<th>Hypoth. MS</th>
<th>Error MS</th>
<th>F</th>
<th>Sig. of F</th>
</tr>
</thead>
<tbody>
<tr>
<td>T9</td>
<td>.04372</td>
<td>.51394</td>
<td>.04372</td>
<td>.02705</td>
<td>1.61618</td>
<td>.219</td>
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<td>T10</td>
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<td>.03247</td>
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EFFECT .. TASK BY FRTOPOS BY LATERAL (Cont.)

Univariate F-tests with (1,19) D. F.

<table>
<thead>
<tr>
<th>Variable</th>
<th>Hypoth. SS</th>
<th>Error SS</th>
<th>Hypoth. MS</th>
<th>Error MS</th>
<th>F</th>
<th>Sig. of F</th>
</tr>
</thead>
<tbody>
<tr>
<td>T15</td>
<td>.04906</td>
<td>.26444</td>
<td>.04906</td>
<td>.01392</td>
<td>3.52527</td>
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<td>T16</td>
<td>.00014</td>
<td>.24950</td>
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<td>T17</td>
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<td>.07528</td>
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**P200 Inter-modal vs. Auditory oddball**

Cell Means and Standard Deviations

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<thead>
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<th>Variable .. F3P21</th>
<th>Mean</th>
<th>Std. Dev.</th>
<th>N</th>
</tr>
</thead>
<tbody>
<tr>
<td>For entire sample</td>
<td>.799</td>
<td>.496</td>
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<table>
<thead>
<tr>
<th>Variable .. F2P21</th>
<th>Mean</th>
<th>Std. Dev.</th>
<th>N</th>
</tr>
</thead>
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<tr>
<td>For entire sample</td>
<td>.859</td>
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</table>

<table>
<thead>
<tr>
<th>Variable .. F4P21</th>
<th>Mean</th>
<th>Std. Dev.</th>
<th>N</th>
</tr>
</thead>
<tbody>
<tr>
<td>For entire sample</td>
<td>.832</td>
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</table>

<table>
<thead>
<tr>
<th>Variable .. C3P21</th>
<th>Mean</th>
<th>Std. Dev.</th>
<th>N</th>
</tr>
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<tbody>
<tr>
<td>For entire sample</td>
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<td>Variable ..</td>
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<td>Std. Dev.</td>
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<tr>
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<td>For entire</td>
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<tr>
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<table>
<thead>
<tr>
<th>Variable ..</th>
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<tbody>
<tr>
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### Analysis of Variance -- design 1

Cell Means and Standard Deviations  (Cont.)

<table>
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<th>Variable ..</th>
<th>Mean</th>
<th>Std. Dev.</th>
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<tbody>
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<table>
<thead>
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<th>Mean</th>
<th>Std. Dev.</th>
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<tr>
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<tr>
<td>For entire</td>
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<table>
<thead>
<tr>
<th>Variable ..</th>
<th>Mean</th>
<th>Std. Dev.</th>
<th>N</th>
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<tbody>
<tr>
<td>P4P21</td>
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<td>.970</td>
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<tr>
<td>sample</td>
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<table>
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<tr>
<th>Variable ..</th>
<th>Mean</th>
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<tr>
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<td>sample</td>
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<table>
<thead>
<tr>
<th>Variable ..</th>
<th>Mean</th>
<th>Std. Dev.</th>
<th>N</th>
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<tbody>
<tr>
<td>FZP22</td>
<td>.929</td>
<td>.773</td>
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<tr>
<td>For entire</td>
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<td></td>
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<tr>
<td>sample</td>
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</tbody>
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<table>
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<th>Variable ..</th>
<th>Mean</th>
<th>Std. Dev.</th>
<th>N</th>
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<tbody>
<tr>
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<td>.929</td>
<td>.773</td>
<td>20</td>
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<tr>
<td>For entire</td>
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<td></td>
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<tr>
<td>sample</td>
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<td>.970</td>
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<tr>
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### Analysis of Variance -- design 1

Cell Means and Standard Deviations  (Cont.)

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<table>
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<tr>
<th>Variable ..</th>
<th>Mean</th>
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<th>N</th>
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</thead>
<tbody>
<tr>
<td>P3P22</td>
<td>.929</td>
<td>.773</td>
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<tr>
<td>For entire</td>
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<tr>
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<tbody>
<tr>
<td>P2P22</td>
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<td>.773</td>
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<tr>
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<tr>
<td>sample</td>
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</table>
**Analysis of Variance -- design 1**

Tests involving 'TASK' Within-Subject Effect.

Tests of Significance for T2 using UNIQUE sums of squares

<table>
<thead>
<tr>
<th>Source of Variation</th>
<th>SS</th>
<th>DF</th>
<th>MS</th>
<th>F</th>
<th>Sig of F</th>
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<tbody>
<tr>
<td>WITHIN CELLS</td>
<td>58.32</td>
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<td>3.07</td>
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**N130 Inter-modal vs. Auditory oddball**

Cell Means and Standard Deviations

<table>
<thead>
<tr>
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<th>Mean</th>
<th>Std. Dev.</th>
<th>N</th>
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<tbody>
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<th>Std. Dev.</th>
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<tbody>
<tr>
<td>For entire sample</td>
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</tr>
<tr>
<td>Variable .. C3N1T1</td>
<td>Mean</td>
<td>Std. Dev.</td>
<td>N</td>
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<td>--------------------</td>
<td>-------</td>
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<td>Variable .. CZN1T1</td>
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<td>N</td>
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** * * * * * Analysis of Variance -- design 1 * * * * * **

<table>
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<th>Std. Dev.</th>
<th>N</th>
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<tr>
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<tr>
<td>Variable .. P2N1T1</td>
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<td>Std. Dev.</td>
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<td>Variable .. P4N1T1</td>
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<td>Std. Dev.</td>
<td>N</td>
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** * * * * * Analysis of Variance -- design 1 * * * * * **

<table>
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<th>N</th>
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<td>-.582</td>
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</table>
### Variable: P3N1T2
- **Mean:** -.832
- **Std. Dev.:** 1.280
- **N:** 20

### Variable: P2N1T2
- **Mean:** -.441
- **Std. Dev.:** 1.052
- **N:** 20

### Variable: P4N1T2
- **Mean:** -.313
- **Std. Dev.:** .935
- **N:** 20

### Analysis of Variance -- design 1

#### Tests involving 'TASK' Within-Subject Effect.

<table>
<thead>
<tr>
<th>Source of Variation</th>
<th>SS</th>
<th>DF</th>
<th>MS</th>
<th>F</th>
<th>Sig of F</th>
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<tbody>
<tr>
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#### Effect: TASK x FRTOPOS (Cont.)

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#### Effect: TASK x LATERAL (Cont.)

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#### Effect: TASK x FRTOPOS x LATERAL (Cont.)

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### N100 Inter-modal vs. Auditory oddball

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#### Cell Means and Standard Deviations

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**Analysis of Variance -- design 1**

Cell Means and Standard Deviations (Cont.)

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**Analysis of Variance -- design 1**

**Cell Means and Standard Deviations (Cont.)**

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**Analysis of Variance -- design 1**

**Tests involving 'TASK' Within-Subject Effect.**

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**EFFECT .. TASK BY FRTOPOS (Cont.)**

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<th>Hypoth. MS</th>
<th>Error MS</th>
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<th>Sig. of F</th>
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<tbody>
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**EFFECT .. TASK BY LATERAL (Cont.)**

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<th>Hypoth. MS</th>
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<th>Sig. of F</th>
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<tbody>
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**EFFECT .. TASK BY FRTOPOS BY LATERAL (Cont.)**

<table>
<thead>
<tr>
<th>Variable</th>
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<th>Hypoth. MS</th>
<th>Error MS</th>
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Latency and Topographic analysis

P3b topography – inter-modal oddball amplitudes

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<th>N</th>
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Univariate F-tests with (1,19) D.F.

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<th>Hypoth. MS</th>
<th>Error MS</th>
<th>F</th>
<th>Sig. of F</th>
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<tbody>
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EFFECT .. LATERAL (Cont.)
## Univariate F-tests with (1,19) D. F.

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<th>Hypoth. MS</th>
<th>Error MS</th>
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<th>Sig. of F</th>
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EFFECT .. FRTOPOS BY LATERAL (Cont.)

## Univariate F-tests with (1,19) D. F.

<table>
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<th>Hypoth. MS</th>
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### P3a topography – inter-modal oddball amplitudes

#### Cell Means and Standard Deviations

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### EFFECT .. FRTOPOS (Cont.)
Univariate F-tests with (1,19) D. F.

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<th>Error MS</th>
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### EFFECT .. LATERAL (Cont.)
Univariate F-tests with (1,19) D. F.

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<th>Hypoth. MS</th>
<th>Error MS</th>
<th>F</th>
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### EFFECT .. FRTOPOS BY LATERAL (Cont.)
Univariate F-tests with (1,19) D. F.

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<th>Hypoth. MS</th>
<th>Error MS</th>
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<tbody>
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<td>1.69265</td>
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### P200 topography – inter-modal oddball amplitudes

Cell Means and Standard Deviations

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</tbody>
</table>

<table>
<thead>
<tr>
<th>Variable .. F4P21</th>
<th>Mean</th>
<th>Std. Dev.</th>
<th>N</th>
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</thead>
<tbody>
<tr>
<td>For entire sample</td>
<td>198.500</td>
<td>16.246</td>
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</tbody>
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<table>
<thead>
<tr>
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<th>Mean</th>
<th>Std. Dev.</th>
<th>N</th>
</tr>
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<tbody>
<tr>
<td>For entire sample</td>
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<td>10.894</td>
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<table>
<thead>
<tr>
<th>Variable .. C2P21</th>
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</tr>
</thead>
<tbody>
<tr>
<td>For entire sample</td>
<td>198.600</td>
<td>14.129</td>
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<table>
<thead>
<tr>
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<tr>
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<td>198.600</td>
<td>14.129</td>
<td>20</td>
</tr>
<tr>
<td></td>
<td>Mean</td>
<td>Std. Dev.</td>
<td>N</td>
</tr>
<tr>
<td>----------</td>
<td>--------</td>
<td>-----------</td>
<td>----</td>
</tr>
<tr>
<td>F3N1T1</td>
<td>134.500</td>
<td>12.513</td>
<td>20</td>
</tr>
<tr>
<td>FZN1T1</td>
<td>133.700</td>
<td>10.428</td>
<td>20</td>
</tr>
<tr>
<td>F4N1T1</td>
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**N130 topography – inter-modal oddball amplitudes**

<table>
<thead>
<tr>
<th></th>
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<th>Std. Dev.</th>
<th>N</th>
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<tbody>
<tr>
<td>F3N1T1</td>
<td>134.500</td>
<td>12.513</td>
<td>20</td>
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<tr>
<td>FZN1T1</td>
<td>133.700</td>
<td>10.428</td>
<td>20</td>
</tr>
<tr>
<td>F4N1T1</td>
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</tbody>
</table>
**Analysis of Variance -- design 1**

Cell Means and Standard Deviations (Cont.)

<table>
<thead>
<tr>
<th>Variable .. P3N1T1</th>
<th>Mean</th>
<th>Std. Dev.</th>
<th>N</th>
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<tbody>
<tr>
<td>For entire sample</td>
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</table>

<table>
<thead>
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<th>Std. Dev.</th>
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<tbody>
<tr>
<td>For entire sample</td>
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<table>
<thead>
<tr>
<th>Variable .. P4N1T1</th>
<th>Mean</th>
<th>Std. Dev.</th>
<th>N</th>
</tr>
</thead>
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<tr>
<td>For entire sample</td>
<td>130.400</td>
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</tbody>
</table>

**EFFECT .. FRTOPOS (Cont.)**

Univariate F-tests with (1,19) D. F.

<table>
<thead>
<tr>
<th>Variable</th>
<th>Hypoth. SS</th>
<th>Error SS</th>
<th>Hypoth. MS</th>
<th>Error MS</th>
<th>F</th>
<th>Sig. of F</th>
</tr>
</thead>
<tbody>
<tr>
<td>T2</td>
<td>730.13333</td>
<td>3073.86667</td>
<td>730.13333</td>
<td>161.78246</td>
<td>4.51306</td>
<td>.047</td>
</tr>
<tr>
<td>T3</td>
<td>139.37778</td>
<td>382.84444</td>
<td>139.37778</td>
<td>20.14971</td>
<td>6.91711</td>
<td>.016</td>
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</table>

**EFFECT .. LATERAL (Cont.)**

Univariate F-tests with (1,19) D. F.

<table>
<thead>
<tr>
<th>Variable</th>
<th>Hypoth. SS</th>
<th>Error SS</th>
<th>Hypoth. MS</th>
<th>Error MS</th>
<th>F</th>
<th>Sig. of F</th>
</tr>
</thead>
<tbody>
<tr>
<td>T4</td>
<td>.00000</td>
<td>260.00000</td>
<td>.00000</td>
<td>13.68421</td>
<td>.00000</td>
<td>1.000</td>
</tr>
<tr>
<td>T5</td>
<td>74.71111</td>
<td>292.84444</td>
<td>74.71111</td>
<td>15.41287</td>
<td>4.84732</td>
<td>.040</td>
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**EFFECT .. FRTOPOS BY LATERAL (Cont.)**

Univariate F-tests with (1,19) D. F.

<table>
<thead>
<tr>
<th>Variable</th>
<th>Hypoth. SS</th>
<th>Error SS</th>
<th>Hypoth. MS</th>
<th>Error MS</th>
<th>F</th>
<th>Sig. of F</th>
</tr>
</thead>
<tbody>
<tr>
<td>T6</td>
<td>33.80000</td>
<td>782.20000</td>
<td>33.80000</td>
<td>41.16842</td>
<td>.82102</td>
<td>.376</td>
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<tr>
<td>T7</td>
<td>91.26667</td>
<td>412.73333</td>
<td>91.26667</td>
<td>21.72281</td>
<td>4.20142</td>
<td>.054</td>
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<tr>
<td>T8</td>
<td>9.60000</td>
<td>270.40000</td>
<td>9.60000</td>
<td>14.23158</td>
<td>.67456</td>
<td>.422</td>
</tr>
<tr>
<td>T9</td>
<td>15.02222</td>
<td>88.08889</td>
<td>15.02222</td>
<td>4.63626</td>
<td>3.24016</td>
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### N100 topography – inter-modal oddball amplitudes

Cell Means and Standard Deviations

<table>
<thead>
<tr>
<th>Variable .. F3N1V1</th>
<th>Mean</th>
<th>Std. Dev.</th>
<th>N</th>
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<tbody>
<tr>
<td>For entire sample</td>
<td>100.400</td>
<td>9.144</td>
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</tbody>
</table>

<table>
<thead>
<tr>
<th>Variable .. FZN1V1</th>
<th>Mean</th>
<th>Std. Dev.</th>
<th>N</th>
</tr>
</thead>
<tbody>
<tr>
<td>For entire sample</td>
<td>103.700</td>
<td>4.555</td>
<td>20</td>
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</tbody>
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<table>
<thead>
<tr>
<th>Variable .. F4N1V1</th>
<th>Mean</th>
<th>Std. Dev.</th>
<th>N</th>
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<tr>
<td>For entire sample</td>
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<table>
<thead>
<tr>
<th>Variable .. C3N1V1</th>
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<th>Std. Dev.</th>
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</tr>
</thead>
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<tr>
<td>For entire sample</td>
<td>100.200</td>
<td>10.258</td>
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<table>
<thead>
<tr>
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<th>Mean</th>
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<tr>
<td>For entire sample</td>
<td>106.400</td>
<td>7.612</td>
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</table>

<table>
<thead>
<tr>
<th>Variable .. C4N1V1</th>
<th>Mean</th>
<th>Std. Dev.</th>
<th>N</th>
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</thead>
<tbody>
<tr>
<td>For entire sample</td>
<td>101.900</td>
<td>6.758</td>
<td>20</td>
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</tbody>
</table>

** * * * * Analysis of Variance -- design 1 * * * * *

Cell Means and Standard Deviations (Cont.)

<table>
<thead>
<tr>
<th>Variable .. P3N1V1</th>
<th>Mean</th>
<th>Std. Dev.</th>
<th>N</th>
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<tbody>
<tr>
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<td>101.000</td>
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<table>
<thead>
<tr>
<th>Variable .. PZN1V1</th>
<th>Mean</th>
<th>Std. Dev.</th>
<th>N</th>
</tr>
</thead>
<tbody>
<tr>
<td>For entire sample</td>
<td>102.600</td>
<td>11.109</td>
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<table>
<thead>
<tr>
<th>Variable .. P4N1V1</th>
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<th>Std. Dev.</th>
<th>N</th>
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</thead>
<tbody>
<tr>
<td>For entire sample</td>
<td>103.300</td>
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</tbody>
</table>

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EFFECT .. FRTOPOS (Cont.)

Univariate F-tests with (1,19) D. F.

<table>
<thead>
<tr>
<th>Variable</th>
<th>Hypoth. SS</th>
<th>Error SS</th>
<th>Hypoth. MS</th>
<th>Error MS</th>
<th>F</th>
<th>Sig. of F</th>
</tr>
</thead>
<tbody>
<tr>
<td>T2</td>
<td>26.13333</td>
<td>2656.53333</td>
<td>26.13333</td>
<td>139.81754</td>
<td>.18691</td>
<td>.670</td>
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<tr>
<td>T3</td>
<td>40.00000</td>
<td>391.11111</td>
<td>40.00000</td>
<td>20.58480</td>
<td>1.94318</td>
<td>.179</td>
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</table>

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EFFECT .. LATERAL (Cont.)
### Univariate F-tests with (1,19) D. F.

<table>
<thead>
<tr>
<th>Variable</th>
<th>Hypoth. SS</th>
<th>Error SS</th>
<th>Hypoth. MS</th>
<th>Error MS</th>
<th>F</th>
<th>Sig. of F</th>
</tr>
</thead>
<tbody>
<tr>
<td>T4</td>
<td>43.20000</td>
<td>443.46667</td>
<td>43.20000</td>
<td>23.34035</td>
<td>1.85087</td>
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<td>T5</td>
<td>384.40000</td>
<td>1242.71111</td>
<td>384.40000</td>
<td>65.40585</td>
<td>5.87715</td>
<td>.025</td>
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</table>

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**EFFECT .. FRTOPOS BY LATERAL (Cont.)**

### Univariate F-tests with (1,19) D. F.

<table>
<thead>
<tr>
<th>Variable</th>
<th>Hypoth. SS</th>
<th>Error SS</th>
<th>Hypoth. MS</th>
<th>Error MS</th>
<th>F</th>
<th>Sig. of F</th>
</tr>
</thead>
<tbody>
<tr>
<td>T6</td>
<td>36.45000</td>
<td>314.55000</td>
<td>36.45000</td>
<td>16.55526</td>
<td>2.20172</td>
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<tr>
<td>T7</td>
<td>62.01667</td>
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<td>1.93701</td>
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</tr>
<tr>
<td>T8</td>
<td>3.75000</td>
<td>226.58333</td>
<td>3.75000</td>
<td>11.92544</td>
<td>.31445</td>
<td>.582</td>
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<tr>
<td>T9</td>
<td>101.25000</td>
<td>367.97222</td>
<td>101.25000</td>
<td>19.36696</td>
<td>5.22798</td>
<td>.034</td>
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</table>

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**P350 topography – inter-modal oddball amplitudes**

### Cell Means and Standard Deviations

- **F3PNC1**
  - Mean: 345.500
  - Std. Dev.: 11.623
  - N: 20

- **FZPNC1**
  - Mean: 348.000
  - Std. Dev.: 13.219
  - N: 20

- **F4PNC1**
  - Mean: 346.700
  - Std. Dev.: 10.569
  - N: 20

- **C3PNC1**
  - Mean: 343.200
  - Std. Dev.: 11.020
  - N: 20

- **CZPNC1**
  - Mean: 343.800
  - Std. Dev.: 8.458
  - N: 20

- **C4PNC1**
  - Mean: 343.500
  - Std. Dev.: 8.870
  - N: 20

---

**Analysis of Variance -- design 1**

### Cell Means and Standard Deviations (Cont.)

- **F3PNC1**
  - Mean: 344.300
  - Std. Dev.: 12.231
  - N: 20

- **F2PNC1**
  - Mean: 348.000
  - Std. Dev.: 13.219
  - N: 20

- **F4PNC1**
  - Mean: 346.700
  - Std. Dev.: 10.569
  - N: 20

- **C3PNC1**
  - Mean: 343.200
  - Std. Dev.: 11.020
  - N: 20

- **C2PNC1**
  - Mean: 343.800
  - Std. Dev.: 8.458
  - N: 20

- **C4PNC1**
  - Mean: 343.500
  - Std. Dev.: 8.870
  - N: 20
Variable .. P4PNC1

Mean  Std. Dev.          N
For entire sample                        345.000      9.211         20

EFFECT .. FRTOPOS (Cont.)
Univariate F-tests with (1,19) D. F.

Variable   Hypoth. SS   Error SS Hypoth. MS   Error MS          F  Sig. of F
T2          140.83333 2234.50000  140.83333  117.60526    1.19751       .287
T3          184.90000  689.54444  184.90000   36.29181    5.09481       .036

EFFECT .. LATERAL (Cont.)
Univariate F-tests with (1,19) D. F.

Variable   Hypoth. SS   Error SS Hypoth. MS   Error MS          F  Sig. of F
T4           16.13333  731.86667   16.13333   38.51930     .41884       .525

EFFECT .. FRTOPOS BY LATERAL (Cont.)
Univariate F-tests with (1,19) D. F.

Variable   Hypoth. SS   Error SS Hypoth. MS   Error MS          F  Sig. of F
T6            1.25000  577.75000    1.25000   30.40789     .04111       .841
T7           30.81667  424.85000   30.81667   22.36053    1.37817       .255
T8           2.81667  450.18333    2.81667   23.69386     .11888       .734
T9            1.25000  677.30556    1.25000   35.64766     .03507       .853

Comparisons

P350 Inter-modal vs. Single tone

Cell Means and Standard Deviations

Variable .. F3PNC1

Mean  Std. Dev.          N
For entire sample                        345.500     11.623         20

Variable .. F2PNC1

Mean  Std. Dev.          N
For entire sample                        348.000     13.219         20

Variable .. F4PNC1

Mean  Std. Dev.          N
For entire sample                        346.700     10.569         20

Variable .. C3PNC1

Mean  Std. Dev.          N
For entire sample                        343.200     11.020         20
<table>
<thead>
<tr>
<th>Variable ..</th>
<th>Mean</th>
<th>Std. Dev.</th>
<th>N</th>
</tr>
</thead>
<tbody>
<tr>
<td>CZPNC1</td>
<td>343.800</td>
<td>8.458</td>
<td>20</td>
</tr>
<tr>
<td>C4PNC1</td>
<td>343.500</td>
<td>8.870</td>
<td>20</td>
</tr>
<tr>
<td>P3PNC1</td>
<td>344.300</td>
<td>12.231</td>
<td>20</td>
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<tr>
<td>PZPNC1</td>
<td>344.400</td>
<td>10.455</td>
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<td>P4PNC1</td>
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<td>9.211</td>
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<tr>
<td>F3PNC3</td>
<td>362.100</td>
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<td>FZPNC3</td>
<td>360.600</td>
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</tr>
<tr>
<td>F4PNC3</td>
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<tr>
<td>C3PNC3</td>
<td>358.000</td>
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<tr>
<td>CZPNC3</td>
<td>357.300</td>
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</table>

**Analysis of Variance -- design 1**

Cell Means and Standard Deviations (Cont.)

<table>
<thead>
<tr>
<th>Variable ..</th>
<th>Mean</th>
<th>Std. Dev.</th>
<th>N</th>
</tr>
</thead>
<tbody>
<tr>
<td>F3PNC1</td>
<td>344.300</td>
<td>12.231</td>
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</tr>
<tr>
<td>P2PNC1</td>
<td>344.400</td>
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<tr>
<td>P4PNC1</td>
<td>345.000</td>
<td>9.211</td>
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</tr>
<tr>
<td>F3PNC3</td>
<td>362.100</td>
<td>15.821</td>
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<tr>
<td>F2PNC3</td>
<td>360.600</td>
<td>17.340</td>
<td>20</td>
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<tr>
<td>F4PNC3</td>
<td>359.900</td>
<td>15.224</td>
<td>20</td>
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<tr>
<td>C3PNC3</td>
<td>358.000</td>
<td>18.422</td>
<td>20</td>
</tr>
<tr>
<td>C2PNC3</td>
<td>357.300</td>
<td>17.738</td>
<td>20</td>
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</table>

**Analysis of Variance -- design 1**

Cell Means and Standard Deviations (Cont.)

<table>
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<tr>
<th>Variable ..</th>
<th>Mean</th>
<th>Std. Dev.</th>
<th>N</th>
</tr>
</thead>
<tbody>
<tr>
<td>C4PNC3</td>
<td>353.100</td>
<td>18.035</td>
<td>20</td>
</tr>
<tr>
<td>P3PNC3</td>
<td>354.700</td>
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<tr>
<td>P2PNC3</td>
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<td>20</td>
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</table>
**Analysis of Variance -- design 1**

Tests involving 'TASK' Within-Subject Effect.

<table>
<thead>
<tr>
<th>Source of Variation</th>
<th>SS</th>
<th>DF</th>
<th>MS</th>
<th>F</th>
<th>Sig of F</th>
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<tbody>
<tr>
<td>WITHIN CELLS</td>
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<td>14313.61</td>
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**EFFECT .. TASK BY FRTOPOS (Cont.)**

Univariate F-tests with (1,19) D. F.

<table>
<thead>
<tr>
<th>Variable</th>
<th>Hypoth. SS</th>
<th>Error SS</th>
<th>Hypoth. MS</th>
<th>Error MS</th>
<th>F</th>
<th>Sig. of F</th>
</tr>
</thead>
<tbody>
<tr>
<td>T7</td>
<td>141.06667</td>
<td>3343.60000</td>
<td>141.06667</td>
<td>175.97895</td>
<td>.80161</td>
<td>.382</td>
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<tr>
<td>T8</td>
<td>.02222</td>
<td>791.75556</td>
<td>.02222</td>
<td>41.67135</td>
<td>.00053</td>
<td>.982</td>
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**EFFECT .. TASK BY LATERAL (Cont.)**

Univariate F-tests with (1,19) D. F.

<table>
<thead>
<tr>
<th>Variable</th>
<th>Hypoth. SS</th>
<th>Error SS</th>
<th>Hypoth. MS</th>
<th>Error MS</th>
<th>F</th>
<th>Sig. of F</th>
</tr>
</thead>
<tbody>
<tr>
<td>T9</td>
<td>74.81667</td>
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<td>7.60556</td>
<td>39.21959</td>
<td>.19392</td>
<td>.665</td>
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**EFFECT .. TASK BY FRTOPOS BY LATERAL (Cont.)**

Univariate F-tests with (1,19) D. F.

<table>
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<tr>
<th>Variable</th>
<th>Hypoth. SS</th>
<th>Error SS</th>
<th>Hypoth. MS</th>
<th>Error MS</th>
<th>F</th>
<th>Sig. of F</th>
</tr>
</thead>
<tbody>
<tr>
<td>T15</td>
<td>70.22500</td>
<td>387.27500</td>
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<td>20.38289</td>
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<tr>
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<td>7.00833</td>
<td>556.82500</td>
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<td>29.30658</td>
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<td>.630</td>
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<tr>
<td>T17</td>
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<td>506.49167</td>
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<td>26.65746</td>
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<tr>
<td>T18</td>
<td>36.73611</td>
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</table>

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**P300 Inter-modal vs. Single tone**

Cell Means and Standard Deviations

<table>
<thead>
<tr>
<th>Variable .. F3P3B1</th>
<th>Mean</th>
<th>Std. Dev.</th>
<th>N</th>
</tr>
</thead>
<tbody>
<tr>
<td>For entire sample</td>
<td>304.700</td>
<td>12.966</td>
<td>20</td>
</tr>
</tbody>
</table>

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<table>
<thead>
<tr>
<th>Variable .. FZP3B1</th>
<th>Mean</th>
<th>Std. Dev.</th>
<th>N</th>
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</thead>
<tbody>
<tr>
<td>For entire sample</td>
<td>305.700</td>
<td>16.030</td>
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</tr>
<tr>
<td>Variable</td>
<td>Mean</td>
<td>Std. Dev.</td>
<td>N</td>
</tr>
<tr>
<td>------------</td>
<td>------</td>
<td>-----------</td>
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</tr>
<tr>
<td>F4P3B1</td>
<td>304.300</td>
<td>15.400</td>
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<td>C3P3B1</td>
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<tr>
<td>C2P3B1</td>
<td>301.500</td>
<td>14.051</td>
<td>20</td>
</tr>
<tr>
<td>C4P3B1</td>
<td>303.900</td>
<td>14.903</td>
<td>20</td>
</tr>
<tr>
<td>P3P3B1</td>
<td>302.800</td>
<td>11.687</td>
<td>20</td>
</tr>
<tr>
<td>P2P3B1</td>
<td>303.100</td>
<td>14.119</td>
<td>20</td>
</tr>
<tr>
<td>P4P3B1</td>
<td>302.500</td>
<td>12.412</td>
<td>20</td>
</tr>
<tr>
<td>F3P3B3</td>
<td>314.100</td>
<td>22.076</td>
<td>20</td>
</tr>
<tr>
<td>F2P3B3</td>
<td>313.900</td>
<td>22.529</td>
<td>20</td>
</tr>
<tr>
<td>F4P3B3</td>
<td>312.900</td>
<td>21.260</td>
<td>20</td>
</tr>
<tr>
<td>C3P3B3</td>
<td>310.300</td>
<td>23.853</td>
<td>20</td>
</tr>
<tr>
<td>CZP3B3</td>
<td>308.700</td>
<td>23.245</td>
<td>20</td>
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</table>

**Analysis of Variance -- design 1**

Cell Means and Standard Deviations (Cont.)

<table>
<thead>
<tr>
<th>Variable</th>
<th>Mean</th>
<th>Std. Dev.</th>
<th>N</th>
</tr>
</thead>
<tbody>
<tr>
<td>F3P3B1</td>
<td>302.800</td>
<td>11.687</td>
<td>20</td>
</tr>
<tr>
<td>F2P3B1</td>
<td>303.100</td>
<td>14.119</td>
<td>20</td>
</tr>
<tr>
<td>F4P3B1</td>
<td>302.500</td>
<td>12.412</td>
<td>20</td>
</tr>
<tr>
<td>F3P3B3</td>
<td>314.100</td>
<td>22.076</td>
<td>20</td>
</tr>
<tr>
<td>F2P3B3</td>
<td>313.900</td>
<td>22.529</td>
<td>20</td>
</tr>
<tr>
<td>F4P3B3</td>
<td>312.900</td>
<td>21.260</td>
<td>20</td>
</tr>
<tr>
<td>C3P3B3</td>
<td>310.300</td>
<td>23.853</td>
<td>20</td>
</tr>
<tr>
<td>CZP3B3</td>
<td>308.700</td>
<td>23.245</td>
<td>20</td>
</tr>
</tbody>
</table>

**Analysis of Variance -- design 1**
**Mean** | **Std. Dev.** | **N**
---|---|---
For entire sample | 309.500 | 22.260 | 20

**Variable** .. **P3P3B3**

**Mean** | **Std. Dev.** | **N**
---|---|---
For entire sample | 310.400 | 18.440 | 20

**Variable** .. **P2P3B3**

**Mean** | **Std. Dev.** | **N**
---|---|---
For entire sample | 310.000 | 17.448 | 20

**Variable** .. **P4P3B3**

**Mean** | **Std. Dev.** | **N**
---|---|---
For entire sample | 308.000 | 19.194 | 20

**** **Analysis of Variance** -- design 1 ****

Tests involving 'TASK' Within-Subject Effect.

Tests of Significance for T2 using UNIQUE sums of squares

<table>
<thead>
<tr>
<th>Source of Variation</th>
<th>SS</th>
<th>DF</th>
<th>MS</th>
<th>F</th>
<th>Sig of F</th>
</tr>
</thead>
<tbody>
<tr>
<td>WITHIN CELLS</td>
<td>46443.73</td>
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<td>2444.41</td>
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<td>TASK</td>
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<td>4665.60</td>
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**EFFECT .. TASK BY FRTOPOS (Cont.)**

Univariate F-tests with (1,19) D. F.

<table>
<thead>
<tr>
<th>Variable</th>
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<th>Hypoth. MS</th>
<th>Error MS</th>
<th>F</th>
<th>Sig. of F</th>
</tr>
</thead>
<tbody>
<tr>
<td>T7</td>
<td>64.06667</td>
<td>3786.6000</td>
<td>64.06667</td>
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<tr>
<td>T8</td>
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<td>1892.3333</td>
<td>45.00000</td>
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</table>

**EFFECT .. TASK BY LATERAL (Cont.)**

Univariate F-tests with (1,19) D. F.

<table>
<thead>
<tr>
<th>Variable</th>
<th>Hypoth. SS</th>
<th>Error SS</th>
<th>Hypoth. MS</th>
<th>Error MS</th>
<th>F</th>
<th>Sig. of F</th>
</tr>
</thead>
<tbody>
<tr>
<td>T10</td>
<td>2.45000</td>
<td>728.55000</td>
<td>2.45000</td>
<td>38.34474</td>
<td>.06389</td>
<td>.803</td>
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**EFFECT .. TASK BY FRTOPOS BY LATERAL (Cont.)**

Univariate F-tests with (1,19) D. F.

<table>
<thead>
<tr>
<th>Variable</th>
<th>Hypoth. SS</th>
<th>Error SS</th>
<th>Hypoth. MS</th>
<th>Error MS</th>
<th>F</th>
<th>Sig. of F</th>
</tr>
</thead>
<tbody>
<tr>
<td>T15</td>
<td>4.22500</td>
<td>691.27500</td>
<td>4.22500</td>
<td>36.38289</td>
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<td>T16</td>
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<td>.688</td>
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<td>5.20833</td>
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<td>5.20833</td>
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<td>.471</td>
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**P250 Inter-modal vs. Single tone**
### Cell Means and Standard Deviations

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<thead>
<tr>
<th>Variable</th>
<th>Mean</th>
<th>Std. Dev.</th>
<th>N</th>
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</thead>
<tbody>
<tr>
<td><strong>F3P3A1</strong></td>
<td>252.600</td>
<td>18.526</td>
<td>20</td>
</tr>
<tr>
<td><strong>FZP3A1</strong></td>
<td>250.800</td>
<td>16.175</td>
<td>20</td>
</tr>
<tr>
<td><strong>F4P3A1</strong></td>
<td>251.000</td>
<td>15.861</td>
<td>20</td>
</tr>
<tr>
<td><strong>C3P3A1</strong></td>
<td>251.700</td>
<td>16.699</td>
<td>20</td>
</tr>
<tr>
<td><strong>CZP3A1</strong></td>
<td>250.900</td>
<td>17.393</td>
<td>20</td>
</tr>
<tr>
<td><strong>C4P3A1</strong></td>
<td>253.900</td>
<td>15.266</td>
<td>20</td>
</tr>
</tbody>
</table>

* * * * * * A n a l y s i s   o f   V a r i a n c e -- design 1 * * * * * *

<table>
<thead>
<tr>
<th>Variable</th>
<th>Mean</th>
<th>Std. Dev.</th>
<th>N</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>P3P3A1</strong></td>
<td>257.300</td>
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</tr>
<tr>
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<td>254.000</td>
<td>17.399</td>
<td>20</td>
</tr>
<tr>
<td><strong>P4P3A1</strong></td>
<td>256.700</td>
<td>13.815</td>
<td>20</td>
</tr>
<tr>
<td><strong>F3P3A3</strong></td>
<td>250.600</td>
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</tr>
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<td><strong>FZP3A3</strong></td>
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**Variable .. C3P3A3**
<table>
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<th>Std. Dev.</th>
<th>N</th>
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<tbody>
<tr>
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<td>247.800</td>
<td>17.615</td>
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<table>
<thead>
<tr>
<th>Variable .. P3P3A3</th>
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<th>Std. Dev.</th>
<th>N</th>
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<tbody>
<tr>
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<td>244.100</td>
<td>14.223</td>
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** * * * * * Analysis of Variance -- design 1 * * * * * **

Cell Means and Standard Deviations (Cont.)

<table>
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<th>Variable .. C4P3A3</th>
<th>Mean</th>
<th>Std. Dev.</th>
<th>N</th>
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<tbody>
<tr>
<td>For entire sample</td>
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</tbody>
</table>

<table>
<thead>
<tr>
<th>Variable .. F2P3A3</th>
<th>Mean</th>
<th>Std. Dev.</th>
<th>N</th>
</tr>
</thead>
<tbody>
<tr>
<td>For entire sample</td>
<td>252.300</td>
<td>19.318</td>
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<table>
<thead>
<tr>
<th>Variable .. B4P3A3</th>
<th>Mean</th>
<th>Std. Dev.</th>
<th>N</th>
</tr>
</thead>
<tbody>
<tr>
<td>For entire sample</td>
<td>249.100</td>
<td>17.369</td>
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</tbody>
</table>

** * * * * * Analysis of Variance -- design 1 * * * * * **

Tests involving 'TASK' Within-Subject Effect.

Tests of Significance for T2 using UNIQUE sums of squares

<table>
<thead>
<tr>
<th>Source of Variation</th>
<th>SS</th>
<th>DF</th>
<th>MS</th>
<th>F</th>
<th>Sig of F</th>
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</thead>
<tbody>
<tr>
<td>WITHIN CELLS</td>
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</table>

** EFFECT ... TASK BY FRTOPOS (Cont.)

Univariate F-tests with (1,19) D. F.

<table>
<thead>
<tr>
<th>Variable</th>
<th>Hypoth. SS</th>
<th>Error SS</th>
<th>Hypoth. MS</th>
<th>Error MS</th>
<th>F</th>
<th>Sig. of F</th>
</tr>
</thead>
<tbody>
<tr>
<td>T7</td>
<td>166.66667</td>
<td>3428.66667</td>
<td>166.66667</td>
<td>180.45614</td>
<td>.92359</td>
<td>.349</td>
</tr>
<tr>
<td>T8</td>
<td>15.02222</td>
<td>943.42222</td>
<td>15.02222</td>
<td>49.65380</td>
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<td>.589</td>
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** EFFECT ... TASK BY LATERAL (Cont.)

Univariate F-tests with (1,19) D. F.

<table>
<thead>
<tr>
<th>Variable</th>
<th>Hypoth. SS</th>
<th>Error SS</th>
<th>Hypoth. MS</th>
<th>Error MS</th>
<th>F</th>
<th>Sig. of F</th>
</tr>
</thead>
<tbody>
<tr>
<td>T9</td>
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</table>

** EFFECT ... TASK BY FRTOPOS BY LATERAL (Cont.)

Univariate F-tests with (1,19) D. F.

<table>
<thead>
<tr>
<th>Variable</th>
<th>Hypoth. SS</th>
<th>Error SS</th>
<th>Hypoth. MS</th>
<th>Error MS</th>
<th>F</th>
<th>Sig. of F</th>
</tr>
</thead>
<tbody>
<tr>
<td>T15</td>
<td>25.60000</td>
<td>339.40000</td>
<td>25.60000</td>
<td>17.86316</td>
<td>1.43312</td>
<td>.246</td>
</tr>
<tr>
<td>T16</td>
<td>48.13333</td>
<td>451.53333</td>
<td>48.13333</td>
<td>23.76491</td>
<td>2.02539</td>
<td>.171</td>
</tr>
<tr>
<td>T17</td>
<td>.83333</td>
<td>710.16667</td>
<td>.83333</td>
<td>37.37719</td>
<td>.02230</td>
<td>.883</td>
</tr>
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</table>
P200 Inter-modal vs. Single tone

Cell Means and Standard Deviations
Variable .. F3P21
Mean Std. Dev. N
For entire sample 198.000 17.327 20

Variable .. F2P21
Mean Std. Dev. N
For entire sample 197.700 16.187 20

Variable .. F4P21
Mean Std. Dev. N
For entire sample 198.500 16.246 20

Variable .. C3P21
Mean Std. Dev. N
For entire sample 199.500 10.894 20

Variable .. CZP21
Mean Std. Dev. N
For entire sample 198.600 14.129 20

Variable .. C4P21
Mean Std. Dev. N
For entire sample 202.100 12.371 20

*** *** Analysis of Variance -- design 1 *** ***

Cell Means and Standard Deviations (Cont.)
Variable .. P3P21
Mean Std. Dev. N
For entire sample 202.100 10.533 20

Variable .. P2P21
Mean Std. Dev. N
For entire sample 201.400 13.597 20

Variable .. P4P21
Mean Std. Dev. N
For entire sample 204.000 12.140 20

Variable .. F3P23
Mean Std. Dev. N
For entire sample 200.800 16.612 20

Variable .. F2P23
**Analysis of Variance -- design 1**

Cell Means and Standard Deviations (Cont.)

<table>
<thead>
<tr>
<th>Variable .. C4P23</th>
<th>Mean</th>
<th>Std. Dev.</th>
<th>N</th>
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</thead>
<tbody>
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<table>
<thead>
<tr>
<th>Variable .. P3P23</th>
<th>Mean</th>
<th>Std. Dev.</th>
<th>N</th>
</tr>
</thead>
<tbody>
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<td>For entire sample</td>
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</table>

<table>
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<tr>
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<th>Mean</th>
<th>Std. Dev.</th>
<th>N</th>
</tr>
</thead>
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<tr>
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<td>18.690</td>
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</table>

<table>
<thead>
<tr>
<th>Variable .. P4P23</th>
<th>Mean</th>
<th>Std. Dev.</th>
<th>N</th>
</tr>
</thead>
<tbody>
<tr>
<td>For entire sample</td>
<td>195.500</td>
<td>18.534</td>
<td>20</td>
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</table>

**Analysis of Variance -- design 1**

Tests involving 'TASK' Within-Subject Effect.

<table>
<thead>
<tr>
<th>Source of Variation</th>
<th>SS</th>
<th>DF</th>
<th>MS</th>
<th>F</th>
<th>Sig of F</th>
</tr>
</thead>
<tbody>
<tr>
<td>WITHIN CELLS</td>
<td>22789.11</td>
<td>19</td>
<td>1199.43</td>
<td>.68</td>
<td>.421</td>
</tr>
<tr>
<td>TASK</td>
<td>810.00</td>
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<td>810.00</td>
<td>.68</td>
<td>.421</td>
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</table>

**Analysis of Variance -- design 1**

Tests of Significance for T2 using UNIQUE sums of squares

<table>
<thead>
<tr>
<th>Variable</th>
<th>Hypoth. SS</th>
<th>Error SS</th>
<th>Hypoth. MS</th>
<th>Error MS</th>
<th>F</th>
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<td>.557</td>
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**Analysis of Variance -- design 1**

Tests involving 'TASK' Within-Subject Effect.

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<td>.35826</td>
<td>.557</td>
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EFFECT .. TASK BY FRTOPOS BY LATERAL (Cont.)
Univariate F-tests with (1,19) D. F.

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N130 Inter-modal vs. Single tone

Cell Means and Standard Deviations

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*** Analysis of Variance -- design 1 ***

Cell Means and Standard Deviations (Cont.)

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**Analysis of Variance -- design 1**

Tests involving 'TASK' Within-Subject Effect.

Tests of Significance for T2 using UNIQUE sums of squares

<table>
<thead>
<tr>
<th>Source of Variation</th>
<th>SS</th>
<th>DF</th>
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EFFECT .. TASK BY FRTOPOS (Cont.)

Univariate F-tests with (1,19) D. F.

<table>
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<th>Error SS</th>
<th>Hypoth. MS</th>
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**EFFECT .. TASK BY LATERAL (Cont.)**

Univariate F-tests with (1,19) D. F.

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**EFFECT .. TASK BY FRTOPOS BY LATERAL (Cont.)**

Univariate F-tests with (1,19) D. F.

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<th>Hypoth. MS</th>
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| N100 Inter-modal vs. Single tone

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**Cell Means and Standard Deviations**

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**Cell Means and Standard Deviations (Cont.)**

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**Cell Means and Standard Deviations (Cont.)**

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**Cell Means and Standard Deviations (Cont.)**

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<tr>
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**Cell Means and Standard Deviations (Cont.)**

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<tr>
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**Cell Means and Standard Deviations (Cont.)**

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<th>Std. Dev.</th>
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<tr>
<td>For entire sample</td>
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**Analysis of Variance -- design 1**

**Cell Means and Standard Deviations (Cont.)**

<table>
<thead>
<tr>
<th>Variable</th>
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<th>Std. Dev.</th>
<th>N</th>
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For entire sample                        101.000     13.385         20
- - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - -
Variable .. PZN1V1  
Mean Std. Dev. N
For entire sample                        102.600     11.109         20
- - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - -
Variable .. P4N1V1  
Mean Std. Dev. N
For entire sample                        103.300     10.707         20
- - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - -
Variable .. F3N1V3  
Mean Std. Dev. N
For entire sample                        103.800     14.362         20
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Variable .. FZN1V3  
Mean Std. Dev. N
For entire sample                        104.400     13.835         20
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Variable .. F4N1V3  
Mean Std. Dev. N
For entire sample                        103.800     15.133         20
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Variable .. C3N1V3  
Mean Std. Dev. N
For entire sample                        103.800     13.885         20
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Variable .. CZN1V3  
Mean Std. Dev. N
For entire sample                        104.200     11.551         20
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Variable .. C4N1V3  
Mean Std. Dev. N
For entire sample                        102.300     11.864         20
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Variable .. P3N1V3  
Mean Std. Dev. N
For entire sample                        101.400     15.302         20
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Variable .. P2N1V3  
Mean Std. Dev. N
For entire sample                        101.900     14.560         20
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Variable .. P4N1V3  
Mean Std. Dev. N
For entire sample                        104.000     15.190         20
- - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - -

* * * * * * Analysis of Variance -- design 1 * * * * * *
Cell Means and Standard Deviations (Cont.)
Variable .. C4N1V3  
Mean Std. Dev. N
For entire sample                        102.300     11.864         20
- - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - -
Variable .. P3N1V3  
Mean Std. Dev. N
For entire sample                        101.400     15.302         20
- - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - -
Variable .. P2N1V3  
Mean Std. Dev. N
For entire sample                        101.900     14.560         20
- - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - -
Variable .. P4N1V3  
Mean Std. Dev. N
For entire sample                        104.000     15.190         20
- - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - -

* * * * * * Analysis of Variance -- design 1 * * * * * *
Tests involving 'TASK' Within-Subject Effect.
Tests of Significance for T2 using UNIQUE sums of squares
Source of Variation   SS   DF   MS    F Sig of F
WITHIN CELLS  13769.54  19  724.71
TASK        113.34  1  113.34  .16  .697

EFFECT .. TASK BY FRTOPOS (Cont.)
Univariate F-tests with (1,19) D. F.

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<th>Hypoth. MS</th>
<th>Error MS</th>
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EFFECT .. TASK BY LATERAL (Cont.)
Univariate F-tests with (1,19) D. F.

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<th>Hypoth. MS</th>
<th>Error MS</th>
<th>F</th>
<th>Sig. of F</th>
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<tr>
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<td>10.41667</td>
<td>519.91667</td>
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EFFECT .. TASK BY FRTOPOS BY LATERAL (Cont.)
Univariate F-tests with (1,19) D. F.

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<th>Hypoth. MS</th>
<th>Error MS</th>
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<tr>
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P350 Inter-modal vs. Auditory oddball

Cell Means and Standard Deviations

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<th>Std. Dev.</th>
<th>N</th>
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<td>F2PNC1</td>
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<td>F4PNC1</td>
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<tr>
<td>C2PNC1</td>
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<td>Std. Dev.</td>
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**Analysis of Variance -- design 1**

Cell Means and Standard Deviations (Cont.)

<table>
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<th>Std. Dev.</th>
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<table>
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<th>N</th>
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<tbody>
<tr>
<td>For entire sample</td>
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<th>N</th>
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<tbody>
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<td>20.208</td>
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<tr>
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**Analysis of Variance -- design 1**

Cell Means and Standard Deviations (Cont.)

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**Analysis of Variance -- design 1**

Tests involving 'TASK' Within-Subject Effect.

Tests of Significance for T2 using UNIQUE sums of squares

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<tr>
<th>Source of Variation</th>
<th>SS</th>
<th>DF</th>
<th>MS</th>
<th>F</th>
<th>Sig of F</th>
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<td>WITHIN CELLS</td>
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Effect.. TASK BY FRTOPOS (Cont.)

Univariate F-tests with (1,19) D. F.

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<th>Error SS</th>
<th>Hypoth. MS</th>
<th>Error MS</th>
<th>F</th>
<th>Sig. of F</th>
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</thead>
<tbody>
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Effect.. TASK BY LATERAL (Cont.)

Univariate F-tests with (1,19) D. F.

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<th>Hypoth. MS</th>
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<tbody>
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Effect.. TASK BY FRTOPOS BY LATERAL (Cont.)

Univariate F-tests with (1,19) D. F.

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<th>Hypoth. MS</th>
<th>Error MS</th>
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<th>Sig. of F</th>
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**P300 Inter-modal vs. Auditory oddball**

Cell Means and Standard Deviations

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<tr>
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<th>Mean</th>
<th>Std. Dev.</th>
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<td>For entire sample</td>
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<table>
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**Analysis of Variance -- design 1**

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**Analysis of Variance -- design 1**

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<th>Std. Dev.</th>
<th>N</th>
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<tr>
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<td>Std. Dev.</td>
<td>N</td>
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<tr>
<td>For entire sample</td>
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<td>Std. Dev.</td>
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**Analysis of Variance -- design 1**

Tests involving 'TASK' Within-Subject Effect.

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<th>Source of Variation</th>
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<th>DF</th>
<th>MS</th>
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<tr>
<td>WITHIN CELLS</td>
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Univariate F-tests with (1,19) D. F.

<table>
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<th>Error SS</th>
<th>Hypoth. MS</th>
<th>Error MS</th>
<th>F</th>
<th>Sig. of F</th>
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<tbody>
<tr>
<td>T7</td>
<td>29.40000</td>
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<td>147.78596</td>
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Univariate F-tests with (1,19) D. F.

<table>
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<th>Hypoth. MS</th>
<th>Error MS</th>
<th>F</th>
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Univariate F-tests with (1,19) D. F.

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<th>Hypoth. MS</th>
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**P250 Inter-modal vs. Auditory oddball**

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<th>Std. Dev.</th>
<th>N</th>
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<td>Std. Dev.</td>
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<td>Variable</td>
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<td>Std. Dev.</td>
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<td>--------------</td>
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<tr>
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<tr>
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* * * * * * Analysis of Variance -- design 1 * * * * * *

<table>
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<tr>
<th>Variable</th>
<th>Mean</th>
<th>Std. Dev.</th>
<th>N</th>
</tr>
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<td>Variable .. C2P3A2</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>For entire sample</td>
<td>250.700</td>
<td>12.819</td>
<td>20</td>
</tr>
</tbody>
</table>
### Analysis of Variance -- design 1

**Cell Means and Standard Deviations (Cont.)**

<table>
<thead>
<tr>
<th>Variable .. C4P3A2</th>
<th>Mean</th>
<th>Std. Dev.</th>
<th>N</th>
</tr>
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<tbody>
<tr>
<td>For entire sample</td>
<td>250.200</td>
<td>11.714</td>
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</tbody>
</table>

<table>
<thead>
<tr>
<th>Variable .. P3P3A2</th>
<th>Mean</th>
<th>Std. Dev.</th>
<th>N</th>
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<tbody>
<tr>
<td>For entire sample</td>
<td>251.600</td>
<td>11.816</td>
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<table>
<thead>
<tr>
<th>Variable .. P2P3A2</th>
<th>Mean</th>
<th>Std. Dev.</th>
<th>N</th>
</tr>
</thead>
<tbody>
<tr>
<td>For entire sample</td>
<td>248.800</td>
<td>12.505</td>
<td>20</td>
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<table>
<thead>
<tr>
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<th>Mean</th>
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<tr>
<td>For entire sample</td>
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</table>

### Tests involving 'TASK' Within-Subject Effect.

Tests of Significance for T2 using UNIQUE sums of squares

<table>
<thead>
<tr>
<th>Source of Variation</th>
<th>SS</th>
<th>DF</th>
<th>MS</th>
<th>F</th>
<th>Sig of F</th>
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<tbody>
<tr>
<td>WITHIN CELLS</td>
<td>21881.07</td>
<td>19</td>
<td>1151.64</td>
<td>.94</td>
<td>.345</td>
</tr>
<tr>
<td>TASK</td>
<td>1081.60</td>
<td>1</td>
<td>1081.60</td>
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</table>

### EFFECT .. TASK BY FRTOPOS (Cont.)

Univariate F-tests with (1,19) D. F.

<table>
<thead>
<tr>
<th>Variable</th>
<th>Hypoth. SS</th>
<th>Error SS</th>
<th>Hypoth. MS</th>
<th>Error MS</th>
<th>F</th>
<th>Sig. of F</th>
</tr>
</thead>
<tbody>
<tr>
<td>T7</td>
<td>176.81667</td>
<td>3638.85000</td>
<td>176.81667</td>
<td>191.51842</td>
<td>.92324</td>
<td>.349</td>
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<tr>
<td>T8</td>
<td>42.05000</td>
<td>1050.28333</td>
<td>42.05000</td>
<td>55.27807</td>
<td>.76070</td>
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### EFFECT .. TASK BY LATERAL (Cont.)

Univariate F-tests with (1,19) D. F.

<table>
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<th>Variable</th>
<th>Hypoth. SS</th>
<th>Error SS</th>
<th>Hypoth. MS</th>
<th>Error MS</th>
<th>F</th>
<th>Sig. of F</th>
</tr>
</thead>
<tbody>
<tr>
<td>T9</td>
<td>4.81667</td>
<td>802.18333</td>
<td>4.81667</td>
<td>42.22018</td>
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### EFFECT .. TASK BY FRTOPOS BY LATERAL (Cont.)

Univariate F-tests with (1,19) D. F.

<table>
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<tr>
<th>Variable</th>
<th>Hypoth. SS</th>
<th>Error SS</th>
<th>Hypoth. MS</th>
<th>Error MS</th>
<th>F</th>
<th>Sig. of F</th>
</tr>
</thead>
<tbody>
<tr>
<td>T16</td>
<td>6.53333</td>
<td>236.80000</td>
<td>6.53333</td>
<td>12.46316</td>
<td>.52421</td>
<td>.478</td>
</tr>
<tr>
<td>T17</td>
<td>3.33333</td>
<td>460.66667</td>
<td>3.33333</td>
<td>24.24561</td>
<td>.13748</td>
<td>.715</td>
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<tr>
<td>T18</td>
<td>52.90000</td>
<td>275.10000</td>
<td>52.90000</td>
<td>14.47895</td>
<td>3.65358</td>
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**P200 Inter-modal vs. Auditory oddball**
<table>
<thead>
<tr>
<th>Variable</th>
<th>Mean</th>
<th>Std. Dev.</th>
<th>N</th>
</tr>
</thead>
<tbody>
<tr>
<td>For entire sample</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>F3P21</td>
<td>198.00</td>
<td>17.327</td>
<td>20</td>
</tr>
<tr>
<td>FZP21</td>
<td>197.70</td>
<td>16.187</td>
<td>20</td>
</tr>
<tr>
<td>F4P21</td>
<td>198.50</td>
<td>16.246</td>
<td>20</td>
</tr>
<tr>
<td>C3P21</td>
<td>199.50</td>
<td>10.894</td>
<td>20</td>
</tr>
<tr>
<td>CZP21</td>
<td>198.60</td>
<td>14.129</td>
<td>20</td>
</tr>
<tr>
<td>C4P21</td>
<td>202.10</td>
<td>12.371</td>
<td>20</td>
</tr>
</tbody>
</table>

**Analysis of Variance -- design 1**

<table>
<thead>
<tr>
<th>Variable</th>
<th>Mean</th>
<th>Std. Dev.</th>
<th>N</th>
</tr>
</thead>
<tbody>
<tr>
<td>For entire sample</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>P3P21</td>
<td>202.10</td>
<td>10.533</td>
<td>20</td>
</tr>
<tr>
<td>PZP21</td>
<td>201.40</td>
<td>13.597</td>
<td>20</td>
</tr>
<tr>
<td>P4P21</td>
<td>204.00</td>
<td>12.140</td>
<td>20</td>
</tr>
<tr>
<td>F3P22</td>
<td>174.40</td>
<td>17.837</td>
<td>20</td>
</tr>
<tr>
<td>FZP22</td>
<td>169.50</td>
<td>17.542</td>
<td>20</td>
</tr>
<tr>
<td>F4P22</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
For entire sample                        171.500     13.169         20
Variable .. C3P22                        Mean Std. Dev.     N
For entire sample                        170.100     15.620         20
Variable .. CZP22                        Mean Std. Dev.     N
For entire sample                        169.200     17.787         20

** ** ** ** Analysis of Variance -- design 1 ** ** ** **
Cell Means and Standard Deviations (Cont.)
Variable .. C4P22                        Mean Std. Dev.     N
For entire sample                        169.100     13.557         20
Variable .. P3P22                        Mean Std. Dev.     N
For entire sample                        173.600     17.455         20
Variable .. PZP22                        Mean Std. Dev.     N
For entire sample                        171.000     17.705         20
Variable .. P4P22                        Mean Std. Dev.     N
For entire sample                        170.300     16.303         20

** ** ** ** Analysis of Variance -- design 1 ** ** ** **
Tests involving 'TASK' Within-Subject Effect.
Tests of Significance for T2 using UNIQUE sums of squares
Source of Variation          SS      DF        MS         F  Sig of F
WITHIN CELLS           28304.18      19   1489.69
TASK                   76971.38       1  76971.38     51.67      .000

** ** ** ** Analysis of Variance -- design 1 ** ** ** **
EFFECT .. TASK BY FRTOPOS (Cont.)
Univariate F-tests with (1,19) D. F.
Variable   Hypoth. SS   Error SS Hypoth. MS   Error MS          F  Sig. of F
T7          317.40000 3543.26667  317.40000  186.48772    1.70199       .208
T8           82.68889 2297.08889   82.68889  120.89942     .68395       .418

** ** ** ** Analysis of Variance -- design 1 ** ** ** **
EFFECT .. TASK BY LATERAL (Cont.)
Univariate F-tests with (1,19) D. F.
Variable   Hypoth. SS   Error SS Hypoth. MS   Error MS          F  Sig. of F
T9          248.06667  713.26667  248.06667  186.48772   1.70199      .208
T10            .35556  797.42222     .35556   41.96959     .00847      .928

** ** ** ** Analysis of Variance -- design 1 ** ** ** **
EFFECT .. TASK BY FRTOPOS BY LATERAL (Cont.)
Univariate F-tests with (1,19) D. F.
<table>
<thead>
<tr>
<th>Variable</th>
<th>Hypoth. SS</th>
<th>Error SS</th>
<th>Hypoth. MS</th>
<th>Error MS</th>
<th>F</th>
<th>Sig. of F</th>
</tr>
</thead>
<tbody>
<tr>
<td>T15</td>
<td>8.10000</td>
<td>774.90000</td>
<td>8.10000</td>
<td>40.78421</td>
<td>.19861</td>
<td>.661</td>
</tr>
<tr>
<td>T16</td>
<td>43.20000</td>
<td>559.13333</td>
<td>43.20000</td>
<td>29.42807</td>
<td>1.46799</td>
<td>.241</td>
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<tr>
<td>T17</td>
<td>1.63333</td>
<td>474.03333</td>
<td>1.63333</td>
<td>24.94912</td>
<td>.06547</td>
<td>.801</td>
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<tr>
<td>T18</td>
<td>37.37778</td>
<td>838.51111</td>
<td>37.37778</td>
<td>44.13216</td>
<td>.84695</td>
<td>.369</td>
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</tbody>
</table>

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**N130 Inter-modal vs. Auditory oddball**

---

### Cell Means and Standard Deviations

#### Variable .. F3N1T1

<table>
<thead>
<tr>
<th></th>
<th>Mean</th>
<th>Std. Dev.</th>
<th>N</th>
</tr>
</thead>
<tbody>
<tr>
<td>For entire sample</td>
<td>134.500</td>
<td>12.513</td>
<td>20</td>
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</tbody>
</table>

#### Variable .. F2N1T1

<table>
<thead>
<tr>
<th></th>
<th>Mean</th>
<th>Std. Dev.</th>
<th>N</th>
</tr>
</thead>
<tbody>
<tr>
<td>For entire sample</td>
<td>133.700</td>
<td>10.428</td>
<td>20</td>
</tr>
</tbody>
</table>

#### Variable .. F4N1T1

<table>
<thead>
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<th>Mean</th>
<th>Std. Dev.</th>
<th>N</th>
</tr>
</thead>
<tbody>
<tr>
<td>For entire sample</td>
<td>132.800</td>
<td>9.611</td>
<td>20</td>
</tr>
</tbody>
</table>

#### Variable .. C3N1T1

<table>
<thead>
<tr>
<th></th>
<th>Mean</th>
<th>Std. Dev.</th>
<th>N</th>
</tr>
</thead>
<tbody>
<tr>
<td>For entire sample</td>
<td>129.100</td>
<td>6.664</td>
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#### Variable .. C2N1T1

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<tr>
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<th>Mean</th>
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<tr>
<td>For entire sample</td>
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#### Variable .. C4N1T1

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<th>Std. Dev.</th>
<th>N</th>
</tr>
</thead>
<tbody>
<tr>
<td>For entire sample</td>
<td>129.900</td>
<td>6.601</td>
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**Analysis of Variance -- design 1**

### Cell Means and Standard Deviations (Cont.)

#### Variable .. P3N1T1

<table>
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<th>Mean</th>
<th>Std. Dev.</th>
<th>N</th>
</tr>
</thead>
<tbody>
<tr>
<td>For entire sample</td>
<td>129.500</td>
<td>5.799</td>
<td>20</td>
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</table>

#### Variable .. P2N1T1

<table>
<thead>
<tr>
<th></th>
<th>Mean</th>
<th>Std. Dev.</th>
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<tbody>
<tr>
<td>For entire sample</td>
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<td>6.997</td>
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#### Variable .. P4N1T1

<table>
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<th>Mean</th>
<th>Std. Dev.</th>
<th>N</th>
</tr>
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<tbody>
<tr>
<td>For entire sample</td>
<td>130.400</td>
<td>5.933</td>
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#### Variable .. P3N1T2

<table>
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<tr>
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<th>Mean</th>
<th>Std. Dev.</th>
<th>N</th>
</tr>
</thead>
</table>

---
For entire sample  131.900  13.002  20
Variable .. FZN1T2
Mean  Std. Dev.  N
For entire sample  130.700  12.402  20

Variable .. F4N1T2
Mean  Std. Dev.  N
For entire sample  131.800  12.944  20

Variable .. C3N1T2
Mean  Std. Dev.  N
For entire sample  129.700  11.917  20
Variable .. CZN1T2
Mean  Std. Dev.  N
For entire sample  126.400  13.774  20

Variable .. C4N1T2
Mean  Std. Dev.  N
For entire sample  129.400  13.721  20

Variable .. P3N1T2
Mean  Std. Dev.  N
For entire sample  129.700  12.868  20
Variable .. PZN1T2
Mean  Std. Dev.  N
For entire sample  127.800  13.717  20
Variable .. P4N1T2
Mean  Std. Dev.  N
For entire sample  129.300  11.448  20

** Analysis of Variance -- design 1 **

Cell Means and Standard Deviations (Cont.)
Variable .. C4N1T2
Mean  Std. Dev.  N
For entire sample  129.400  13.721  20

Variable .. P3N1T2
Mean  Std. Dev.  N
For entire sample  129.700  12.868  20

Variable .. P2N1T2
Mean  Std. Dev.  N
For entire sample  127.800  13.717  20

Variable .. P4N1T2
Mean  Std. Dev.  N
For entire sample  129.300  11.448  20

** Analysis of Variance -- design 1 **

Tests involving 'TASK' Within-Subject Effect.

Tests of Significance for T2 using UNIQUE sums of squares

<table>
<thead>
<tr>
<th>Source of Variation</th>
<th>SS</th>
<th>DF</th>
<th>MS</th>
<th>F</th>
<th>Sig of F</th>
</tr>
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<tbody>
<tr>
<td>WITHIN CELLS</td>
<td>9855.06</td>
<td>19</td>
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<td>TASK</td>
<td>80.28</td>
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</tr>
</tbody>
</table>

EFFECT .. TASK BY FRTOPOS (Cont.)
Univariate F-tests with (1,19) D. F.

<table>
<thead>
<tr>
<th>Variable</th>
<th>Hypoth. SS</th>
<th>Error SS</th>
<th>Hypoth. MS</th>
<th>Error MS</th>
<th>F</th>
<th>Sig. of F</th>
</tr>
</thead>
<tbody>
<tr>
<td>T7</td>
<td>86.40000</td>
<td>2094.26667</td>
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<td>110.22456</td>
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<tr>
<td>T8</td>
<td>.55556</td>
<td>.772.11111</td>
<td>.55556</td>
<td>40.63743</td>
<td>.01367</td>
<td>.908</td>
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</table>

EFFECT .. TASK BY LATERAL (Cont.)
Univariate F-tests with (1,19) D. F.
### Variable Hypoth. SS Error SS Hypoth. MS Error MS          F  Sig. of F

<p>| | | | | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
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</tr>
</thead>
<tbody>
<tr>
<td>T9</td>
<td>1.06667</td>
<td>780.93333</td>
<td>1.06667</td>
<td>41.10175</td>
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<tr>
<td>T10</td>
<td>8.02222</td>
<td>372.64444</td>
<td>8.02222</td>
<td>19.61287</td>
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### EFFECT . . TASK BY FRTEPOS BY LATERAL (Cont.)

#### Univariate F-tests with (1,19) D. F.

<p>| | | | | |</p>
<table>
<thead>
<tr>
<th></th>
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</thead>
<tbody>
<tr>
<td>T15</td>
<td>21.02500</td>
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<td>33.07500</td>
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<td>5.20833</td>
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</tbody>
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### N100 Inter-modal vs. Auditory oddball

#### Cell Means and Standard Deviations

**F3N1V1**

<table>
<thead>
<tr>
<th>Mean</th>
<th>Std. Dev.</th>
<th>N</th>
</tr>
</thead>
<tbody>
<tr>
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<td>9.144</td>
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</tbody>
</table>

**F3N1V1**

<table>
<thead>
<tr>
<th>Mean</th>
<th>Std. Dev.</th>
<th>N</th>
</tr>
</thead>
<tbody>
<tr>
<td>For entire sample</td>
<td>103.700</td>
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</tbody>
</table>

**F4N1V1**

<table>
<thead>
<tr>
<th>Mean</th>
<th>Std. Dev.</th>
<th>N</th>
</tr>
</thead>
<tbody>
<tr>
<td>For entire sample</td>
<td>100.000</td>
<td>6.836</td>
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**C3N1V1**

<table>
<thead>
<tr>
<th>Mean</th>
<th>Std. Dev.</th>
<th>N</th>
</tr>
</thead>
<tbody>
<tr>
<td>For entire sample</td>
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<td>10.258</td>
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</table>

**C4N1V1**

<table>
<thead>
<tr>
<th>Mean</th>
<th>Std. Dev.</th>
<th>N</th>
</tr>
</thead>
<tbody>
<tr>
<td>For entire sample</td>
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<td>7.612</td>
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</table>

**C4N1V1**

<table>
<thead>
<tr>
<th>Mean</th>
<th>Std. Dev.</th>
<th>N</th>
</tr>
</thead>
<tbody>
<tr>
<td>For entire sample</td>
<td>101.900</td>
<td>6.758</td>
</tr>
</tbody>
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### * * * * * A n a l y s i s o f V a r i a n c e -- design 1 * * * * *

#### Cell Means and Standard Deviations (Cont.)

**F3N1V1**

<table>
<thead>
<tr>
<th>Mean</th>
<th>Std. Dev.</th>
<th>N</th>
</tr>
</thead>
<tbody>
<tr>
<td>For entire sample</td>
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<td>13.385</td>
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</tbody>
</table>

**F3N1V1**

<table>
<thead>
<tr>
<th>Mean</th>
<th>Std. Dev.</th>
<th>N</th>
</tr>
</thead>
<tbody>
<tr>
<td>For entire sample</td>
<td>101.000</td>
<td>13.385</td>
</tr>
</tbody>
</table>
For entire sample 102.600 11.109 20

Variable .. P4N1V1
Mean Std. Dev. N
For entire sample 103.300 10.707 20

Variable .. F3N1V2
Mean Std. Dev. N
For entire sample 103.100 12.690 20

Variable .. FZN1V2
Mean Std. Dev. N
For entire sample 99.600 11.798 20

Variable .. F4N1V2
Mean Std. Dev. N
For entire sample 101.000 12.790 20

Variable .. C3N1V2
Mean Std. Dev. N
For entire sample 98.600 13.644 20

Variable .. CZN1V2
Mean Std. Dev. N
For entire sample 97.300 13.079 20

* * * * * * Analysis of Variance -- design 1 * * * * * *

Cell Means and Standard Deviations (Cont.)
Variable .. C4N1V2
Mean Std. Dev. N
For entire sample 98.700 13.063 20

Variable .. F3N1V2
Mean Std. Dev. N
For entire sample 99.900 13.400 20

Variable .. F2N1V2
Mean Std. Dev. N
For entire sample 98.900 13.369 20

Variable .. F4N1V2
Mean Std. Dev. N
For entire sample 97.000 14.776 20

* * * * * * Analysis of Variance -- design 1 * * * * * *

Tests involving 'TASK' Within-Subject Effect.

Tests of Significance for T2 using UNIQUE sums of squares
Source of Variation SS DF MS F Sig of F
WITHIN CELLS 14106.71 19 742.46
TASK 716.84 1 716.84 .97 .338

* * * * * * Analysis of Variance -- design 1 * * * * * *

EFFECT .. TASK BY FRTOPOS (Cont.)
Univariate F-tests with (1,19) D. F.
<table>
<thead>
<tr>
<th>Variable</th>
<th>Hypoth. SS</th>
<th>Error SS</th>
<th>Hypoth. MS</th>
<th>Error MS</th>
<th>F</th>
<th>Sig. of F</th>
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<tbody>
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<td>190.81667</td>
<td>2447.51667</td>
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<tr>
<td>T9</td>
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<td>635.25000</td>
<td>120.41667</td>
<td>33.43421</td>
<td>3.60160</td>
<td>.073</td>
</tr>
<tr>
<td>T10</td>
<td>355.60556</td>
<td>689.17222</td>
<td>355.60556</td>
<td>36.27222</td>
<td>9.80380</td>
<td>.005</td>
</tr>
<tr>
<td>T15</td>
<td>30.62500</td>
<td>689.87500</td>
<td>30.62500</td>
<td>36.30921</td>
<td>.84345</td>
<td>.370</td>
</tr>
<tr>
<td>T16</td>
<td>118.00833</td>
<td>516.15833</td>
<td>118.00833</td>
<td>27.16623</td>
<td>4.34394</td>
<td>.051</td>
</tr>
<tr>
<td>T17</td>
<td>11.40833</td>
<td>257.42500</td>
<td>11.40833</td>
<td>13.54868</td>
<td>.84203</td>
<td>.370</td>
</tr>
<tr>
<td>T18</td>
<td>61.66944</td>
<td>302.38611</td>
<td>61.66944</td>
<td>15.91506</td>
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**EFFECT .. TASK BY LATERAL (Cont.)**

Univariate F-tests with (1,19) D. F.

<table>
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<th>Variable</th>
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<tbody>
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<td>3.60160</td>
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<td>355.60556</td>
<td>36.27222</td>
<td>9.80380</td>
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**EFFECT .. TASK BY FRTOPOS BY LATERAL (Cont.)**

Univariate F-tests with (1,19) D. F.

<table>
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<tr>
<th>Variable</th>
<th>Hypoth. SS</th>
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<th>Hypoth. MS</th>
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</thead>
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<td>36.30921</td>
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<td>.370</td>
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<td>516.15833</td>
<td>118.00833</td>
<td>27.16623</td>
<td>4.34394</td>
<td>.051</td>
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<tr>
<td>T17</td>
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<td>257.42500</td>
<td>11.40833</td>
<td>13.54868</td>
<td>.84203</td>
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<tr>
<td>T18</td>
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<td>15.91506</td>
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**Post hoc Analyses**

**P200 (inter-modal) vs. N200 (auditory) latency**

<table>
<thead>
<tr>
<th>Variable</th>
<th>Mean</th>
<th>Std. Dev.</th>
<th>N</th>
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<tbody>
<tr>
<td>F3P21</td>
<td>198.000</td>
<td>17.327</td>
<td>20</td>
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<tr>
<td>FZP21</td>
<td>197.700</td>
<td>16.187</td>
<td>20</td>
</tr>
<tr>
<td>F4P21</td>
<td>198.500</td>
<td>16.246</td>
<td>20</td>
</tr>
<tr>
<td>C3P21</td>
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<td>10.894</td>
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<tr>
<td>CZP21</td>
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<tr>
<td>Variable</td>
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<td>Std. Dev.</td>
<td>N</td>
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<td>------------</td>
<td>-------</td>
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<tr>
<td>C4P21</td>
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<tr>
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</tr>
<tr>
<td>F3N22</td>
<td>197.500</td>
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<tr>
<td>F2N22</td>
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<td>C3N22</td>
<td>201.200</td>
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<tr>
<td>CZN22</td>
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**Analysis of Variance**

<table>
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<tr>
<th>Variable</th>
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<th>Std. Dev.</th>
<th>N</th>
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<tbody>
<tr>
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<td>P3N22</td>
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<tr>
<td>P2N22</td>
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### Variable .. P4N22

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<th>For entire sample</th>
<th>Mean</th>
<th>Std. Dev.</th>
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<tr>
<td></td>
<td>199.800</td>
<td>8.823</td>
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**Analysis of Variance -- design 1**

Tests involving 'TASK' Within-Subject Effect.

Tests of Significance for T2 using UNIQUE sums of squares

<table>
<thead>
<tr>
<th>Source of Variation</th>
<th>SS</th>
<th>DF</th>
<th>MS</th>
<th>F</th>
<th>Sig of F</th>
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**P300 (inter-modal) vs. P350 (auditory) amplitude**

Cell Means and Standard Deviations

<table>
<thead>
<tr>
<th>Variable .. F3P3B1</th>
<th>Mean</th>
<th>Std. Dev.</th>
<th>N</th>
</tr>
</thead>
<tbody>
<tr>
<td>For entire sample</td>
<td>3.604</td>
<td>3.618</td>
<td>20</td>
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</table>

<table>
<thead>
<tr>
<th>Variable .. F2P3B1</th>
<th>Mean</th>
<th>Std. Dev.</th>
<th>N</th>
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<tbody>
<tr>
<td>For entire sample</td>
<td>3.692</td>
<td>4.256</td>
<td>20</td>
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</tbody>
</table>

<table>
<thead>
<tr>
<th>Variable .. F4P3B1</th>
<th>Mean</th>
<th>Std. Dev.</th>
<th>N</th>
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<tbody>
<tr>
<td>For entire sample</td>
<td>3.624</td>
<td>3.553</td>
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<table>
<thead>
<tr>
<th>Variable .. C3P3B1</th>
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<th>Std. Dev.</th>
<th>N</th>
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<tbody>
<tr>
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</table>

<table>
<thead>
<tr>
<th>Variable .. C2P3B1</th>
<th>Mean</th>
<th>Std. Dev.</th>
<th>N</th>
</tr>
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<tbody>
<tr>
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<td>3.831</td>
<td>3.806</td>
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<table>
<thead>
<tr>
<th>Variable .. C4P3B1</th>
<th>Mean</th>
<th>Std. Dev.</th>
<th>N</th>
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<tr>
<td>For entire sample</td>
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**Analysis of Variance -- design 1**

Cell Means and Standard Deviations (Cont.)

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<th>Variable .. P3P3B1</th>
<th>Mean</th>
<th>Std. Dev.</th>
<th>N</th>
</tr>
</thead>
<tbody>
<tr>
<td>For entire sample</td>
<td>4.832</td>
<td>2.922</td>
<td>20</td>
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</table>

<table>
<thead>
<tr>
<th>Variable .. PZP3B1</th>
<th>Mean</th>
<th>Std. Dev.</th>
<th>N</th>
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<tbody>
<tr>
<td>For entire sample</td>
<td>5.410</td>
<td>2.994</td>
<td>20</td>
</tr>
<tr>
<td>Variable ..</td>
<td>Mean</td>
<td>Std. Dev.</td>
<td>N</td>
</tr>
<tr>
<td>-------------</td>
<td>-------</td>
<td>-----------</td>
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<tr>
<td>P4P3B1</td>
<td>4.964</td>
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<tr>
<td>P3PNC2</td>
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<td>P4PNC2</td>
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**Analysis of Variance -- design 1**

Tests involving 'TASK' Within-Subject Effect.

<table>
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<tr>
<th>Source of Variation</th>
<th>SS</th>
<th>DF</th>
<th>MS</th>
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<th>Sig of F</th>
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<tr>
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<td>77.74</td>
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<td>124.78</td>
<td>1.61</td>
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**Analysis of Variance -- design 1**

Univariate F-tests with (1,19) D. F.
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<th>Error SS</th>
<th>Hypoth. MS</th>
<th>Error MS</th>
<th>F</th>
<th>Sig. of F</th>
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<tbody>
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EFFECT .. TASK BY LATERAL (Cont.)
Univariate F-tests with (1,19) D. F.

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<th>Variable</th>
<th>Hypoth. SS</th>
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<th>Hypoth. MS</th>
<th>Error MS</th>
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<tr>
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<td>.40512</td>
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EFFECT .. TASK BY FRTOPOS BY LATERAL (Cont.)
Univariate F-tests with (1,19) D. F.

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<td>.273</td>
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SPSS output – Study 2  
Comparison of auditory/visual oddball and auditory oddball ERPs

Amplitude

Manova

N100 Amplitude

* * * * * A n a l y s i s   o f   V a r i a n c e -- design 1 * * * * *

Tests involving 'TASK' Within-Subject Effect.

Tests of Significance for T2 using UNIQUE sums of squares

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<tr>
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<td>12.89</td>
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EFFECT .. TASK BY FROTOPOS (Cont.)

Univariate F-tests with (1,16) D. F.

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<th>Error SS</th>
<th>Hypoth. MS</th>
<th>Error MS</th>
<th>F</th>
<th>Sig. of F</th>
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<tbody>
<tr>
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EFFECT .. TASK BY LATERAL (Cont.)

Univariate F-tests with (1,16) D. F.

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<th>Error MS</th>
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EFFECT .. TASK BY FROTOPOS BY LATERAL (Cont.)

Univariate F-tests with (1,16) D. F.

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<th>Hypoth. MS</th>
<th>Error MS</th>
<th>F</th>
<th>Sig. of F</th>
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</thead>
<tbody>
<tr>
<td>T15</td>
<td>.14522</td>
<td>6.39927</td>
<td>.14522</td>
<td>.39995</td>
<td>.36310</td>
<td>.555</td>
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<td>1.40706</td>
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Manova

N100 Amplitudes (normalised)

* * * * * A n a l y s i s   o f   V a r i a n c e -- design 1 * * * * *

Tests involving 'TASK' Within-Subject Effect.
Tests of Significance for T2 using UNIQUE sums of squares

<table>
<thead>
<tr>
<th>Source of Variation</th>
<th>SS</th>
<th>DF</th>
<th>MS</th>
<th>F</th>
<th>Sig of F</th>
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<tr>
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EFFECT .. TASK BY FRTOPOS (Cont.)

Univariate F-tests with (1,16) D. F.

<table>
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<tr>
<th>Variable</th>
<th>Hypoth. SS</th>
<th>Error SS</th>
<th>Hypoth. MS</th>
<th>Error MS</th>
<th>F</th>
<th>Sig. of F</th>
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<tbody>
<tr>
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EFFECT .. TASK BY LATERAL (Cont.)

Univariate F-tests with (1,16) D. F.

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<th>Variable</th>
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<th>Hypoth. MS</th>
<th>Error MS</th>
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<th>Sig. of F</th>
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<tbody>
<tr>
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EFFECT .. TASK BY FRTOPOS BY LATERAL (Cont.)

Univariate F-tests with (1,16) D. F.

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<th>Variable</th>
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<th>Hypoth. MS</th>
<th>Error MS</th>
<th>F</th>
<th>Sig. of F</th>
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<tbody>
<tr>
<td>T15</td>
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<td>.42529</td>
<td>.01063</td>
<td>.02658</td>
<td>.40005</td>
<td>.536</td>
</tr>
<tr>
<td>T16</td>
<td>.01288</td>
<td>.10959</td>
<td>.01288</td>
<td>.00685</td>
<td>1.87994</td>
<td>.189</td>
</tr>
<tr>
<td>T17</td>
<td>.02383</td>
<td>.11029</td>
<td>.02383</td>
<td>.00689</td>
<td>3.45688</td>
<td>.081</td>
</tr>
<tr>
<td>T18</td>
<td>.00512</td>
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<td>.00528</td>
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Manova

P200 Amplitude

*** Analysis of Variance -- design 1 ***

Tests involving 'TASK' Within-Subject Effect.

Tests of Significance for T2 using UNIQUE sums of squares

<table>
<thead>
<tr>
<th>Source of Variation</th>
<th>SS</th>
<th>DF</th>
<th>MS</th>
<th>F</th>
<th>Sig of F</th>
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<tr>
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EFFECT .. TASK BY FRTOPOS (Cont.)

Univariate F-tests with (1,16) D. F.

<table>
<thead>
<tr>
<th>Variable</th>
<th>Hypoth. SS</th>
<th>Error SS</th>
<th>Hypoth. MS</th>
<th>Error MS</th>
<th>F</th>
<th>Sig. of F</th>
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</thead>
<tbody>
<tr>
<td>T15</td>
<td>.01063</td>
<td>.42529</td>
<td>.01063</td>
<td>.02658</td>
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<tr>
<td>T16</td>
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<td>.01288</td>
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<td>.189</td>
</tr>
<tr>
<td>T17</td>
<td>.02383</td>
<td>.11029</td>
<td>.02383</td>
<td>.00689</td>
<td>3.45688</td>
<td>.081</td>
</tr>
<tr>
<td>T18</td>
<td>.00512</td>
<td>.08445</td>
<td>.00512</td>
<td>.00528</td>
<td>.97044</td>
<td>.339</td>
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</tbody>
</table>
T7            13.61427  123.45194   13.61427    7.71575    1.76448       .203
T8            1.86494   14.59487    1.86494     .91218    2.04449       .172

- - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - -
- - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - -
EFFECT .. TASK BY LATERAL (Cont.)
Univariate F-tests with (1,16) D. F.
Variable   Hypoth. SS   Error SS Hypoth. MS   Error MS          F  Sig. of F
T9            1.03636   10.76231    1.03636     .67264    1.54072       .232
T10           1.45345   10.31086    1.45345     .64443    2.25541       .153

- - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - -
- - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - -
EFFECT .. TASK BY FRTOPOS BY LATERAL (Cont.)
Univariate F-tests with (1,16) D. F.
Variable   Hypoth. SS   Error SS Hypoth. MS   Error MS          F  Sig. of F
T15           1.03624   10.44638    1.03624     .65290    1.58713       .226
T16            .02435    3.54154     .02435     .22135     .11001       .744
T17            .22459    2.03394     .22459     .12712    1.76675       .202
T18            .00021    2.65765     .00021     .16610     .00125       .972

- - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - -
- - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - -
EFFECT .. TASK BY FRTOPOS (Cont.)
Univariate F-tests with (1,16) D. F.
Variable   Hypoth. SS   Error SS Hypoth. MS   Error MS          F  Sig. of F
T7             6.55317   42.28238    6.55317    2.64265    2.47977       .135
T8             .35841    4.51311     .35841     .28207    1.27065       .276

- - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - -
- - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - -
EFFECT .. TASK BY LATERAL (Cont.)
Univariate F-tests with (1,16) D. F.
Variable   Hypoth. SS   Error SS Hypoth. MS   Error MS          F  Sig. of F
T9             .23273    3.79354     .23273     .23710     .98158       .337
T10            .19190    3.31695     .19190     .20731    1.92565       .350

Manova

P200 Amplitudes (normalised)

* * * * * A n a l y s i s   o f   V a r i a n c e -- design 1 * * * * *

Tests involving 'TASK' Within-Subject Effect.

Tests of Significance for T2 using UNIQUE sums of squares
Source of Variation          SS      DF        MS         F  Sig of F
WITHIN CELLS              61.61      16      3.85
TASK                        .61       1       .61       .16      .696

- - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - -
- - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - -
EFFECT .. TASK BY FRTOPOS (Cont.)
Univariate F-tests with (1,16) D. F.
Variable   Hypoth. SS   Error SS Hypoth. MS   Error MS          F  Sig. of F
T7             6.55317   42.28238    6.55317    2.64265    2.47977       .135
T8             .35841    4.51311     .35841     .28207    1.27065       .276

- - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - -
- - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - -
EFFECT .. TASK BY LATERAL (Cont.)
Univariate F-tests with (1,16) D. F.
Variable   Hypoth. SS   Error SS Hypoth. MS   Error MS          F  Sig. of F
T9             .23273    3.79354     .23273     .23710     .98158       .337
T10            .19190    3.31695     .19190     .20731    1.92565       .350
EFFECT .. TASK BY FRTOPOS BY LATERAL (Cont.)
Univariate F-tests with (1,16) D. F.

<table>
<thead>
<tr>
<th>Variable</th>
<th>Hypoth. SS</th>
<th>Error SS</th>
<th>Hypoth. MS</th>
<th>Error MS</th>
<th>F</th>
<th>Sig. of F</th>
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<tbody>
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<td>.07731</td>
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<td>.02266</td>
<td>.05868</td>
<td>.38612</td>
<td>.543</td>
</tr>
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</table>

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**Manova**

**N200 Amplitude**

* * * * * Analysis of Variance -- design 1 * * * * *

Tests involving 'TASK' Within-Subject Effect.

Tests of Significance for T2 using UNIQUE sums of squares

<table>
<thead>
<tr>
<th>Source of Variation</th>
<th>SS</th>
<th>DF</th>
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<th>Sig of F</th>
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EFFECT .. TASK BY FRTOPOS (Cont.)
Univariate F-tests with (1,16) D. F.

<table>
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<tr>
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<th>Hypoth. SS</th>
<th>Error SS</th>
<th>Hypoth. MS</th>
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EFFECT .. TASK BY LATERAL (Cont.)
Univariate F-tests with (1,16) D. F.

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EFFECT .. TASK BY FRTOPOS BY LATERAL (Cont.)
Univariate F-tests with (1,16) D. F.

<table>
<thead>
<tr>
<th>Variable</th>
<th>Hypoth. SS</th>
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<th>Hypoth. MS</th>
<th>Error MS</th>
<th>F</th>
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<tbody>
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Manova

### N200 Amplitudes (normalised)

* * * * * Analysis of Variance -- design 1 * * * * *

Tests involving 'TASK' Within-Subject Effect.

Tests of Significance for T2 using UNIQUE sums of squares

<table>
<thead>
<tr>
<th>Source of Variation</th>
<th>SS</th>
<th>DF</th>
<th>MS</th>
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<th>Sig of F</th>
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<tr>
<td>WITHIN CELLS</td>
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EFFECT .. TASK BY FRTOPOS (Cont.)

Univariate F-tests with (1,16) D. F.

<table>
<thead>
<tr>
<th>Variable</th>
<th>Hypoth. SS</th>
<th>Error SS</th>
<th>Hypoth. MS</th>
<th>Error MS</th>
<th>F</th>
<th>Sig. of F</th>
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<tbody>
<tr>
<td>T7</td>
<td>1.05487</td>
<td>9.40821</td>
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EFFECT .. TASK BY LATERAL (Cont.)

Univariate F-tests with (1,16) D. F.

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<th>F</th>
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<tbody>
<tr>
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EFFECT .. TASK BY FRTOPOS BY LATERAL (Cont.)

Univariate F-tests with (1,16) D. F.

<table>
<thead>
<tr>
<th>Variable</th>
<th>Hypoth. SS</th>
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<th>Error MS</th>
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</table>

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Manova

### P250 Amplitude

* * * * * Analysis of Variance -- design 1 * * * * *

Tests involving 'TASK' Within-Subject Effect.

Tests of Significance for T2 using UNIQUE sums of squares

<table>
<thead>
<tr>
<th>Source of Variation</th>
<th>SS</th>
<th>DF</th>
<th>MS</th>
<th>F</th>
<th>Sig of F</th>
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### EFFECT .. TASK BY FRTOPOS (Cont.)
Univariate F-tests with (1,16) D. F.

<table>
<thead>
<tr>
<th>Variable</th>
<th>Hypoth. SS</th>
<th>Error SS</th>
<th>Hypoth. MS</th>
<th>Error MS</th>
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### EFFECT .. TASK BY LATERAL (Cont.)
Univariate F-tests with (1,16) D. F.

<table>
<thead>
<tr>
<th>Variable</th>
<th>Hypoth. SS</th>
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<tbody>
<tr>
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### EFFECT .. TASK BY FRTOPOS BY LATERAL (Cont.)
Univariate F-tests with (1,16) D. F.

<table>
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<th>Variable</th>
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<th>Error MS</th>
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### Manova

**P250 Amplitudes (normalised)**

* * * * * * A n a l y s i s   o f   V a r i a n c e -- d e s i g n 1 * * * * * *

Tests involving 'TASK' Within-Subject Effect.

Tests of Significance for T2 using UNIQUE sums of squares

<table>
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<tr>
<th>Source of Variation</th>
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### EFFECT .. TASK BY FRTOPOS (Cont.)
Univariate F-tests with (1,16) D. F.

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### EFFECT .. TASK BY LATERAL (Cont.)

Univariate F-tests with (1, 16) D. F.

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### EFFECT .. TASK BY FRTOPOS BY LATERAL (Cont.)

Univariate F-tests with (1, 16) D. F.

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### Manova

**P300 Amplitude**

**Analysis of Variance** -- design 1

Tests involving 'TASK' Within-Subject Effect.

Tests of Significance for T2 using UNIQUE sums of squares

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<tr>
<th>Source of Variation</th>
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### EFFECT .. TASK BY FRTOPOS (Cont.)

Univariate F-tests with (1, 16) D. F.

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### EFFECT .. TASK BY LATERAL (Cont.)

Univariate F-tests with (1, 16) D. F.

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### EFFECT .. TASK BY FRTOPOS BY LATERAL (Cont.)

Univariate F-tests with (1, 16) D. F.
### Variable Hypoth. SS Error SS Hypoth. MS Error MS F Sig. of F

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**Manova**

**P300 Amplitudes (normalised)**

**Analysis of Variance -- design 1**

Tests involving 'TASK' Within-Subject Effect.

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<tr>
<th>Source of Variation</th>
<th>SS</th>
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**EFFECT .. TASK BY FRTOPOS (Cont.)**

Univariate F-tests with (1,16) D. F.

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**EFFECT .. TASK BY LATERAL (Cont.)**

Univariate F-tests with (1,16) D. F.

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**EFFECT .. TASK BY FRTOPOS BY LATERAL (Cont.)**

Univariate F-tests with (1,16) D. F.

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**P350 Amplitudes**

**Analysis of Variance -- design 1**

Tests involving 'TASK' Within-Subject Effect.
Tests of Significance for T2 using UNIQUE sums of squares

<table>
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<tr>
<th>Source of Variation</th>
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EFFECT .. TASK BY FRTOPOS (Cont.)

Univariate F-tests with (1,16) D. F.

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EFFECT .. TASK BY LATERAL (Cont.)

Univariate F-tests with (1,16) D. F.

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EFFECT .. TASK BY FRTOPOS BY LATERAL (Cont.)

Univariate F-tests with (1,16) D. F.

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P350 Amplitudes (normalised)

** * * * * Analysis of Variance -- design 1 * * * * **

Tests involving 'TASK' Within-Subject Effect.

Tests of Significance for T2 using UNIQUE sums of squares

<table>
<thead>
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<th>Source of Variation</th>
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EFFECT .. TASK BY FRTOPOS (Cont.)

Univariate F-tests with (1,16) D. F.
### Latency

#### Manova

**N100 Latency**

* * * * * A n a l y s i s o f V a r i a n c e -- design 1 * * * * *

Tests involving 'TASK' Within-Subject Effect.

Tests of Significance for T2 using UNIQUE sums of squares

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### EFFECT .. TASK BY LATERAL (Cont.)

Univariate F-tests with (1,16) D. F.

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### EFFECT .. TASK BY FRTOPOS BY LATERAL (Cont.)

Univariate F-tests with (1,16) D. F.

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### EFFECT .. TASK BY FRTOPOS (Cont.)

Univariate F-tests with (1,16) D. F.

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EFFECT .. TASK BY LATERAL (Cont.)
Univariate F-tests with (1,16) D. F.

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EFFECT .. TASK BY FRTOPOS BY LATERAL (Cont.)
Univariate F-tests with (1,16) D. F.

<table>
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Manova

**P200 Latency**

* * * * * A n a l y s i s o f V a r i a n c e -- design 1 * * * * *

Tests involving 'TASK' Within-Subject Effect.

Tests of Significance for T2 using UNIQUE sums of squares

<table>
<thead>
<tr>
<th>Source of Variation</th>
<th>SS</th>
<th>DF</th>
<th>MS</th>
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EFFECT .. TASK BY FRTOPOS (Cont.)
Univariate F-tests with (1,16) D. F.

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<th>Hypoth. MS</th>
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EFFECT .. TASK BY LATERAL (Cont.)
Univariate F-tests with (1,16) D. F.

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EFFECT .. TASK BY FRTOPOS BY LATERAL (Cont.)
Univariate F-tests with (1,16) D. F.
Variable   Hypoth. SS   Error SS Hypoth. MS   Error MS          F  Sig. of F
T15        .02941  595.47059     .02941   37.21691     .00079       .978
T16       77.65686  212.17647   77.65686   13.26103    5.85602       .028
T17        .00980  243.15686     .00980   15.19730     .00065       .980
T18        .73529  728.54248     .73529  45.53391     .01615       .900

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Manova

N200 Latency

* * * * * Analysis of Variance -- design 1 * * * * *

Tests involving 'TASK' Within-Subject Effect.

Tests of Significance for T2 using UNIQUE sums of squares
Source of Variation          SS      DF        MS         F  Sig of F
WITHIN CELLS            4991.58      16    311.97
TASK                     117.97       1    117.97       .38      .547

- - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - -

- - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - -

EFFECT .. TASK BY FRTOPS (Cont.)
Univariate F-tests with (1,16) D. F.

Variable   Hypoth. SS   Error SS Hypoth. MS   Error MS          F  Sig. of F
T7           400.96078 1672.70588  400.96078  104.54412    3.83533       .068
T8            4.08497 1322.69281    4.08497   82.66830     .04941       .827

- - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - -

- - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - -

EFFECT .. TASK BY LATERAL (Cont.)
Univariate F-tests with (1,16) D. F.

Variable   Hypoth. SS   Error SS Hypoth. MS   Error MS          F  Sig. of F
T9           26.84314  481.49020   26.84314   30.09314     .89200       .359
T10           4.08497  214.69281    4.08497   13.41830     .30443       .589

- - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - -

- - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - -

EFFECT .. TASK BY FRTOPS BY LATERAL (Cont.)
Univariate F-tests with (1,16) D. F.

Variable   Hypoth. SS   Error SS Hypoth. MS   Error MS          F  Sig. of F
T15        .26471  608.23529     .26471   38.01471     .00696       .935
T16       44.00980  190.82353   44.00980   11.92647    3.69009       .073
T17       23.53922  336.62745   23.53922   21.03922    1.11883       .306

- - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - -

Manova

P250 Latency

* * * * * Analysis of Variance -- design 1 * * * * *
Tests involving 'TASK' Within-Subject Effect.

Tests of Significance for T2 using UNIQUE sums of squares

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<th>Source of Variation</th>
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EFFECT .. TASK BY FRTOPOS (Cont.)

Univariate F-tests with (1,16) D. F.

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<th>Hypoth. MS</th>
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<td>2224.07843</td>
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<td>29.99837</td>
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EFFECT .. TASK BY LATERAL (Cont.)

Univariate F-tests with (1,16) D. F.

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EFFECT .. TASK BY FRTOPOS BY LATERAL (Cont.)

Univariate F-tests with (1,16) D. F.

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<th>Hypoth. MS</th>
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Manova

**P300 Latency**

**Analysis of Variance -- design 1**

Tests involving 'TASK' Within-Subject Effect.

Tests of Significance for T2 using UNIQUE sums of squares

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<tr>
<th>Source of Variation</th>
<th>SS</th>
<th>DF</th>
<th>MS</th>
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EFFECT .. TASK BY FRTOPOS (Cont.)

Univariate F-tests with (1,16) D. F.
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<th>Hypoth. MS</th>
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EFFECT .. TASK BY LATERAL (Cont.)
Univariate F-tests with (1,16) D. F.

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<th>Hypoth. SS</th>
<th>Error SS</th>
<th>Hypoth. MS</th>
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<tr>
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EFFECT .. TASK BY FRTOPOS BY LATERAL (Cont.)
Univariate F-tests with (1,16) D. F.

<table>
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<tr>
<td>T7</td>
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P350 Latency

Tests involving 'TASK' Within-Subject Effect.
Tests of Significance for T2 using UNIQUE sums of squares

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<th>Source of Variation</th>
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EFFECT .. TASK BY FRTOPOS (Cont.)
Univariate F-tests with (1,16) D. F.

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<tr>
<td>T7</td>
<td>36.25490</td>
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EFFECT .. TASK BY LATERAL (Cont.)
Univariate F-tests with (1,16) D. F.

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EFFECT .. TASK BY FRTOPOS BY LATERAL (Cont.)
Univariate F-tests with (1,16) D. F.

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## Comparison of AV vs. A + V Standard Stimuli

### Amplitudes

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* * * * * Analysis of Variance -- design 1 * * * * *

Tests involving 'TASK' Within-Subject Effect.

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Univariate F-tests with (1,16) D. F.

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Univariate F-tests with (1,16) D. F.

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N300

Cell Means and Standard Deviations

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**Analysis of Variance -- design 1**

Tests involving 'TASK' Within-Subject Effect.

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**EFFECT .. TASK BY RTPOS**

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**EFFECT .. TASK BY RTPOS BY LATERAL**

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*** * * * * * Analysis of Variance -- design 1 * * * * * ***

Tests involving 'TASK' Within-Subject Effect.

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### EFFECT .. TASK BY FRTOPOS (Cont.)

Univariate F-tests with (1,16) D. F.

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<th>Hypoth. SS</th>
<th>Error SS</th>
<th>Hypoth. MS</th>
<th>Error MS</th>
<th>F</th>
<th>Sig. of F</th>
</tr>
</thead>
<tbody>
<tr>
<td>T7</td>
<td>1.83510</td>
<td>64.93913</td>
<td>1.83510</td>
<td>4.05870</td>
<td>0.45214</td>
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<td>T8</td>
<td>0.68373</td>
<td>10.26216</td>
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### EFFECT .. TASK BY LATERAL (Cont.)

Univariate F-tests with (1,16) D. F.

<table>
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<tr>
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<th>Error SS</th>
<th>Hypoth. MS</th>
<th>Error MS</th>
<th>F</th>
<th>Sig. of F</th>
</tr>
</thead>
<tbody>
<tr>
<td>T9</td>
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<td>12.14108</td>
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<td>0.75882</td>
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<td>T10</td>
<td>1.30577</td>
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### EFFECT .. TASK BY FRTOPOS BY LATERAL (Cont.)

Univariate F-tests with (1,16) D. F.

<table>
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<tr>
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<th>Hypoth. SS</th>
<th>Error SS</th>
<th>Hypoth. MS</th>
<th>Error MS</th>
<th>F</th>
<th>Sig. of F</th>
</tr>
</thead>
<tbody>
<tr>
<td>T15</td>
<td>0.20412</td>
<td>3.52264</td>
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<td>0.22017</td>
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<td>T16</td>
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<td>3.13801</td>
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<td>0.118</td>
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<td>0.05382</td>
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<tr>
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<td>0.00226</td>
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**P200**

----------

**Cell Means and Standard Deviations**

**Variable .. F3P2AV**

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<tr>
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<th>Std. Dev.</th>
<th>N</th>
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**Variable .. F2P2AV**

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**Variable .. F4P2AV**

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**Variable .. C3P2AV**

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<td>Std. Dev.</td>
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<tr>
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<td>4.110</td>
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<td>Mean</td>
<td>Std. Dev.</td>
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<tr>
<td>----------------------</td>
<td>-------</td>
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<tr>
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<td>6.464</td>
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<table>
<thead>
<tr>
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<th>Mean</th>
<th>Std. Dev.</th>
<th>N</th>
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<tbody>
<tr>
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<td>7.438</td>
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</table>

<table>
<thead>
<tr>
<th>Variable .. P4P2AVPL</th>
<th>Mean</th>
<th>Std. Dev.</th>
<th>N</th>
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<tr>
<td>For entire sample</td>
<td>7.191</td>
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* * * * * Analysis of Variance -- design 1 * * * * *
```

Tests involving 'TASK' Within-Subject Effect.

Tests of Significance for T2 using UNIQUE sums of squares

<table>
<thead>
<tr>
<th>Source of Variation</th>
<th>SS</th>
<th>DF</th>
<th>MS</th>
<th>F</th>
<th>Sig of F</th>
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<tbody>
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<td>WITHIN CELLS</td>
<td>477.90</td>
<td>16</td>
<td>29.87</td>
<td>.33</td>
<td>.575</td>
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<td>TASK</td>
<td>9.77</td>
<td>1</td>
<td>9.77</td>
<td>.33</td>
<td>.575</td>
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* * * * * EFFECT .. TASK BY FRTOPOS (Cont.)
```
Univariate F-tests with (1,16) D. F.

<table>
<thead>
<tr>
<th>Variable</th>
<th>Hypoth. SS</th>
<th>Error SS</th>
<th>Hypoth. MS</th>
<th>Error MS</th>
<th>F</th>
<th>Sig. of F</th>
</tr>
</thead>
<tbody>
<tr>
<td>T7</td>
<td>5.52310</td>
<td>96.01927</td>
<td>5.52310</td>
<td>6.00120</td>
<td>.92033</td>
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</tr>
<tr>
<td>T8</td>
<td>5.73476</td>
<td>15.61276</td>
<td>5.73476</td>
<td>.97580</td>
<td>5.87700</td>
<td>.028</td>
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</table>

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* * * * * EFFECT .. TASK BY LATERAL (Cont.)
```
Univariate F-tests with (1,16) D. F.

<table>
<thead>
<tr>
<th>Variable</th>
<th>Hypoth. SS</th>
<th>Error SS</th>
<th>Hypoth. MS</th>
<th>Error MS</th>
<th>F</th>
<th>Sig. of F</th>
</tr>
</thead>
<tbody>
<tr>
<td>T9</td>
<td>1.07162</td>
<td>6.53759</td>
<td>1.07162</td>
<td>.40860</td>
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<td>T10</td>
<td>.13222</td>
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<td>.13222</td>
<td>.32697</td>
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<td>.534</td>
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</table>

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* * * * * EFFECT .. TASK BY FRTOPOS BY LATERAL (Cont.)
```
Univariate F-tests with (1,16) D. F.

<table>
<thead>
<tr>
<th>Variable</th>
<th>Hypoth. SS</th>
<th>Error SS</th>
<th>Hypoth. MS</th>
<th>Error MS</th>
<th>F</th>
<th>Sig. of F</th>
</tr>
</thead>
<tbody>
<tr>
<td>T15</td>
<td>.18707</td>
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<td>.91769</td>
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<tr>
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<td>.05663</td>
<td>.08731</td>
<td>.64865</td>
<td>.432</td>
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<tr>
<td>T17</td>
<td>.11435</td>
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<td>.03534</td>
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<td>.091</td>
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<tr>
<td>T18</td>
<td>.00098</td>
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<td>.00098</td>
<td>.12744</td>
<td>.00769</td>
<td>.931</td>
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</table>
P130 – Parietal sites

Cell Means and Standard Deviations
Variable .. P3P130AV
For entire sample                          3.954      3.639         17

Variable .. P2P130AV
For entire sample                          5.631      4.273         17

Variable .. P4P130AV
For entire sample                          5.051      3.670         17

Variable .. P313AVPL
For entire sample                          3.123      3.161         17

Variable .. P213AVPL
For entire sample                          4.722      3.517         17

Variable .. P413AVPL
For entire sample                          4.384      3.104         17

** Analysis of Variance -- design 1 **

Tests involving 'TASK' Within-Subject Effect.

Tests of Significance for T2 using UNIQUE sums of squares
Source of Variation   SS  DF  MS    F   Sig of F
WITHIN CELLS 132.30  16    8.27
TASK 16.41     1  16.41  1.98  .178

EFFECT .. TASK BY PARIETAL (Cont.)
Univariate F-tests with (1,16) D. F.
Variable   Hypoth. SS  Error SS Hypoth. MS  Error MS  F  Sig. of F
T5   .11463   9.26607    .11463    .57913  .19793  .662
T6   .14597   2.65399    .14597   1.6587    .87998  .362
N160 – Parietal sites

Cell Means and Standard Deviations

<table>
<thead>
<tr>
<th>Variable</th>
<th>Mean</th>
<th>Std. Dev.</th>
<th>N</th>
</tr>
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<tbody>
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<td>.938</td>
<td>2.882</td>
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</tr>
<tr>
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<td></td>
<td></td>
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<tr>
<td>PZN160AV</td>
<td>1.582</td>
<td>3.012</td>
<td>17</td>
</tr>
<tr>
<td>For entire sample</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>P4N160AV</td>
<td>1.181</td>
<td>3.285</td>
<td>17</td>
</tr>
<tr>
<td>For entire sample</td>
<td></td>
<td></td>
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<tr>
<td>P316AVPL</td>
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</tr>
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<td>For entire sample</td>
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<tr>
<td>PZ16AVPL</td>
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<tr>
<td>P416AVPL</td>
<td>-.003</td>
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<tr>
<td>For entire sample</td>
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</tbody>
</table>

* * * * * A n a l y s i s   o f   V a r i a n c e -- design 1 * * * * *

Tests involving 'TASK' Within-Subject Effect.

Tests of Significance for T2 using UNIQUE sums of squares

<table>
<thead>
<tr>
<th>Source of Variation</th>
<th>SS</th>
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<th>MS</th>
<th>F</th>
<th>Sig. of F</th>
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<tbody>
<tr>
<td>WITHIN CELLS</td>
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EFFECT .. TASK BY PARIETAL (Cont.)

Univariate F-tests with (1,16) D. F.

<table>
<thead>
<tr>
<th>Variable</th>
<th>Hypoth. SS</th>
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<th>Hypoth. MS</th>
<th>Error MS</th>
<th>F</th>
<th>Sig. of F</th>
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<tbody>
<tr>
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</table>
### Latencies

#### N100

<table>
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<th>Std. Dev.</th>
<th>N</th>
</tr>
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<tr>
<td>Std. Dev.</td>
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<tr>
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<tr>
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<tr>
<td>Std. Dev.</td>
<td>N</td>
<td></td>
<td></td>
</tr>
<tr>
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<tr>
<td>Std. Dev.</td>
<td>N</td>
<td></td>
<td></td>
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<tr>
<td>N</td>
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<td>Std. Dev.</td>
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<tr>
<td>-----------------</td>
<td>-------</td>
<td>-----------</td>
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<tr>
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<td>N</td>
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<td>Std. Dev.</td>
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<tr>
<td>For entire sample</td>
<td>108.824</td>
<td>6.247</td>
<td>17</td>
</tr>
<tr>
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<td>Mean</td>
<td>Std. Dev.</td>
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** Analysis of Variance -- design 1 **

Tests involving 'TASK' Within-Subject Effect.

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EFFECT .. TASK BY FRTOPOS (Cont.)
Univariate F-tests with (1,16) D. F.

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<th>Hypoth. MS</th>
<th>Error MS</th>
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<tbody>
<tr>
<td>T7</td>
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EFFECT .. TASK BY LATERAL (Cont.)
Univariate F-tests with (1,16) D. F.

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EFFECT .. TASK BY FRTOPOS BY LATERAL (Cont.)
Univariate F-tests with (1,16) D. F.

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N300

Cell Means and Standard Deviations

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### Analysis of Variance -- design 1

Tests involving 'TASK' Within-Subject Effect.

Tests of Significance for T2 using UNIQUE sums of squares

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EFFECT .. TASK BY FRTOPOS (Cont.)

Univariate F-tests with (1,16) D. F.

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<th>Error SS</th>
<th>Hypoth. MS</th>
<th>Error MS</th>
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EFFECT .. TASK BY LATERAL (Cont.)

Univariate F-tests with (1,16) D. F.

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<th>Hypoth. MS</th>
<th>Error MS</th>
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<tr>
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EFFECT .. TASK BY FRTOPOS BY LATERAL (Cont.)

Univariate F-tests with (1,16) D. F.

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**P350**

Cell Means and Standard Deviations

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<td>F335AVPL For entire sample</td>
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**Analysis of Variance -- design 1**

Tests involving 'TASK' Within-Subject Effect.

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EFFECT .. TASK BY FRTOPOS (Cont.)
Univariate F-tests with (1,16) D. F.

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EFFECT .. TASK BY LATERAL (Cont.)
Univariate F-tests with (1,16) D. F.

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EFFECT .. TASK BY FRTOPOS BY LATERAL (Cont.)
Univariate F-tests with (1,16) D. F.

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P200

Cell Means and Standard Deviations

Variable .. F3P2AV

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Variable .. FZP2AV

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Variable .. F4P2AV

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Variable .. C4P2AVPL
Mean  Std. Dev.          N
For entire sample                        212.471     12.156         17

Variable .. P3P2AVPL
Mean  Std. Dev.          N
For entire sample                        215.059     11.600         17

Variable .. P2P2AVPL
Mean  Std. Dev.          N
For entire sample                        215.647     12.908         17

Variable .. P4P2AVPL
Mean  Std. Dev.          N
For entire sample                        215.294     13.963         17

* * * * * A n a l y s i s o f V a r i a n c e -- d e s i g n 1 * * * * *
Tests involving 'TASK' Within-Subject Effect.
Tests of Significance for T2 using UNIQUE sums of squares
Source of Variation          SS      DF        MS         F  Sig of F
WITHIN CELLS            5350.12      16    334.38
TASK                     200.99       1    200.99       .60      .449

EFFECT .. TASK BY FRTOPOS (Cont.)
Univariate F-tests with (1,16) D. F.
Variable   Hypoth. SS   Error SS Hypoth. MS   Error MS          F  Sig. of F
T7             .17647 1138.15686     .17647   71.13480     .00248       .961
T8           12.08497  295.80392   12.08497   18.48775     .65367       .431

EFFECT .. TASK BY LATERAL (Cont.)
Univariate F-tests with (1,16) D. F.
Variable   Hypoth. SS   Error SS Hypoth. MS   Error MS          F  Sig. of F
T9            1.25490 295.41176    1.25490   18.46324     .06797       .798
T10           5.12418 213.76471    5.12418  13.36029     .38354       .544
**P130 – Parietal sites**

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**Tests involving 'TASK' Within-Subject Effect.**

Tests of Significance for T2 using UNIQUE sums of squares

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EFFECT .. TASK BY PARIETAL (Cont.)
Univariate F-tests with (1,16) D. F.

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<th>Error MS</th>
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<td>11.52941</td>
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N160 – Parietal sites

Cell Means and Standard Deviations
Variable .. P3N160AV

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Variable .. PZN160AV

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Variable .. P4N160AV

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Variable .. P416AVPL

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* * * * * Analysis of Variance -- design 1 * * * * *

Tests involving 'TASK' Within-Subject Effect.

Tests of Significance for T2 using UNIQUE sums of squares

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<th>Source of Variation</th>
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**EFFECT . TASK BY PARIETAL (Cont.)**

Univariate F-tests with (1,16) D. F.

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<th>Hypoth. MS</th>
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<th>Sig. of F</th>
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# ANOVA of difference waves

## Pd (e)

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* * * * * Analysis of Variance -- design 1 * * * * *

Tests of Between-Subjects Effects.

Tests of Significance for T1 using UNIQUE sums of squares

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<th>Source of Variation</th>
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### WITHIN CELLS

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#### EFFECT .. FRTOPOS (Cont.)

Univariate F-tests with (1,16) D. F.

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<th>Sig. of F</th>
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#### EFFECT .. LATERAL (Cont.)

Univariate F-tests with (1,16) D. F.

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#### EFFECT .. FRTOPOS BY LATERAL (Cont.)

Univariate F-tests with (1,16) D. F.

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### Nd (e)

#### Cell Means and Standard Deviations

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For entire sample -1.128 1.114 17

Variable .. C480

Mean Std. Dev. N

For entire sample -1.036 1.082 17

Variable .. P380

Mean Std. Dev. N

For entire sample -.366 .903 17

Variable .. P880

Mean Std. Dev. N

For entire sample -.382 1.034 17

Variable .. P480

Mean Std. Dev. N

For entire sample -.329 1.085 17

* * * * * ** A n a l y s i s o f V a r i a n c e -- d e s i g n 1 * * * * * * *

Tests of Between-Subjects Effects.

Tests of Significance for T1 using UNIQUE sums of squares

<table>
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<th>Source of Variation</th>
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EFFECT .. FRTOPOS (Cont.)

Univariate F-tests with (1,16) D. F.

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<th>Error MS</th>
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EFFECT .. LATERAL (Cont.)

Univariate F-tests with (1,16) D. F.

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<th>Hypoth. MS</th>
<th>Error MS</th>
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EFFECT .. FRTOPOS BY LATERAL (Cont.)

Univariate F-tests with (1,16) D. F.

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<tr>
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<td>0.575</td>
<td>0.706</td>
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**Pd (I)**

Cell Means and Standard Deviations

Tests of Between-Subjects Effects.

Tests of Significance for T1 using UNIQUE sums of squares

Source of Variation | SS  | DF  | MS  | F   | Sig of F
--- | --- | --- | --- | --- | ---

<table>
<thead>
<tr>
<th>Variable</th>
<th>Hypoth. SS</th>
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<th>Hypoth. MS</th>
<th>Error MS</th>
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<th>Sig. of F</th>
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<th>Error MS</th>
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### Nd (l)

**Cell Means and Standard Deviations**

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</table>
For entire sample

Variable .. C4220

Variable .. P3220

Variable .. P2220

Variable .. P4220

* * * * * * Analysis of Variance -- design 1 * * * * * *

Tests of Between-Subjects Effects.

Tests of Significance for T1 using UNIQUE sums of squares

Source of Variation | SS   | DF | MS   | F    | Sig of F
---------------------|------|----|------|------|---------
WITHIN CELLS         | 91.15| 16 | 5.70 |      |         
CONSTANT             | 28.29| 1  | 28.29| 4.97 | .041    

EFFECT .. FRTOPOS (Cont.)
Univariate F-tests with (1,16) D. F.

Variable | Hypoth. SS | Error SS | Hypoth. MS | Error MS | F    | Sig. of F
----------|------------|----------|------------|----------|------|---------
T2        | .01481     | 15.07566 | .01481     | .94223   | .01572| .902    
T3        | 2.30843    | 2.13678  | 2.30843    | .13355   | 17.28529| .001    

EFFECT .. LATERAL (Cont.)
Univariate F-tests with (1,16) D. F.

Variable | Hypoth. SS | Error SS | Hypoth. MS | Error MS | F    | Sig. of F
----------|------------|----------|------------|----------|------|---------
T4        | .00033     | 4.36292  | .00033     | .27268   | .00122| .973    
T5        | .22042     | 2.29168  | .22042     | .14323   | 1.53895| .233    

EFFECT .. FRTOPOS BY LATERAL (Cont.)
Univariate F-tests with (1,16) D. F.

Variable | Hypoth. SS | Error SS | Hypoth. MS | Error MS | F    | Sig. of F
----------|------------|----------|------------|----------|------|---------
T6        | .03428     | 1.75276  | .03428     | .10955   | .31291| .584    

* * * * * * A n a l y s i s o f V a r i a n c e -- d e s i g n 1 * * * * * *
<table>
<thead>
<tr>
<th></th>
<th>T7</th>
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<th>T9</th>
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<tr>
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<td>0.05068</td>
<td>0.43108</td>
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SPSS output – Study 3

Comparison of two- and three stimulus inter-modal oddball ERPs

Amplitude

**N100 Mean Amplitude**

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<th>N</th>
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<td>3.831</td>
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<tr>
<td>fzn11</td>
<td>-6.969</td>
<td>4.257</td>
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<tr>
<td>f4n11</td>
<td>-6.453</td>
<td>3.893</td>
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<td>c3n11</td>
<td>-7.676</td>
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***Analysis of Variance -- design 1***

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<tr>
<td>----------------</td>
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<tr>
<td>For entire sample</td>
<td>-4.857</td>
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** * * * * * Analysis of Variance -- design 1 * * * * * **

Cell Means and Standard Deviations (Cont.)
Variable .. c4n12
        Mean  Std. Dev.  N

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**Analysis of Variance -- design 1**

Cell Means and Standard Deviations (Cont.)

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<tbody>
<tr>
<td>czn13</td>
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</table>
For entire sample    -8.259    6.021    17

--------------------------
Variable .. c4n13

Mean     Std. Dev.     N

For entire sample    -7.164    4.375    17

--------------------------
Variable .. p3n13

Mean     Std. Dev.     N

For entire sample    -4.437    4.038    17

--------------------------
Variable .. pzn13

Mean     Std. Dev.     N

For entire sample    -5.122    4.372    17

--------------------------
Variable .. p4n13

Mean     Std. Dev.     N

For entire sample    -4.871    3.803    17

--------------------------
EFFECT .. TASK (Cont.)

Univariate F-tests with (1,16) D. F.

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<tr>
<th>Variable</th>
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<th>Hypoth. MS</th>
<th>Error MS</th>
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<tr>
<td>T2</td>
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EFFECT .. FRTOPOS (Cont.)

Univariate F-tests with (1,16) D. F.

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EFFECT .. LATERAL (Cont.)
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* * * * * Analysis of Variance -- design 1 * * * * *

Cell Means and Standard Deviations (Cont.)

Variable .. p3p21
Mean Std. Dev. N
For entire sample 6.301 4.016 17

Variable .. pzp21
Mean Std. Dev. N
For entire sample 8.055 4.517 17

Variable .. p4p21
Mean Std. Dev. N
For entire sample 6.916 4.006 17

Variable .. f3p22
Mean Std. Dev. N
For entire sample 6.357 4.443 17

Variable .. fzp22
Mean Std. Dev. N
For entire sample 7.843 5.495 17

Variable .. f4p22
Mean Std. Dev. N
For entire sample 7.058 4.917 17

Variable .. c3p22
Mean Std. Dev. N
For entire sample 10.342 5.658 17

Variable .. czp22
Mean Std. Dev. N
For entire sample 14.100 8.387 17
**Analysis of Variance -- design 1**

Cell Means and Standard Deviations (Cont.)

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**EFFECT .. FRTOPOS (Cont.)**

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**Cell Means and Standard Deviations (Cont.)**

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**EFFECT .. TASK (Cont.)**

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**EFFECT .. LATERAL (Cont.)**

Univariate F-tests with (1,16) D. F.

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**EFFECT .. TASK BY FRTOPOS (Cont.)**

Univariate F-tests with (1,16) D. F.

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**EFFECT .. TASK BY LATERAL (Cont.)**

Univariate F-tests with (1,16) D. F.

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**EFFECT .. FRTOPOS BY LATERAL (Cont.)**

Univariate F-tests with (1,16) D. F.
EFFECT .. TASK BY FRTOPOS BY LATERAL (Cont.)

Univariate F-tests with (1,16) D. F.

<table>
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**N220 Mean Amplitude**

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Cell Means and Standard Deviations

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**Analysis of Variance -- design 1**

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**Analysis of Variance -- design 1**

Cell Means and Standard Deviations (Cont.)

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Variable: fzn2203

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**Analysis of Variance -- design 1**

Variable .. c3n2203

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For entire sample

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Variable .. czn2203

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For entire sample

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For entire sample

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Variable .. p3n2203

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For entire sample

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For entire sample

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For entire sample

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**EFFECT .. TASK (Cont.)**

Univariate F-tests with (1,16) D. F.

<table>
<thead>
<tr>
<th>Variable</th>
<th>Hypoth. SS</th>
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<th>Hypoth. MS</th>
<th>Error MS</th>
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Univariate F-tests with (1,16) D. F.  

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Univariate F-tests with (1,16) D. F.  

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Univariate F-tests with (1,16) D. F.  

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### EFFECT .. FRTOPOS BY LATERAL (Cont.)
Univariate F-tests with (1,16) D. F.  

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**P350 Mean Amplitude T3 vs. NT**

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### Analysis of Variance -- design 1

**Tests involving 'TASK' Within-Subject Effect.**

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**EFFECT .. TASK BY FRTOPOS (Cont.)**

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**EFFECT .. TASK BY LATERAL (Cont.)**

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**EFFECT .. TASK BY FRTOPOS BY LATERAL (Cont.)**

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### Mean, Std. Dev., N for entire sample

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## P350 Mean Amplitude T3 vs. T2

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**Analysis of Variance -- design 1**

Tests involving 'TASK' Within-Subject Effect.

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<th>MS</th>
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### EFFECT .. TASK BY FRTOPOS (Cont.)
Univariate F-tests with (1,16) D. F.

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<th>Hypoth. SS</th>
<th>Error SS</th>
<th>Hypoth. MS</th>
<th>Error MS</th>
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<tbody>
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<td>.08894</td>
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### EFFECT .. TASK BY LATERAL (Cont.)
Univariate F-tests with (1,16) D. F.

<table>
<thead>
<tr>
<th>Variable</th>
<th>Hypoth. SS</th>
<th>Error SS</th>
<th>Hypoth. MS</th>
<th>Error MS</th>
<th>F</th>
<th>Sig. of F</th>
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<tbody>
<tr>
<td>T9</td>
<td>7.06514</td>
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### EFFECT .. TASK BY FRTOPOS BY LATERAL (Cont.)
Univariate F-tests with (1,16) D. F.

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<th>Error MS</th>
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<th>Sig. of F</th>
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<tbody>
<tr>
<td>T15</td>
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<td>.65853</td>
<td>1.19919</td>
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<td>T16</td>
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<tr>
<td>T17</td>
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<td>12.00776</td>
<td>3.41260</td>
<td>.75048</td>
<td>4.54719</td>
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<td>.80860</td>
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### P250 Mean Amplitude – Targets only

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<th>N</th>
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<td>Variable</td>
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<tr>
<td>------------</td>
<td>-------</td>
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</tr>
<tr>
<td>c3p2501</td>
<td></td>
<td></td>
<td></td>
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<tr>
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<tr>
<td>czp2501</td>
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<tr>
<td>For entire sample</td>
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<tr>
<td>c4p2501</td>
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<tr>
<td>For entire sample</td>
<td>11.167</td>
<td>5.899</td>
<td>17</td>
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* * * * * A n a l y s i s o f   V a r i a n c e -- d e s i g n  1 * * * * *

<table>
<thead>
<tr>
<th>Variable</th>
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<td>pzp2501</td>
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<tr>
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### For entire sample

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</table>

### Variable .. c3p2503

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</table>

### Variable .. czp2503

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<tr>
<td>For entire sample</td>
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### Analysis of Variance -- design 1

#### Cell Means and Standard Deviations (Cont.)

### Variable .. c4p2503

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<th>Mean</th>
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<tbody>
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<td>For entire sample</td>
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</table>

### Variable .. p3p2503

<table>
<thead>
<tr>
<th>Mean</th>
<th>Std. Dev.</th>
<th>N</th>
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<td>For entire sample</td>
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### Variable .. pzp2503

<table>
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<td>For entire sample</td>
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### Variable .. p4p2503

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### Analysis of Variance -- design 1
Tests involving 'TASK' Within-Subject Effect.

Tests of Significance for T2 using UNIQUE sums of squares

<table>
<thead>
<tr>
<th>Source of Variation</th>
<th>SS</th>
<th>DF</th>
<th>MS</th>
<th>F</th>
<th>Sig of F</th>
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<tbody>
<tr>
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EFFECT .. FRTOPOS (Cont.)

Univariate F-tests with (1,16) D. F.

<table>
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<th>Variable</th>
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<th>Error SS</th>
<th>Hypoth. MS</th>
<th>Error MS</th>
<th>F</th>
<th>Sig. of F</th>
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<tbody>
<tr>
<td>T3</td>
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<td>216.86477</td>
<td>51.37064</td>
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EFFECT .. LATERAL (Cont.)

Univariate F-tests with (1,16) D. F.

<table>
<thead>
<tr>
<th>Variable</th>
<th>Hypoth. SS</th>
<th>Error SS</th>
<th>Hypoth. MS</th>
<th>Error MS</th>
<th>F</th>
<th>Sig. of F</th>
</tr>
</thead>
<tbody>
<tr>
<td>T5</td>
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<td>192.77049</td>
<td>95.02398</td>
<td>12.04816</td>
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<tr>
<td>T6</td>
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<td>158.34689</td>
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EFFECT .. TASK BY FRTOPOS (Cont.)

Univariate F-tests with (1,16) D. F.

<table>
<thead>
<tr>
<th>Variable</th>
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<th>Error SS</th>
<th>Hypoth. MS</th>
<th>Error MS</th>
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<th>Sig. of F</th>
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<tbody>
<tr>
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EFFECT .. TASK BY LATERAL (Cont.)

Univariate F-tests with (1,16) D. F.

<table>
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<tr>
<th>Variable</th>
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<th>Hypoth. MS</th>
<th>Error MS</th>
<th>F</th>
<th>Sig. of F</th>
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<tbody>
<tr>
<td>T9</td>
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<td>1.89074</td>
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EFFECT .. FRTOPOS BY LATERAL (Cont.)
Univariate F-tests with (1,16) D. F.

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<th>Hypoth. MS</th>
<th>Error MS</th>
<th>F</th>
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<td>43.27971</td>
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<td>2.70498</td>
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EFFECT .. TASK BY FRTOPOS BY LATERAL (Cont.)
Univariate F-tests with (1,16) D. F.

<table>
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<tr>
<th>Variable</th>
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<th>Hypoth. MS</th>
<th>Error MS</th>
<th>F</th>
<th>Sig. of F</th>
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<tr>
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<td>.71729</td>
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<td>11.83615</td>
<td>.71825</td>
<td>.73976</td>
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P300 Mean Amplitude – Targets only

Cell Means and Standard Deviations

<table>
<thead>
<tr>
<th>Variable .. f3p31</th>
<th>Mean</th>
<th>Std. Dev.</th>
<th>N</th>
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<tbody>
<tr>
<td>For entire sample</td>
<td>9.134</td>
<td>4.544</td>
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<table>
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<tr>
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<table>
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<th>Mean</th>
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<table>
<thead>
<tr>
<th>Variable .. c3p31</th>
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<th>Std. Dev.</th>
<th>N</th>
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<td>For entire sample</td>
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<tr>
<td>Variable</td>
<td>Mean</td>
<td>Std. Dev.</td>
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**Analysis of Variance -- design 1**
Variable .. f4p33
For entire sample                          8.424      5.111         17

Variable .. c3p33
For entire sample                          9.247      6.115         17

Variable .. czp33
For entire sample                          8.326      7.108         17

* * * * * * A n a l y s i s   o f   V a r i a n c e -- design 1 * * * * * *

Cell Means and Standard Deviations (Cont.)
Variable .. c4p33
For entire sample                          9.672      5.840         17

Variable .. p3p33
For entire sample                          10.153     5.350         17

Variable .. pzp33
For entire sample                          10.585     6.043         17

Variable .. p4p33
For entire sample                          9.290      5.169         17

* * * * * * A n a l y s i s   o f   V a r i a n c e -- design 1 * * * * * *

Tests involving 'TASK' Within-Subject Effect.
### Tests of Significance for T2 using UNIQUE sums of squares

<table>
<thead>
<tr>
<th>Source of Variation</th>
<th>SS</th>
<th>DF</th>
<th>MS</th>
<th>F</th>
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### EFFECT .. FRTOPOS (Cont.)

Univariate F-tests with (1,16) D. F.

<table>
<thead>
<tr>
<th>Variable</th>
<th>Hypoth. SS</th>
<th>Error SS</th>
<th>Hypoth. MS</th>
<th>Error MS</th>
<th>F</th>
<th>Sig. of F</th>
</tr>
</thead>
<tbody>
<tr>
<td>T3</td>
<td>160.59559</td>
<td>532.46455</td>
<td>160.59559</td>
<td>33.27903</td>
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<td>T4</td>
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### EFFECT .. LATERAL (Cont.)

Univariate F-tests with (1,16) D. F.

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<tr>
<th>Variable</th>
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<th>Error SS</th>
<th>Hypoth. MS</th>
<th>Error MS</th>
<th>F</th>
<th>Sig. of F</th>
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</thead>
<tbody>
<tr>
<td>T5</td>
<td>6.20404</td>
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<td>6.20404</td>
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### EFFECT .. TASK BY FRTOPOS (Cont.)

Univariate F-tests with (1,16) D. F.

<table>
<thead>
<tr>
<th>Variable</th>
<th>Hypoth. SS</th>
<th>Error SS</th>
<th>Hypoth. MS</th>
<th>Error MS</th>
<th>F</th>
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<tbody>
<tr>
<td>T7</td>
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### EFFECT .. TASK BY LATERAL (Cont.)

Univariate F-tests with (1,16) D. F.

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<th>Error SS</th>
<th>Hypoth. MS</th>
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<tbody>
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### Univariate F-tests with (1,16) D. F.

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<th>Sig. of F</th>
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### Univariate F-tests with (1,16) D. F. (Cont.)

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### Cell Means and Standard Deviations

**N140 Mean Amplitude - Frontal sites**

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**Variable .. f3n1301**

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**Variable .. f4n1301**

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Variable .. f3n1302

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Variable .. fzn1302

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Univariate F-tests with (1,16) D. F.

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<th>Hypoth. MS</th>
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<th>Sig. of F</th>
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### EFFECT .. LATERAL (Cont.)

Univariate F-tests with (1,16) D. F.

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<th>Sig. of F</th>
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### EFFECT .. TASK BY LATERAL (Cont.)

Univariate F-tests with (1,16) D. F.

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<th>Error MS</th>
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### N285 Amplitude

Cell Means and Standard Deviations

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<th>N</th>
<th>95 percent Conf.</th>
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<td>Interval</td>
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<td>Interval</td>
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<td>Interval</td>
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EFFECT .. FRTOPOS (Cont.)

Univariate F-tests with (1,16) D. F.

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<th>Hypoth. MS</th>
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<tbody>
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<td>Error SS</td>
<td>Hypoth. MS</td>
<td>Error MS</td>
<td>F</td>
<td>Sig. of F</td>
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<td>----------</td>
<td>------------</td>
<td>----------</td>
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<tr>
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EFFECT .. LATERAL (Cont.)

Univariate F-tests with (1,16) D. F.

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<tbody>
<tr>
<td>T4</td>
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EFFECT .. FRTOPOS BY LATERAL (Cont.)

Univariate F-tests with (1,16) D. F.

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<th>Hypoth. MS</th>
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<th>Sig. of F</th>
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N100 Amplitudes - Normalised

Cell Means and Standard Deviations

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* * * * * * A n a l y s i s o f V a r i a n c e -- design 1 * * * * * *

Cell Means and Standard Deviations (Cont.)

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Variable .. pzn13

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For entire sample

Variable .. p4n13

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For entire sample

EFFECT .. TASK (Cont.)

Univariate F-tests with (1,16) D. F.

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EFFECT .. FRTOPOS (Cont.)

Univariate F-tests with (1,16) D. F.

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EFFECT .. LATERAL (Cont.)

Univariate F-tests with (1,16) D. F.

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Univariate F-tests with (1,16) D. F.

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Univariate F-tests with (1,16) D. F.

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Univariate F-tests with (1,16) D. F.

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### EFFECT . TASK BY FRTOPOS BY LATERAL (Cont.)

Univariate F-tests with (1,16) D. F.

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**P200 Amplitudes - Normalised**

Cell Means and Standard Deviations

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For entire sample
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** * * * * * A n a l y s i s o f V a r i a n c e -- design 1 * * * * * **

Cell Means and Standard Deviations (Cont.)
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**Analysis of Variance -- design 1**
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For entire sample                           .928       .557         17

Variable .. pzp23
Mean       Std. Dev.      N
For entire sample                           1.186       .625         17

Variable .. p4p23
Mean       Std. Dev.      N
For entire sample                           .977       .502         17

EFFECT .. TASK (Cont.)
Univariate F-tests with (1,16) D. F.

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EFFECT .. FRTOPOS (Cont.)
Univariate F-tests with (1,16) D. F.

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EFFECT .. LATERAL (Cont.)
Univariate F-tests with (1,16) D. F.

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EFFECT .. TASK BY FRTOPOS (Cont.)
Univariate F-tests with (1,16) D. F.
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**EFFECT .. TASK BY LATERAL (Cont.)**

Univariate F-tests with (1,16) D. F.

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**EFFECT .. FRTOPOS BY LATERAL (Cont.)**

Univariate F-tests with (1,16) D. F.

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**EFFECT .. TASK BY FRTOPOS BY LATERAL (Cont.)**

Univariate F-tests with (1,16) D. F.

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**N220 Amplitudes - Normalised**

Cell Means and Standard Deviations
Variable .. f3n2201  
Mean Std. Dev.  N  
For entire sample .212  1.205  17

Variable .. fzn2201  
Mean Std. Dev.  N  
For entire sample .470  1.160  17

Variable .. f4n2201  
Mean Std. Dev.  N  
For entire sample .529  1.175  17

Variable .. c3n2201  
Mean Std. Dev.  N  
For entire sample .884  1.021  17

Variable .. czn2201  
Mean Std. Dev.  N  
For entire sample 1.498  1.406  17

Variable .. c4n2201  
Mean Std. Dev.  N  
For entire sample 1.223  1.150  17

* * * * * Analysis of Variance -- design 1 * * * * *

Cell Means and Standard Deviations (Cont.)  
Variable .. p3n2201  
Mean Std. Dev.  N 
For entire sample .885  .795  17

Variable .. pzn2201  
Mean Std. Dev.  N 
For entire sample 1.373  1.068  17
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<th>N</th>
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- **Mean:** 1.246
- **Std. Dev.:** 1.049
- **N:** 17

### Variable: p4n2202
- **Mean:** 0.872
- **Std. Dev.:** 0.982
- **N:** 17

### Variable: f3n2203
- **Mean:** 0.360
- **Std. Dev.:** 0.876
- **N:** 17

### Variable: fzn2203
- **Mean:** 0.651
- **Std. Dev.:** 0.895
- **N:** 17

### Variable: f4n2203
- **Mean:** 0.579
- **Std. Dev.:** 0.713
- **N:** 17

### Variable: c3n2203
- **Mean:** 0.850
- **Std. Dev.:** 0.694
- **N:** 17

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***Analysis of Variance -- design 1***

---

### Cell Means and Standard Deviations (Cont.)

#### Variable: czn2203
- **Mean:** 1.429
- **Std. Dev.:** 0.998
- **N:** 17

#### Variable: c4n2203
- **Mean:** 1.208
- **Std. Dev.:** 0.794
- **N:** 17
Variable .. p3n2203

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Variable .. pzn2203

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Variable .. p4n2203

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EFFECT .. TASK (Cont.)

Univariate F-tests with (1,16) D. F.

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<th>Hypoth. MS</th>
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EFFECT .. FRTOPOS (Cont.)

Univariate F-tests with (1,16) D. F.

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EFFECT .. LATERAL (Cont.)

Univariate F-tests with (1,16) D. F.

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### EFFECT .. TASK BY FRTOPOS (Cont.)

Univariate F-tests with (1,16) D. F.

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### EFFECT .. TASK BY LATERAL (Cont.)

Univariate F-tests with (1,16) D. F.

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### EFFECT .. FRTOPOS BY LATERAL (Cont.)

Univariate F-tests with (1,16) D. F.

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### EFFECT .. TASK BY FRTOPOS BY LATERAL (Cont.)

Univariate F-tests with (1,16) D. F.

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### P350 Amplitudes - Normalised - T3 vs. NT

#### Cell Means and Standard Deviations

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<th>Variable .. p4p3502</th>
<th>Mean</th>
<th>Std. Dev.</th>
<th>N</th>
</tr>
</thead>
<tbody>
<tr>
<td>For entire sample</td>
<td>.928</td>
<td>.559</td>
<td>17</td>
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</tbody>
</table>

**Analysis of Variance -- design 1**

Tests involving 'TASK' Within-Subject Effect.

Tests of Significance for T2 using UNIQUE sums of squares

<table>
<thead>
<tr>
<th>Source of Variation</th>
<th>SS</th>
<th>DF</th>
<th>MS</th>
<th>F</th>
<th>Sig of F</th>
</tr>
</thead>
<tbody>
<tr>
<td>WITHIN CELLS</td>
<td>8.94</td>
<td>16</td>
<td>.56</td>
<td>.999</td>
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</tr>
<tr>
<td>TASK</td>
<td>.00</td>
<td>1</td>
<td>.00</td>
<td>.00</td>
<td>.999</td>
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</table>

EFFECT .. TASK BY FRTOPOS (Cont.)

Univariate F-tests with (1,16) D. F.

<table>
<thead>
<tr>
<th>Variable F</th>
<th>Hypoth. SS</th>
<th>Error SS</th>
<th>Hypoth. MS</th>
<th>Error MS</th>
<th>F</th>
<th>Sig. of F</th>
</tr>
</thead>
<tbody>
<tr>
<td>T7</td>
<td>1.07483</td>
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<td>4.21972</td>
<td></td>
</tr>
<tr>
<td>.057</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>T8</td>
<td>.19545</td>
<td>.46789</td>
<td>.19545</td>
<td>.02924</td>
<td>6.68370</td>
<td></td>
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<tr>
<td>.020</td>
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EFFECT .. TASK BY LATERAL (Cont.)

Univariate F-tests with (1,16) D. F.
<table>
<thead>
<tr>
<th>Variable</th>
<th>Hypoth. SS</th>
<th>Error SS</th>
<th>Hypoth. MS</th>
<th>Error MS</th>
<th>F</th>
<th>Sig. of F</th>
</tr>
</thead>
<tbody>
<tr>
<td>T15</td>
<td>.00837</td>
<td>.23197</td>
<td>.00837</td>
<td>.01450</td>
<td>.57734</td>
<td>.458</td>
</tr>
<tr>
<td>T16</td>
<td>.06122</td>
<td>.39632</td>
<td>.06122</td>
<td>.02477</td>
<td>2.47149</td>
<td>.135</td>
</tr>
<tr>
<td>T17</td>
<td>.02422</td>
<td>.10900</td>
<td>.02422</td>
<td>.00681</td>
<td>3.55497</td>
<td>.078</td>
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<tr>
<td>T18</td>
<td>.04057</td>
<td>.15603</td>
<td>.04057</td>
<td>.00975</td>
<td>4.16036</td>
<td>.058</td>
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</tbody>
</table>

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**P350 Amplitudes - Normalised - T3 vs. T2**

---

**Cell Means and Standard Deviations**

**Variable .. f3p3501**

<table>
<thead>
<tr>
<th>Mean</th>
<th>Std. Dev.</th>
<th>N</th>
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</thead>
<tbody>
<tr>
<td>.946</td>
<td>.668</td>
<td>17</td>
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**Variable .. fzp3501**

<table>
<thead>
<tr>
<th>Mean</th>
<th>Std. Dev.</th>
<th>N</th>
</tr>
</thead>
<tbody>
<tr>
<td>.963</td>
<td>.563</td>
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</table>

**Variable .. f4p3501**

<table>
<thead>
<tr>
<th>Mean</th>
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<tr>
<td>.986</td>
<td>.587</td>
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**Variable .. c3p3501**

<table>
<thead>
<tr>
<th>Mean</th>
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<tr>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Variable</td>
<td>Mean</td>
<td>Std. Dev.</td>
</tr>
<tr>
<td>--------------</td>
<td>-------</td>
<td>-----------</td>
</tr>
<tr>
<td>For entire sample</td>
<td>.927</td>
<td>.431</td>
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### Variable: czp3501

<table>
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<tr>
<th>Mean</th>
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</thead>
<tbody>
<tr>
<td>.881</td>
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### Variable: c4p3501

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<tr>
<th>Mean</th>
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</thead>
<tbody>
<tr>
<td>1.043</td>
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### Variable: p3p3501

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<th>N</th>
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</thead>
<tbody>
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<td>1.049</td>
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### Variable: pzp3501

<table>
<thead>
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<th>N</th>
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</thead>
<tbody>
<tr>
<td>1.163</td>
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### Variable: p4p3501

<table>
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<tbody>
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<tr>
<th>Mean</th>
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<th>N</th>
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</thead>
<tbody>
<tr>
<td>1.128</td>
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<td>17</td>
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### Variable: fzp3503

<table>
<thead>
<tr>
<th>Mean</th>
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</thead>
<tbody>
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<td>1.088</td>
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### Variable: f4p3503
<table>
<thead>
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<th>N</th>
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<tbody>
<tr>
<td>For entire sample</td>
<td>1.160</td>
<td>.707</td>
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**Variable .. c3p3503**

<table>
<thead>
<tr>
<th>Mean</th>
<th>Std. Dev.</th>
<th>N</th>
</tr>
</thead>
<tbody>
<tr>
<td>For entire sample</td>
<td>1.107</td>
<td>.805</td>
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</table>

**Variable .. czp3503**

<table>
<thead>
<tr>
<th>Mean</th>
<th>Std. Dev.</th>
<th>N</th>
</tr>
</thead>
<tbody>
<tr>
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<td>.727</td>
<td>1.024</td>
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**Variable .. c4p3503**

<table>
<thead>
<tr>
<th>Mean</th>
<th>Std. Dev.</th>
<th>N</th>
</tr>
</thead>
<tbody>
<tr>
<td>For entire sample</td>
<td>.986</td>
<td>.802</td>
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**Variable .. p3p3503**

<table>
<thead>
<tr>
<th>Mean</th>
<th>Std. Dev.</th>
<th>N</th>
</tr>
</thead>
<tbody>
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<td>.982</td>
<td>.771</td>
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**Variable .. pzp3503**

<table>
<thead>
<tr>
<th>Mean</th>
<th>Std. Dev.</th>
<th>N</th>
</tr>
</thead>
<tbody>
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<td>.916</td>
<td>.815</td>
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**Variable .. p4p3503**

<table>
<thead>
<tr>
<th>Mean</th>
<th>Std. Dev.</th>
<th>N</th>
</tr>
</thead>
<tbody>
<tr>
<td>For entire sample</td>
<td>.818</td>
<td>.647</td>
</tr>
</tbody>
</table>

**Analysis of Variance -- design 1**

Tests involving 'TASK' Within-Subject Effect.

Tests of Significance for T2 using UNIQUE sums of squares

<table>
<thead>
<tr>
<th>Source of Variation</th>
<th>SS</th>
<th>DF</th>
<th>MS</th>
<th>F</th>
<th>Sig of F</th>
</tr>
</thead>
</table>

---
WITHIN CELLS              23.92      16      1.50
TASK                        .00       1     .00      .00      .962

---

EFFECT .. TASK BY FRTOPOS (Cont.)
Univariate F-tests with (1,16) D. F.

<table>
<thead>
<tr>
<th>Variable</th>
<th>Hypoth. SS</th>
<th>Error SS</th>
<th>Hypoth. MS</th>
<th>Error MS</th>
<th>F</th>
<th>Sig. of F</th>
</tr>
</thead>
<tbody>
<tr>
<td>T7</td>
<td>1.39721</td>
<td>3.79329</td>
<td>1.39721</td>
<td>.23708</td>
<td>5.89338</td>
<td>.027</td>
</tr>
<tr>
<td>T8</td>
<td>.00064</td>
<td>1.75680</td>
<td>.00064</td>
<td>.10980</td>
<td>.00582</td>
<td>.940</td>
</tr>
</tbody>
</table>

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EFFECT .. TASK BY LATERAL (Cont.)
Univariate F-tests with (1,16) D. F.

<table>
<thead>
<tr>
<th>Variable</th>
<th>Hypoth. SS</th>
<th>Error SS</th>
<th>Hypoth. MS</th>
<th>Error MS</th>
<th>F</th>
<th>Sig. of F</th>
</tr>
</thead>
<tbody>
<tr>
<td>T9</td>
<td>.19774</td>
<td>1.34476</td>
<td>.19774</td>
<td>.08405</td>
<td>2.35273</td>
<td>.145</td>
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<tr>
<td>T10</td>
<td>.27838</td>
<td>.62346</td>
<td>.27838</td>
<td>.03897</td>
<td>7.14417</td>
<td>.017</td>
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EFFECT .. TASK BY FRTOPOS BY LATERAL (Cont.)
Univariate F-tests with (1,16) D. F.

<table>
<thead>
<tr>
<th>Variable</th>
<th>Hypoth. SS</th>
<th>Error SS</th>
<th>Hypoth. MS</th>
<th>Error MS</th>
<th>F</th>
<th>Sig. of F</th>
</tr>
</thead>
<tbody>
<tr>
<td>T15</td>
<td>.03141</td>
<td>.51310</td>
<td>.03141</td>
<td>.03207</td>
<td>.97932</td>
<td>.337</td>
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<tr>
<td>T16</td>
<td>.01076</td>
<td>.21095</td>
<td>.01076</td>
<td>.01318</td>
<td>.81589</td>
<td>.380</td>
</tr>
<tr>
<td>T17</td>
<td>.08054</td>
<td>.34043</td>
<td>.08054</td>
<td>.02128</td>
<td>3.78533</td>
<td>.069</td>
</tr>
<tr>
<td>T18</td>
<td>.06475</td>
<td>.56313</td>
<td>.06475</td>
<td>.03520</td>
<td>1.83970</td>
<td>.194</td>
</tr>
</tbody>
</table>

---

**P250 Amplitudes – Normalised**

---

Cell Means and Standard Deviations

Variable .. f3p2501
Mean  Std. Dev.          N

For entire sample                           .751       .543         17

Variable .. frp2501

Mean Std. Dev. N

For entire sample                           .954       .655         17

Variable .. f4p2501

Mean Std. Dev. N

For entire sample                           .908       .631         17

Variable .. c3p2501

Mean Std. Dev. N

For entire sample                           .951       .510         17

Variable .. czp2501

Mean Std. Dev. N

For entire sample                           1.233       .629         17

Variable .. c4p2501

Mean Std. Dev. N

For entire sample                           1.131       .597         17

** * * * * * Analysis of Variance -- design 1 * * * * * **

Cell Means and Standard Deviations (Cont.)

Variable .. p3p2501

Mean Std. Dev. N

For entire sample                           .877       .378         17

Variable .. pzp2501

Mean Std. Dev. N

For entire sample                           1.121       .428         17
<table>
<thead>
<tr>
<th>Variable . . p4p2501</th>
<th>Mean</th>
<th>Std. Dev.</th>
<th>N</th>
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<tbody>
<tr>
<td>For entire sample</td>
<td>.985</td>
<td>.387</td>
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<table>
<thead>
<tr>
<th>Variable . . f3p2503</th>
<th>Mean</th>
<th>Std. Dev.</th>
<th>N</th>
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<tbody>
<tr>
<td>For entire sample</td>
<td>.565</td>
<td>.607</td>
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<table>
<thead>
<tr>
<th>Variable . . fzp2503</th>
<th>Mean</th>
<th>Std. Dev.</th>
<th>N</th>
</tr>
</thead>
<tbody>
<tr>
<td>For entire sample</td>
<td>.843</td>
<td>.717</td>
<td>17</td>
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</tbody>
</table>

<table>
<thead>
<tr>
<th>Variable . . f4p2503</th>
<th>Mean</th>
<th>Std. Dev.</th>
<th>N</th>
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<tbody>
<tr>
<td>For entire sample</td>
<td>.806</td>
<td>.592</td>
<td>17</td>
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</tbody>
</table>

<table>
<thead>
<tr>
<th>Variable . . c3p2503</th>
<th>Mean</th>
<th>Std. Dev.</th>
<th>N</th>
</tr>
</thead>
<tbody>
<tr>
<td>For entire sample</td>
<td>.945</td>
<td>.632</td>
<td>17</td>
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<tr>
<td>Variable . . czp2503</td>
<td>Mean</td>
<td>Std. Dev.</td>
<td>N</td>
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<tr>
<td>For entire sample</td>
<td>1.221</td>
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* * * * * A n a l y s i s   o f   V a r i a n c e   --   d e s i g n   1 * * * * *

<table>
<thead>
<tr>
<th>Cell Means and Standard Deviations (Cont.)</th>
<th>Mean</th>
<th>Std. Dev.</th>
<th>N</th>
</tr>
</thead>
<tbody>
<tr>
<td>Variable . . c4p2503</td>
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</tr>
<tr>
<td>For entire sample</td>
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<table>
<thead>
<tr>
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<th>Mean</th>
<th>Std. Dev.</th>
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Variable .. pzp2503

<table>
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<th>N</th>
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<tr>
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Variable .. p4p2503

<table>
<thead>
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<tbody>
<tr>
<td>1.019</td>
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</table>

* * * * * Analysis of Variance -- design 1 * * * * *

Tests involving 'TASK' Within-Subject Effect.

Tests of Significance for T2 using UNIQUE sums of squares

<table>
<thead>
<tr>
<th>Source of Variation</th>
<th>SS</th>
<th>DF</th>
<th>MS</th>
<th>F</th>
<th>Sig. of F</th>
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<tr>
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<td>15.67</td>
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<td></td>
<td></td>
</tr>
<tr>
<td>TASK</td>
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<td>.01</td>
<td>.01</td>
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EFFECT .. FRTOPOS (Cont.)

Univariate F-tests with (1,16) D. F.

<table>
<thead>
<tr>
<th>Variable</th>
<th>Hypoth. SS</th>
<th>Error SS</th>
<th>Hypoth. MS</th>
<th>Error MS</th>
<th>F</th>
<th>Sig. of F</th>
</tr>
</thead>
<tbody>
<tr>
<td>T3</td>
<td>2.82780</td>
<td>9.88573</td>
<td>2.82780</td>
<td>.61766</td>
<td>4.57677</td>
<td>.048</td>
</tr>
<tr>
<td>T4</td>
<td>2.38142</td>
<td>2.22412</td>
<td>2.38142</td>
<td>.13901</td>
<td>17.13160</td>
<td>.001</td>
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EFFECT .. LATERAL (Cont.)

Univariate F-tests with (1,16) D. F.

<table>
<thead>
<tr>
<th>Variable</th>
<th>Hypoth. SS</th>
<th>Error SS</th>
<th>Hypoth. MS</th>
<th>Error MS</th>
<th>F</th>
<th>Sig. of F</th>
</tr>
</thead>
<tbody>
<tr>
<td>T5</td>
<td>1.14717</td>
<td>2.27648</td>
<td>1.14717</td>
<td>.14228</td>
<td>8.06276</td>
<td>.012</td>
</tr>
<tr>
<td>T6</td>
<td>1.90146</td>
<td>1.13532</td>
<td>1.90146</td>
<td>.07096</td>
<td>26.79728</td>
<td>.000</td>
</tr>
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</table>

EFFECT .. TASK BY FRTOPOS (Cont.)

Univariate F-tests with (1,16) D. F.
### EFFECT .. TASK BY LATERAL (Cont.)

Univariate F-tests with (1, 16) D. F.

<table>
<thead>
<tr>
<th>Variable</th>
<th>Hypoth. SS</th>
<th>Error SS</th>
<th>Hypoth. MS</th>
<th>Error MS</th>
<th>F</th>
<th>Sig. of F</th>
</tr>
</thead>
<tbody>
<tr>
<td>T9</td>
<td>.00019</td>
<td>.30835</td>
<td>.00019</td>
<td>.01927</td>
<td>.00997</td>
<td>.922</td>
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<tr>
<td>T10</td>
<td>.00021</td>
<td>.44071</td>
<td>.00021</td>
<td>.02754</td>
<td>.00757</td>
<td>.932</td>
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### EFFECT .. FRTOPOS BY LATERAL (Cont.)

Univariate F-tests with (1, 16) D. F.

<table>
<thead>
<tr>
<th>Variable</th>
<th>Hypoth. SS</th>
<th>Error SS</th>
<th>Hypoth. MS</th>
<th>Error MS</th>
<th>F</th>
<th>Sig. of F</th>
</tr>
</thead>
<tbody>
<tr>
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<td>.37473</td>
<td>.19743</td>
<td>.02342</td>
<td>8.42979</td>
<td>.010</td>
</tr>
<tr>
<td>T12</td>
<td>.02057</td>
<td>.17022</td>
<td>.02057</td>
<td>.01064</td>
<td>1.93316</td>
<td>.183</td>
</tr>
<tr>
<td>T13</td>
<td>.07518</td>
<td>.52264</td>
<td>.07518</td>
<td>.03266</td>
<td>2.30165</td>
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### EFFECT .. TASK BY FRTOPOS BY LATERAL (Cont.)

Univariate F-tests with (1, 16) D. F.

<table>
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<tr>
<th>Variable</th>
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<th>Error SS</th>
<th>Hypoth. MS</th>
<th>Error MS</th>
<th>F</th>
<th>Sig. of F</th>
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<tbody>
<tr>
<td>T15</td>
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**P300 Amplitudes - Normalised**

Cell Means and Standard Deviations

<table>
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<th>Mean</th>
<th>Std. Dev.</th>
<th>N</th>
</tr>
</thead>
<tbody>
<tr>
<td>For entire sample</td>
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<table>
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<table>
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<th>Mean</th>
<th>Std. Dev.</th>
<th>N</th>
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<tr>
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<tr>
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**Analysis of Variance -- design 1**

Cell Means and Standard Deviations (Cont.)

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<td>.477</td>
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<td>1.066</td>
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<td>f3p33</td>
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<td>Std. Dev.</td>
<td>N</td>
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** * * * * A n a l y s i s o f V a r i a n c e -- d e s i g n 1 * * * * **

Cell Means and Standard Deviations (Cont.)

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### Analysis of Variance

For entire sample | 1.018 | .566 | 17

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Tests involving 'TASK' Within-Subject Effect.

Tests of Significance for T2 using UNIQUE sums of squares

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<thead>
<tr>
<th>Source of Variation</th>
<th>SS</th>
<th>DF</th>
<th>MS</th>
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<th>Sig of F</th>
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EFFECT .. FRTOPOS (Cont.)

Univariate F-tests with (1,16) D. F.

<table>
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<th>Variable</th>
<th>Hypoth. SS</th>
<th>Error SS</th>
<th>Hypoth. MS</th>
<th>Error MS</th>
<th>F</th>
<th>Sig of F</th>
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<tbody>
<tr>
<td>T3</td>
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EFFECT .. LATERAL (Cont.)

Univariate F-tests with (1,16) D. F.

<table>
<thead>
<tr>
<th>Variable</th>
<th>Hypoth. SS</th>
<th>Error SS</th>
<th>Hypoth. MS</th>
<th>Error MS</th>
<th>F</th>
<th>Sig of F</th>
</tr>
</thead>
<tbody>
<tr>
<td>T5</td>
<td>.06034</td>
<td>2.27322</td>
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<tr>
<td>T6</td>
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<td>1.01331</td>
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EFFECT .. TASK BY FRTOPOS (Cont.)

Univariate F-tests with (1,16) D. F.

<table>
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<th>Hypoth. MS</th>
<th>Error MS</th>
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<th>Sig of F</th>
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EFFECT .. TASK BY LATERAL (Cont.)

Univariate F-tests with (1,16) D. F.
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<th>Hypoth. MS</th>
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<th>F</th>
<th>Sig. of F</th>
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</thead>
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<td>T13</td>
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<td>.02621</td>
<td>.02125</td>
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<table>
<thead>
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<th>Error MS</th>
<th>F</th>
<th>Sig. of F</th>
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</thead>
<tbody>
<tr>
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<td>.11322</td>
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<td>1.86712</td>
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<tr>
<td>T17</td>
<td>.00273</td>
<td>.03199</td>
<td>.00273</td>
<td>.00200</td>
<td>1.36633</td>
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<tr>
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<td>.01891</td>
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### N140 Amplitudes – Normalised – targets vs non-targets

#### Cell Means and Standard Deviations

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<tr>
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<th>Mean</th>
<th>Std. Dev.</th>
<th>N</th>
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<tbody>
<tr>
<td>For entire sample</td>
<td>-1.152</td>
<td>.710</td>
<td>17</td>
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</tbody>
</table>

<table>
<thead>
<tr>
<th>Variable</th>
<th>Mean</th>
<th>Std. Dev.</th>
<th>N</th>
</tr>
</thead>
<tbody>
<tr>
<td>For entire sample</td>
<td>-1.445</td>
<td>.914</td>
<td>17</td>
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</table>

<table>
<thead>
<tr>
<th>Variable</th>
<th>Mean</th>
<th>Std. Dev.</th>
<th>N</th>
</tr>
</thead>
<tbody>
<tr>
<td>For entire sample</td>
<td>-1.298</td>
<td>.873</td>
<td>17</td>
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</table>
**Variable .. f3n1302**

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**Variable .. fzn1302**

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**Variable .. f4n1302**

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**Analysis of Variance -- design 1**

Tests involving 'TASK' Within-Subject Effect.

<table>
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<th>SS</th>
<th>DF</th>
<th>MS</th>
<th>F</th>
<th>Sig of F</th>
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<tbody>
<tr>
<td>WITHIN CELLS</td>
<td>2.28</td>
<td>16</td>
<td>.14</td>
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</tr>
<tr>
<td>TASK</td>
<td>.22</td>
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</table>

Effect .. FRONTAL (Cont.)

Univariate F-tests with (1,16) D. F.

<table>
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<tr>
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<th>Hypoth. SS</th>
<th>Error SS</th>
<th>Hypoth. MS</th>
<th>Error MS</th>
<th>F</th>
<th>Sig. of F</th>
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</thead>
<tbody>
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Effect .. TASK BY FRONTAL (Cont.)

Univariate F-tests with (1,16) D. F.

<table>
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<th>Hypoth. MS</th>
<th>Error MS</th>
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<tbody>
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**N140 Amplitudes – Normalised – 2 stimulus targets vs. 3 stimulus targets**

Cell Means and Standard Deviations

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<th>Variable</th>
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<th>Std. Dev.</th>
<th>N</th>
</tr>
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<tbody>
<tr>
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<tr>
<td>For entire sample</td>
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<tr>
<td>fzn1301</td>
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<td>17</td>
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<tr>
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<tr>
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</table>

* * * * * Analysis of Variance -- design 1 * * * * *

Tests involving 'TASK' Within-Subject Effect.

Tests of Significance for T2 using UNIQUE sums of squares

<table>
<thead>
<tr>
<th>Source of Variation</th>
<th>SS</th>
<th>DF</th>
<th>MS</th>
<th>F</th>
<th>Sig of F</th>
</tr>
</thead>
<tbody>
<tr>
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EFFECT . FRONTAL (Cont.)

Univariate F-tests with (1,16) D. F.

<table>
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<th>Hypoth. SS</th>
<th>Error SS</th>
<th>Hypoth. MS</th>
<th>Error MS</th>
<th>F</th>
<th>Sig. of F</th>
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</thead>
<tbody>
<tr>
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EFFECT . TASK BY FRONTAL (Cont.)

Univariate F-tests with (1,16) D. F.

<table>
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<th>Hypoth. MS</th>
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<td>.02134</td>
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Latency

**N100 Latency**

Cell Means and Standard Deviations

<table>
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<th>Std. Dev.</th>
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<table>
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<tbody>
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<table>
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</thead>
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<table>
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<tbody>
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Variable .. czn11

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Variable .. c4n11

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**Analysis of Variance -- design 1**

Cell Means and Standard Deviations (Cont.)

Variable .. p3n11

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Variable . . c3n12
For entire sample                        112.824      7.748         17

Variable . . czn12
For entire sample                        113.882      5.633         17

* * * * * * A n a l y s i s   o f   V a r i a n c e -- design 1 * * * * * *

Cell Means and Standard Deviations (Cont.)
Variable . . c4n12
For entire sample                        113.765      6.359         17

Variable . . p3n12
For entire sample                        114.588      5.864         17

Variable . . pzn12
For entire sample                        113.412      5.038         17

Variable . . p4n12
For entire sample                        113.765      7.276         17

Variable . . f3n13
For entire sample                        106.941      7.215         17

Variable . . fzn13
For entire sample                        109.059      6.046         17
Variable .. f4n13

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For entire sample

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For entire sample

**Analysis of Variance -- design 1**

Cell Means and Standard Deviations (Cont.)

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For entire sample

**EFFECT .. TASK (Cont.)**

Univariate F-tests with (1,16) D. F.
### EFFECT .. TASK BY LATE

**Univariate F-tests with (1, 16) D. F.**

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<tr>
<th>Variable</th>
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<th>Hypoth. MS</th>
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### EFFECT .. LATERAL (Cont.)

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### EFFECT .. TASK BY FRTOPOS (Cont.)

**Univariate F-tests with (1, 16) D. F.**

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### EFFECT .. TASK BY LATERAL (Cont.)

**Univariate F-tests with (1, 16) D. F.**

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### EFFECT .. FRTOPOS BY LATERAL (Cont.)

Univariate F-tests with (1,16) D. F.

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### EFFECT .. TASK BY FRTOPOS BY LATERAL (Cont.)

Univariate F-tests with (1,16) D. F.

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<th>Variable</th>
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<th>Hypoth. MS</th>
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### P200 Latency

Cell Means and Standard Deviations

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For entire sample 190.588 13.449 17

Variable .. czp21

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For entire sample 190.824 13.324 17

Variable .. c4p21

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For entire sample 191.529 13.703 17

* * * * * Analysis of Variance -- design 1 * * * * *

Cell Means and Standard Deviations (Cont.)
Variable .. p3p21

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For entire sample 194.118 16.209 17

Variable .. pzp21

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For entire sample 193.059 15.734 17

Variable .. p4p21

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For entire sample 193.176 15.985 17

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For entire sample 194.941 11.272 17

Variable .. fzp22

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For entire sample 194.706 10.838 17
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**Analysis of Variance -- design 1**

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**Analysis of Variance -- design 1**

Cell Means and Standard Deviations (Cont.)

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EFFECT .. TASK (Cont.)
Univariate F-tests with (1,16) D. F.

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Univariate F-tests with (1,16) D. F.

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Univariate F-tests with (1,16) D. F.

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Univariate F-tests with (1,16) D. F.

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Univariate F-tests with (1,16) D. F.

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**N220 Latency**

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Cell Means and Standard Deviations

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**Analysis of Variance -- design 1**

#### Cell Means and Standard Deviations (Cont.)

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** * * * * * Analysis of Variance -- design 1 * * * * * **

Cell Means and Standard Deviations (Cont.)

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**Analysis of Variance -- design 1**

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For entire sample: 221.412 15.391 17

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**EFFECT .. TASK (Cont.)**

Univariate F-tests with (1,16) D. F.

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**EFFECT .. FRTOPos (Cont.)**

Univariate F-tests with (1,16) D. F.

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**EFFECT .. LATERAL (Cont.)**

Univariate F-tests with (1,16) D. F.

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**EFFECT .. TASK BY FRTOpOS (Cont.)**

Univariate F-tests with (1,16) D. F.

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**EFFECT .. TASK BY LATERAL (Cont.)**

Univariate F-tests with (1,16) D. F.

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### Cell Means and Standard Deviations

**Variable**: f3p3501

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**Variable**: fzp3501

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For entire sample                             343.176     18.372         17

* * * * * Analysis of Variance -- design 1 * * * * *

Tests involving 'TASK' Within-Subject Effect.

Tests of Significance for T2 using UNIQUE sums of squares

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EFFECT .. TASK BY FRTOPOS (Cont.)

Univariate F-tests with (1,16) D. F.

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EFFECT .. TASK BY LATERAL (Cont.)

Univariate F-tests with (1,16) D. F.

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EFFECT .. TASK BY FRTOPOS BY LATERAL (Cont.)

Univariate F-tests with (1,16) D. F.

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### Cell Means and Standard Deviations

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**Tests involving 'TASK' Within-Subject Effect.**

Univariate F-tests with (1,16) D. F.

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Univariate F-tests with (1,16) D. F.

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EFFECT .. TASK BY FRTOPOS BY LATERAL (Cont.)

Univariate F-tests with (1,16) D. F.

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P250 Latency – Targets only

Cell Means and Standard Deviations

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<th>Std. Dev.</th>
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Mean  Std. Dev.          N
For entire sample                        252.000     13.748         17

* * * * * A n a l y s i s   o f   V a r i a n c e -- design l * * * * *

Cell Means and Standard Deviations (Cont.)
Variable .. p3p2501
Mean  Std. Dev.          N
For entire sample                        257.647     9.414         17

Variable .. pzp2501
Mean  Std. Dev.          N
For entire sample                        255.412     10.926         17

Variable .. p4p2501
Mean  Std. Dev.          N
For entire sample                        259.294     12.449         17

Variable .. f3p2503
Mean  Std. Dev.          N
For entire sample                        249.647     11.774         17

Variable .. fzp2503
Mean  Std. Dev.          N
For entire sample                        250.471     12.094         17

Variable .. f4p2503
Mean  Std. Dev.          N
For entire sample                        251.176     12.411         17

Variable .. c3p2503
Mean  Std. Dev.          N
For entire sample                        248.588     16.625         17
Variable .. czp2503
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<tbody>
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**Analysis of Variance -- design 1**

Tests involving 'TASK' Within-Subject Effect.

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EFFECT .. FRTOPOS (Cont.)

Univariate F-tests with (1,16) D. F.

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<th>Error SS</th>
<th>Hypoth. MS</th>
<th>Error MS</th>
<th>F</th>
<th>Sig. of F</th>
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<td>Error SS</td>
<td>Hypoth. MS</td>
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<td>Sig. of F</td>
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<tr>
<td>T5</td>
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<td>1812.3524</td>
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<td>113.27206</td>
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**EFFECT .. LATERAL (Cont.)**

Univariate F-tests with (1,16) D. F.

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<th>Hypoth. MS</th>
<th>Error MS</th>
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**EFFECT .. TASK BY FRTOPOS (Cont.)**

Univariate F-tests with (1,16) D. F.

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<th>Hypoth. MS</th>
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**EFFECT .. TASK BY LATERAL (Cont.)**

Univariate F-tests with (1,16) D. F.

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<td>T12</td>
<td>38.91176</td>
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<td>T13</td>
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<td>624.35249</td>
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<td>T14</td>
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<td>410.77124</td>
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**EFFECT .. FRTOPOS BY LATERAL (Cont.)**

Univariate F-tests with (1,16) D. F.
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<td>T16</td>
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<td>497.92157</td>
<td>.24510</td>
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<td>9.17974</td>
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**P300 Latency - Targets only**

Cell Means and Standard Deviations

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<tbody>
<tr>
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<td>16.523</td>
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<th>N</th>
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<tbody>
<tr>
<td>For entire sample</td>
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<table>
<thead>
<tr>
<th>Variable</th>
<th>Mean</th>
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<tr>
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**Analysis of Variance -- design 1**

Cell Means and Standard Deviations (Cont.)

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### Analysis of Variance -- design 1

Cell Means and Standard Deviations (Cont.)

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Tests involving 'TASK' Within-Subject Effect.

Tests of Significance for T2 using UNIQUE sums of squares

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EFFECT .. FRTPOS (Cont.)

Univariate F-tests with (1,16) D. F.

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<th>Error SS</th>
<th>Hypoth. MS</th>
<th>Error MS</th>
<th>F</th>
<th>Sig. of F</th>
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<td>Error SS</td>
<td>Hypoth. MS</td>
<td>Error MS</td>
<td>F</td>
<td>Sig. of F</td>
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### N140 Latency

Cell Means and Standard Deviations

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Variable .. fzn1303

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Variable .. f4n1303

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EFFECT .. TASK (Cont.)

Univariate F-tests with (1,16) D. F.

<table>
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<tr>
<th>Variable</th>
<th>Hypoth. SS</th>
<th>Error SS</th>
<th>Hypoth. MS</th>
<th>Error MS</th>
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EFFECT .. LATERAL (Cont.)

Univariate F-tests with (1,16) D. F.

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<th>Hypoth. MS</th>
<th>Error MS</th>
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EFFECT .. TASK BY LATERAL (Cont.)

Univariate F-tests with (1,16) D. F.

<table>
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<tr>
<th>Variable</th>
<th>Hypoth. SS</th>
<th>Error SS</th>
<th>Hypoth. MS</th>
<th>Error MS</th>
<th>F</th>
<th>Sig. of F</th>
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<tbody>
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<td>295.41176</td>
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<td>13.83007</td>
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<td>8.37173</td>
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<td>T8</td>
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### N285 Latency

Cell Means and Standard Deviations

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<th>95 percent Conf.</th>
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<tr>
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Variable .. czln2

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Variable .. c4ln2

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Variable .. p3ln2

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<tr>
<td>284.235</td>
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Variable .. pzln2

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Variable .. p4ln2

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EFFECT .. FRTOPOS (Cont.)

Univariate F-tests with (1,16) D. F.

<table>
<thead>
<tr>
<th>Variable</th>
<th>Hypoth. SS</th>
<th>Error SS</th>
<th>Hypoth. MS</th>
<th>Error MS</th>
<th>F</th>
<th>Sig. of F</th>
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<tbody>
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EFFECT .. LATERAL (Cont.)

Univariate F-tests with (1,16) D. F.

<table>
<thead>
<tr>
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<th>Error SS</th>
<th>Hypoth. MS</th>
<th>Error MS</th>
<th>F</th>
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<tbody>
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EFFECT .. FRTOPOS BY LATERAL (Cont.)

Univariate F-tests with (1,16) D. F.

<table>
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<th>Variable</th>
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<th>Hypoth. MS</th>
<th>Error MS</th>
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<tbody>
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<td>T6</td>
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<tr>
<td>T8</td>
<td>.01961</td>
<td>357.64706</td>
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<td>T9</td>
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### Topographic analysis of peak-picked amplitude data

**N100**

<table>
<thead>
<tr>
<th>Variable</th>
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<tr>
<td>For entire sample</td>
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<td>2.831</td>
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<tr>
<td>Variable .. F1F2</td>
<td>Mean</td>
<td>Std. Dev.</td>
<td>N</td>
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<tr>
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<tr>
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<tr>
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**EFFECT .. FRTOPOS (Cont.)**

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EFFECT .. LATERAL (Cont.)
Univariate F-tests with (1,42) D. F.

<table>
<thead>
<tr>
<th>Variable</th>
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<th>Error SS</th>
<th>Hypoth. MS</th>
<th>Error MS</th>
<th>F</th>
<th>Sig. of F</th>
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EFFECT .. FRTOPOS BY LATERAL (Cont.)
Univariate F-tests with (1,42) D. F.

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<th>Variable</th>
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<th>Hypoth. MS</th>
<th>Error MS</th>
<th>F</th>
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Cell Means and Standard Deviations

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Variable  ..  F2Pz
For entire sample  -2.295  3.234  43

Variable  ..  F2P4
For entire sample  -2.436  2.681  43

EFFECT  ..  FRTOPOS (Cont.)
Univariate F-tests with (1,42) D. F.

<table>
<thead>
<tr>
<th>Variable</th>
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<th>Hypoth. MS</th>
<th>Error MS</th>
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<th>Sig. of F</th>
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EFFECT  ..  LATERAL (Cont.)
Univariate F-tests with (1,42) D. F.

<table>
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<th>Hypoth. MS</th>
<th>Error MS</th>
<th>F</th>
<th>Sig. of F</th>
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</thead>
<tbody>
<tr>
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EFFECT  ..  FRTOPOS BY LATERAL (Cont.)
Univariate F-tests with (1,42) D. F.

<table>
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<tr>
<th>Variable</th>
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<th>Hypoth. MS</th>
<th>Error MS</th>
<th>F</th>
<th>Sig. of F</th>
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<tbody>
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<td>T7</td>
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<td>.86040</td>
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<td>5.29214</td>
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Cell Means and Standard Deviations

<table>
<thead>
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<th>Std. Dev.</th>
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<table>
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Variable: F3C3
Mean  Std. Dev.  N
For entire sample 8.564 3.450 43

Variable: F3Cz
Mean  Std. Dev.  N
For entire sample 10.827 5.222 43

Variable: F3C4
Mean  Std. Dev.  N
For entire sample 8.799 4.073 43

Variable: F3P3
Mean  Std. Dev.  N
For entire sample 5.736 2.834 43

Variable: F3Pz
Mean  Std. Dev.  N
For entire sample 7.286 3.788 43

Variable: F3P4
Mean  Std. Dev.  N
For entire sample 5.951 3.054 43

EFFECT: FRTOPOS (Cont.)
Univariate F-tests with (1,42) D. F.
Variable   Hypoth. SS   Error SS Hypoth. MS   Error MS          F  Sig. of F
T2            2.24417 1000.71311    2.24417   23.82650     .09419       .760
T3          861.91936  314.18862  861.91936    7.48068  115.21937       .000

EFFECT: LATERAL (Cont.)
Univariate F-tests with (1,42) D. F.
Variable   Hypoth. SS   Error SS Hypoth. MS   Error MS          F  Sig. of F
T4             .05687   41.89977     .05687     .99761     .05701       .812
T5           12.49497   37.73101   12.49497     .89836   13.90869       .001
T8             .00409   18.95980     .00409     .45142     .00905       .925
T9           26.15315   37.39019   26.15315     .89024   29.37755       .000
**Cell Means and Standard Deviations**

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**EFFECT .. FRTOPOS (Cont.)**

Univariate F-tests with (1,42) D. F.

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EFFECT .. LATERAL (Cont.)
Univariate F-tests with (1,42) D. F.

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EFFECT .. FRTOPOS BY LATERAL (Cont.)
Univariate F-tests with (1,42) D. F.

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P300

Cell Means and Standard Deviations

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Variable .. F5Pz
Mean  Std. Dev.          N
For entire sample                          6.172      3.949         43

Variable .. F5P4
Mean  Std. Dev.          N
For entire sample                          5.662      3.605         43

EFFECT .. FRTOPOS (Cont.)
Univariate F-tests with (1,42) D. F.
Variable   Hypoth. SS   Error SS Hypoth. MS   Error MS          F  Sig. of F
T2          179.63646  527.30508  179.63646   12.55488   14.30810       .000
T3             .08385  181.35390     .08385    4.31795     .01942       .890

EFFECT .. LATERAL (Cont.)
Univariate F-tests with (1,42) D. F.
Variable   Hypoth. SS   Error SS Hypoth. MS   Error MS          F  Sig. of F
T4           19.58380   88.90013   19.58380    2.11667    9.25217       .004
T5             .20965   91.93698     .20965    2.18898     .09577       .758

EFFECT .. FRTOPOS BY LATERAL (Cont.)
Univariate F-tests with (1,42) D. F.
Variable   Hypoth. SS   Error SS Hypoth. MS   Error MS          F  Sig. of F
T6            2.65107   52.30230    2.65107    1.24529    2.12887       .152
T7            3.70518   25.23800    3.70518     .60090    6.16600       .017
T8            5.22713   36.93085    5.22713     .87931    5.94461       .019
T9           11.39685   35.29999   11.39685     .84048   13.56000       .001

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Cell Means and Standard Deviations
Variable .. F6F3
Mean  Std. Dev.          N
For entire sample                          2.888      3.502         43

Variable .. F6Fz
Mean  Std. Dev.          N
For entire sample                          2.564      3.787         43

Variable .. F6F4
Mean  Std. Dev.          N
For entire sample                          3.144      3.245         43
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**EFFECT .. FRTOPOS (Cont.)**

Univariate F-tests with (1,42) D. F.

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**EFFECT .. LATERAL (Cont.)**

Univariate F-tests with (1,42) D. F.

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**EFFECT .. FRTOPOS BY LATERAL (Cont.)**

Univariate F-tests with (1,42) D. F.

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For entire sample                          5.320      3.767         43

Variable .. F7P4

For entire sample                          4.222      3.354         43

EFFECT .. FRTOPOS (Cont.)
Univariate F-tests with (1,42) D. F.

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<th>Error MS</th>
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EFFECT .. LATERAL (Cont.)
Univariate F-tests with (1,42) D. F.

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EFFECT .. FRTOPOS BY LATERAL (Cont.)
Univariate F-tests with (1,42) D. F.

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<td>18.91645</td>
<td>.32589</td>
<td>.45039</td>
<td>.72358</td>
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<tr>
<td>T9</td>
<td>9.60134</td>
<td>49.46383</td>
<td>9.60134</td>
<td>1.17771</td>
<td>8.15255</td>
<td>.007</td>
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</tbody>
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# Principles Components Analysis – Topographic analysis of factor scores

## Factor 1

### Cell Means and Standard Deviations

<table>
<thead>
<tr>
<th>Variable ..</th>
<th>F1</th>
<th>F3</th>
<th>Mean</th>
<th>Std. Dev.</th>
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<tbody>
<tr>
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<td>1.005</td>
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### Variable .. F1Fz

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**EFFECT .. FRTOPOS (Cont.)**

Univariate F-tests with (1,42) D. F.

<table>
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<tr>
<th>Variable</th>
<th>Hypoth. SS</th>
<th>Error SS</th>
<th>Hypoth. MS</th>
<th>Error MS</th>
<th>F</th>
<th>Sig. of F</th>
</tr>
</thead>
<tbody>
<tr>
<td>T2</td>
<td>1.24108</td>
<td>67.28230</td>
<td>1.24108</td>
<td>1.60196</td>
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<tr>
<td>T3</td>
<td>56.60559</td>
<td>18.65983</td>
<td>56.60559</td>
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### EFFECT .. LATERAL (Cont.)
Univariate F-tests with (1,42) D. F.

<table>
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<tr>
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<th>Hypoth. SS</th>
<th>Error SS</th>
<th>Hypoth. MS</th>
<th>Error MS</th>
<th>F</th>
<th>Sig. of F</th>
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</thead>
<tbody>
<tr>
<td>T4</td>
<td>.05906</td>
<td>5.98886</td>
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<td>.14259</td>
<td>.41417</td>
<td>.523</td>
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<td>3.00421</td>
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### EFFECT .. FRPOS BY LATERAL (Cont.)
Univariate F-tests with (1,42) D. F.

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<th>Hypoth. MS</th>
<th>Error MS</th>
<th>F</th>
<th>Sig. of F</th>
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### Factor 2

#### Cell Means and Standard Deviations

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<tr>
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<td>Variable .. F2F3</td>
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<td></td>
<td></td>
</tr>
<tr>
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### Variable .. F2P3

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### Variable .. F2Pz

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### Variable .. F2P4

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**EFFECT .. FROPOS (Cont.)**

Univariate F-tests with (1, 42) D. F.

<table>
<thead>
<tr>
<th>Variable</th>
<th>Hypoth. SS</th>
<th>Error SS</th>
<th>Hypoth. MS</th>
<th>Error MS</th>
<th>F</th>
<th>Sig. of F</th>
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<tbody>
<tr>
<td>T2</td>
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<td>47.33691</td>
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<td>T3</td>
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**EFFECT .. LATERAL (Cont.)**

Univariate F-tests with (1, 42) D. F.

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<th>Variable</th>
<th>Hypoth. SS</th>
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<th>Hypoth. MS</th>
<th>Error MS</th>
<th>F</th>
<th>Sig. of F</th>
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<tbody>
<tr>
<td>T4</td>
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<td>.17712</td>
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<td>T5</td>
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**EFFECT .. FROPOS BY LATERAL (Cont.)**

Univariate F-tests with (1, 42) D. F.

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<tr>
<th>Variable</th>
<th>Hypoth. SS</th>
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<th>Hypoth. MS</th>
<th>Error MS</th>
<th>F</th>
<th>Sig. of F</th>
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</thead>
<tbody>
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**Factor 3**

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**Cell Means and Standard Deviations**

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<tbody>
<tr>
<td>For entire sample</td>
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<td>1.089</td>
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<table>
<thead>
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<th>N</th>
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<tr>
<td>For entire sample</td>
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### Variable .. F3F4

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For entire sample

### Variable .. F3C3

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For entire sample

### Variable .. F3Cz

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For entire sample

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For entire sample

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For entire sample

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For entire sample

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For entire sample

### EFFECT .. FRTOPOS (Cont.)

Univariate F-tests with (1,42) D. F.

<table>
<thead>
<tr>
<th>Variable</th>
<th>Hypoth. SS</th>
<th>Error SS Hypoth. MS</th>
<th>Error MS</th>
<th>F</th>
<th>Sig. of F</th>
</tr>
</thead>
<tbody>
<tr>
<td>T2</td>
<td>21.39953</td>
<td>48.05973</td>
<td>21.39953</td>
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<tr>
<td>T3</td>
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<td>.40650</td>
<td>.35782</td>
<td>1.13604</td>
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### EFFECT .. LATERAL (Cont.)

Univariate F-tests with (1,42) D. F.

<table>
<thead>
<tr>
<th>Variable</th>
<th>Hypoth. SS</th>
<th>Error SS Hypoth. MS</th>
<th>Error MS</th>
<th>F</th>
<th>Sig. of F</th>
</tr>
</thead>
<tbody>
<tr>
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<td>6.03894</td>
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### EFFECT .. FRTOPOS BY LATERAL (Cont.)

Univariate F-tests with (1,42) D. F.

<table>
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<th>Variable</th>
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<th>Error SS Hypoth. MS</th>
<th>Error MS</th>
<th>F</th>
<th>Sig. of F</th>
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### Factor 4

**Variable .. F4F3**

<table>
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**Variable .. F4Fz**

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**Variable .. F4F4**

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</thead>
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**Variable .. F4C3**

<table>
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**Variable .. F4Cz**

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**Variable .. F4C4**

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**Variable .. F4P3**

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**Variable .. F4Pz**

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**Variable .. F4P4**

<table>
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<td>1.157</td>
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**EFFECT .. FRTPOS (Cont.)**

Univariate F-tests with (1,42) D. F.
Variable   Hypoth. SS   Error SS Hypoth. MS   Error MS          F  Sig. of F
T2            1.28140   51.21768    1.28140    1.21947    1.05079       .311
T3            6.59548   16.31597    6.59548     .38848   16.97785       .000

EFFECT .. LATERAL (Cont.)
Univariate F-tests with (1,42) D. F.

Variable   Hypoth. SS   Error SS Hypoth. MS   Error MS          F  Sig. of F
T4             .03494   10.03872     .03494     .23902     .14619       .704
T5            2.02493    7.69559    2.02493     .18323   11.05141       .002

EFFECT .. FRTOPOS BY LATERAL (Cont.)
Univariate F-tests with (1,42) D. F.

Variable   Hypoth. SS   Error SS Hypoth. MS   Error MS          F  Sig. of F
T6             .00787    3.42912     .00787     .08165     .09634       .758
T7             .15148    2.03026     .15148     .04834    3.13367       .084
T8             .01168    1.88640     .01168     .04491     .26016       .613
T9            1.96137    2.22522    1.96137     .05298   37.01999       .000

Factor 5

Cell Means and Standard Deviations
Variable .. F5F3
Mean  Std. Dev.          N
For entire sample                          -.136      1.118         43

Variable .. F5Fz
Mean  Std. Dev.          N
For entire sample                          -.262      1.232         43

Variable .. F5F4
Mean  Std. Dev.          N
For entire sample                          -.121      1.108         43

Variable .. F5C3
Mean  Std. Dev.          N
For entire sample                           .026      1.026         43

Variable .. F5Cz
Mean  Std. Dev.          N
For entire sample                          -.307      1.145         43

Variable .. F5C4
Mean  Std. Dev.          N
For entire sample                          -.038      1.000         43
Variable .. F5P3

<table>
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<tr>
<th>Mean</th>
<th>Std. Dev.</th>
<th>N</th>
</tr>
</thead>
<tbody>
<tr>
<td>For entire sample</td>
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Variable .. F5Pz

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Variable .. F5P4

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EFFECT .. FRTOPOS (Cont.)
Univariate F-tests with (1,42) D. F.

<table>
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EFFECT .. LATERAL (Cont.)
Univariate F-tests with (1,42) D. F.

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EFFECT .. FRTOPOS BY LATERAL (Cont.)
Univariate F-tests with (1,42) D. F.

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<th>Sig. of F</th>
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Factor 6

Cell Means and Standard Deviations

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Variable .. F6Fz

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**EFFECT .. FRTOPOS (Cont.)**

Univariate F-tests with (1,42) D. F.

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**EFFECT .. LATERAL (Cont.)**

Univariate F-tests with (1,42) D. F.

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**EFFECT .. FRTOPOS BY LATERAL (Cont.)**

Univariate F-tests with (1,42) D. F.
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**Factor 7**

Cell Means and Standard Deviations

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Univariate F-tests with (1, 42) D. F.

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### EFFECT .. LATERAL (Cont.)
Univariate F-tests with (1, 42) D. F.

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### EFFECT .. FRTOPOS BY LATERAL (Cont.)
Univariate F-tests with (1, 42) D. F.

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### Factor 8

#### Cell Means and Standard Deviations

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For entire sample                           .066       1.100         43

Variable .. F8P3
For entire sample                           .098       1.011         43

Variable .. F8Pz
Mean  Std. Dev.          N
For entire sample                           .182       1.216         43

Variable .. F8P4
Mean  Std. Dev.          N
For entire sample                           .164       1.085         43

- - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - -

EFFECT .. FRTOPOS (Cont.)
Univariate F-tests with (1,42) D. F.

<table>
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<th>Hypoth. MS</th>
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EFFECT .. LATERAL (Cont.)
Univariate F-tests with (1,42) D. F.

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EFFECT .. FRTOPOS BY LATERAL (Cont.)
Univariate F-tests with (1,42) D. F.

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Factor 9

Cell Means and Standard Deviations
Variable .. F9F3
For entire sample                           .040       .981         43

Variable .. F9Fz
Mean  Std. Dev.          N
For entire sample                           .040       .981         43
For entire sample                           .038      1.090         43
Variable .. F9F4                            
For entire sample                           .032      1.099         43
Variable .. F9C3                            
For entire sample                          -.048      1.022         43
Variable .. F9C2                            
For entire sample                           .161      1.291         43
Variable .. F9C4                            
For entire sample                           .079      1.112         43
Variable .. F9P3                            
For entire sample                          -.180      1.130         43
Variable .. F9P2                            
For entire sample                           .087      1.114         43
Variable .. F9P4                            
For entire sample                           .025       .954         43

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EFFECT .. FRTOPOS (Cont.)
Univariate F-tests with (1,42) D. F.

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<tr>
<th>Variable</th>
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<th>Error MS</th>
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<th>Sig. of F</th>
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EFFECT .. LATERAL (Cont.)
Univariate F-tests with (1,42) D. F.

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EFFECT .. FRTOP BY LATERAL (Cont.)
Univariate F-tests with (1,42) D. F.

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<th>Hypoth. MS</th>
<th>Error MS</th>
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<th>Sig. of F</th>
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### Post hoc Analysis – Factor 6 (N140) Outer Hemispheres vs. Midline

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**Cell Means and Standard Deviations**

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**** Analysis of Variance -- design 1 ****

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**Cell Means and Standard Deviations (Cont.)**

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EFFECT .. FRTOPOS (Cont.)
Univariate F-tests with (1,42) D. F.

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<th>Hypoth. MS</th>
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<th>Sig. of F</th>
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EFFECT .. LATERAL (Cont.)
Univariate F-tests with (1,42) D. F.

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EFFECT .. FRTOPOS BY LATERAL (Cont.)
Univariate F-tests with (1,42) D. F.

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