The psychology of reading: temporal processing and reading

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The Psychology of Reading: Temporal Processing and Reading

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SOURCES STATEMENT

The present thesis describes original research undertaken in the Department of Psychology, University of Wollongong. To the best of my knowledge and belief, any theories ar l techniques not my own have been acknowledged in the text. The theoretical contributions in this thesis are my own original work and the thesis has not been submitted for any other degree to any other university or institution.

Agnes Au

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ABSTRACT

Dyslexics exhibit visual and auditory temporal processing deficits and these have been attributed to some abnormality in their sensory systems specialising in processing rapidly presented stimuli - transient systems. As a result, a generalised temporal processing deficit across modalities has been hypothesised. Research also shows a relationship between auditory temporal processing deficits and phonological deficits (deficits in reading nonsense words) and it is suggested that visual temporal processing deficits may be related to deficits in reading irregular words (Farmer & Klein, 1995). In addition, it has been argued that the sustained visual system is involved in reading singly presented words whereas the transient visual system is involved in reading continuous presented text (Hill & Lovegrove, 1992).

Therefore, this thesis investigated in normal readers: 1) whether there is a common temporal processing mechanism across vision and audition; 2) the relationship between auditory temporal processing and nonsense word performance, and between visual temporal processing and irregular word performance; 3) the role of the sustained and transient visual systems in reading single words and continuous text; and 4) whether good readers exhibit better temporal resolution than normal readers.

Results are suggestive of a common temporal processing mechanism across modalities. Visual temporal processing is related to irregular words whereas auditory temporal processing is related to nonsense words. The transient visual system is involved in processing continuous text whereas the sustained visual system is involved in processing single text. "Nonsense word" readers who had better phonological skills tended to perform better in the auditory tasks but "irregular word" readers who had

better whole-word skills did not perform better in the visual tasks. However, once IQ was controlled, the relationship between auditory temporal processing and nonsense words remained but the link between visual temporal processing and irregular words was not found. Similarly, the differential effect of the transient and sustained visual systems in different text presentation was not found when IQ was controlled. Good readers exhibited better auditory temporal resolution and a trend for a faster transient visual system. Although good readers and "nonsense word" readers excelled in the auditory tasks, choice of reading strategies was independent of reading proficiency. Temporal processing was an effective discriminant for good and normal readers but not for whole-word and phonological skills.

Although this experimental work refers only to "normal" readers and not dyslexics, the results are consistent with other dyslexic research. The results implicate the facilitation of phonological skills by auditory temporal perception, but the facilitation of whole-word skills is unrelated to visual temporal perception. This corroborates other research (e.g., Tallal & Stark, 1982) in that temporal processing deficits may only appear in dyslexics who have phonological deficits and that visual temporal processing deficit may be secondary to the auditory one. Consequently, dyslexic subtypes may have different sources of origin and should be considered separately.

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Chapter 1: Overview

Both psychophysical and anatomical evidence show that the human visual system, like that in cats and monkeys, has two subsystems (Bassi & Lehmkuhle, 1990). One subsystem is a fast, rapid subsystem responsible for coarse and global analysis. The other subsystem is a slow subsystem responsible for form and detail analysis (Livingstone & Hubel, 1987, 1988). These subsystems, which have complementary functions, ensure accurate visual information input and processing.

Similarly, the human auditory system, like that in cats and rats, is thought to have two subsystems (Burbeck & Luce, 1982). However, evidence for such a division in audition is less convincing than in vision.

Children with specific reading disabilities (SRD) have been shown to have an imbalance in the functioning of the two visual subsystems (Lovegrove, Martin & Slaghuis, 1986a). Besides having difficulty in reading, many SRDs also have difficulty processing rapidly presented visual stimuli (Williams & LeCluyse, 1990).

On the other hand, SRDs and language-impaired children are shown to have difficulty processing rapidly presented auditory stimuli and are suggested to have similar deficits in one of the auditory subsystems (Tallal, Sainburg & Jernigan, 1991; Galaburda & Livingstone, 1993).

Interestingly, both SRDs and language-impaired children have poor phonological skills and evidence suggests that this is linked to their temporal processing deficits (Lovegrove, Pepper, Martin, Mackenzie & McNicol, 1989; Tallal & Stark, 1982).

Inspired by Marshall and Newcombe (1973), Coltheart (1978) suggested that reading is performed via two routes: 1) a visual route which links up the visual features of the word and its pronunciation; and 2) a grapheme-phoneme-correspondence (GPC) route which links the graphemes with their phonemes and blends their sounds together to form the pronunciation. Dysphonetic dyslexics are SRDs who have more difficulty reading nonsense words whereas dyseidetic dyslexics are SRDs who have more difficulty reading irregular words (Licht, 1994). There is evidence that dysphonetic dyslexics, compared to dyseidetic dyslexics, are more impaired in higher-order phonics processing skills (Newby, Recht & Caldwell, 1993) and also, it has been suggested that visual temporal processing deficits are more related to dyseidetic dyslexia while auditory temporal processing deficits are more related to dysphonetic dyslexia (Farmer & Klein, 1995). Therefore, it is hypothesised that visual temporal processing measures will have a stronger relationship with processing of irregular words while auditory temporal processing measures will more closely relate to processing of nonsense words.

Thus, this thesis aimed to:

1) investigate the relationship between different temporal processing measures in vision and audition. The major interest is to find out whether there is a single temporal processing mechanism within each modality and / or in both modalities;
2) investigate the relationship between these temporal processing measures and various reading measures;
3) investigate how well these measures differentiate various reading groups; and
4) investigate whether good readers exhibit better temporal perception than normal readers.

Chapter 2: Parallel Visual Pathways

2.1 Introduction

Both anatomical (e.g., Galaburda & Livingstone, 1993) and psychophysical findings (e.g., Kulikowski & Tolhurst, 1973) suggest that the human visual system, like that in cats (Enroth-Cugell & Robson, 1966) and macaque monkeys (Merigan & Maunsell, 1993), contains two sets of neurons with different spatiotemporal properties. In this chapter, the following are considered: 1) evidence for the parallel visual pathways; and 2) their proposed functions in reading.

2.2 The Process of Seeing

The process of seeing starts when an image is formed on the retina and stimulates the photoreceptors (rods and cones) and then the retinal ganglion cells. Impulses are then sent from the ganglion cells via the optic nerve to the lateral geniculate nucleus (LGN) and / or to the superior colliculus (SC), and then further to the visual cortex (Sekular & Blake, 1990).

2.3 Anatomical Evidence for the Parallel Visual Pathways

It is evident that the visual pathway is already partially segregated at early stages in processing such as in the pupillary responses (Young, Han & Wu, 1993) and the retinal ganglion cells (Merigan & Maunsell, 1993). Moreover, this segregation continues to higher levels and goes beyond the visual cortex, even though the segregation is incomplete most of the time (Merigan & Maunsell, 1993). I will consider the segregation at each level, and evidence will be mainly cited from primates (including humans) but sometimes, from cats. The presentation style is based on Bassi and Lehmkuhle (1990).

2.3.1 Segregation in the Retinal Ganglion Cells

Early evidence of segregation comes from Enroth-Cugell and Robson (1966), who described two types of retinal ganglion cells in cats as X and Y cells. Similarly, for primates, the two groups of ganglion cells were described as P and M cells (Shapley & Perry, 1986), which is approximately equivalent to the X / Y cell distinction. Even though these are similar classifications, most people do not argue that they are equivalent. [For details, please see Bassi & Lehmkuhle, 1990.]

The major features of the P-ganglion (also known as Type-B retinal ganglion cells in human) or the X-cells are: 1) smaller soma, dendritic fields and thinly myelinated axons (Leventhal, Rodieck & Dreher, 1981; Perry & Cowey, 1981; Lehmkuhle, 1995); 2) project to the parvocellular dorsal lateral geniculate nucleus (dLGN); 3) comprise 80% of the retinal ganglion cells in primates (Perry, Oehler & Cowey, 1984); and 4) have higher density in the fovea (DeMonasterio, 1978). The P-ganglion cells almost entirely receive inputs from the cones which are adapted for colour vision (Shapley, 1990; Grosser & Spafford, 1992; Kaplan, Lee & Shapley, 1990).

On the other hand, the major features of the M-ganglion (also known as Type-A retinal ganglion cells in human) or the Y-cells are: 1) larger soma, dendritic fields and thickly myelinated axons (Lehmkuhle, 1995); 2) project to the magnocellular dLGN (Leventhal et al, 1981); 3) comprise 10% of the retinal ganglion cells in primates (Perry et al, 1984); and 4) are evenly distributed across the retina (DeMonasterio, 1978). The

M-ganglion cells receive inputs from both cones and rods (Grosser & Spafford, 1992; Lehmkuhle, 1995).

2.3.2 Segregation in the Dorsal Lateral Geniculate Nucleus (dLGN)

The dorsal lateral geniculate nucleus, for example, in primates and human, has three layers (two parvo and one magnocellular) which receive inputs from the ipsilateral eye and another three layers (two parvo and one magnocellular) which receive inputs from the contralateral eye (Bassi & Lehmkuhle, 1990).

The magnocellular layers receive inputs from Type-A or M retinal ganglion cells whereas the parvocellular layers receive inputs from Type-B or P cells (Leventhal et al, 1981; Perry et al, 1984). The parvo (via thinly myelinated axons) and magnocellular layers (via thickly myelinated axons) then project to the striate cortex (Bassi & Lehmkuhle, 1990).

2.3.3 Segregation in the Visual Cortex

The visual cortex has six layers with subdivisions in layers III and IV. Output from the dLGN is projected to layer IV, also known as V-1, Area 17 or striate cortex (Hassler, 1966).

The P-cells in the dLGN project to V1 layers 4A and 4Cβ (Leventhal et al, 1981; Hubel & Wiesel, 1972), and layer 4Cβ projects the output to the blobs and interblobs of layer III. Layer III projects to the pale stripes in Area 18 (Livingstone & Hubel, 1984b), then to the dorsal lateral cortex (Weller & Kaas, 1985; Kaas, Lin & Wagor, 1977), and then to the caudal portion of the inferior temporal cortex (Felleman & Van Essen, 1983), a region important for the perception of form and shape (Merigan & Maunsell, 1993).

The M-cells in the geniculate layers project to 4Cα (Fitzpatrick, Lund & Blasdel, 1985), then to layer 4B (Lund & Boothe, 1975) and then to the blobs of layer III. The projections from 4B project either to the middle temporal (MT) visual area directly or via the thick stripes in V2 (Merigan & Maunsell, 1993). The medial temporal area is important for processing motion information (Newsome, Wurtz, Dursteler & Mikami, 1985). MT projects to the superior temporal (ST) region and then to the posterior parietal (PP) cortex (Bassi & Lehmkuhle, 1990), an area important for spatial constancy and figure-ground segregation (Andersen, 1989). Nonetheless, the M pathway also projects to the inferior temporal cortex, an area which the P pathway also projects to (Merigan & Maunsell, 1993). In fact, the areas where M-cells project to (e.g., blobs of layer 3) are also dominated by parvo input and the dorsal pathway mainly passes via the thick stripes in V2 to MT and PP (Stein, personal communication).

The segregation of the two visual pathways is illustrated in Figure 2-1.

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Figure 2-1: Parallel pathways in the primate visual system. The visual system is shown in schematic form from the retinal ganglion cells (*bottom*) to the higher levels of visual cerebral cortex (*top*). The components of the magnocellular and parietal pathways have been grouped to the left; those of the parvocellular and temporal pathways have been grouped to the right. Lines show established connections between the illustrated components. As in other summaries of visual pathways, many cortical areas and connections have been omitted. Abbreviations: AIT, anterior inferotemporal area; CIT, central inferotemporal area; LIP, lateral intraparietal area; Magno, magnocellular layers of the LGN; MST, medial superior temporal area; MT, middle temporal area; Parvo, parvocellular layers of the LGN; PIT, posterior inferotemporal area; VIP, ventral intraparietal area.
Source: Merigan, W.H., & Maunsell, J.H.R. (1993). How Parallel are the Primate Visual Pathways? Annual Review of Neuroscience, 16, 369-402.

2.4 Chemical and Morphological Evidence for the Parallel Visual Pathways

Tootell, Silverman, Hamilton, Switkes and De-Valois (1988) found the greatest uptake of 2-deoxyglucose (2-DG) in layer 4Cβ and the interblobs (the P-pathway) when macaque monkeys were presented high spatial frequency stimuli. Conversely, greatest uptake occurred in layer 4Cα and the blobs (the M-pathway) when low spatial frequency stimuli were used. The high levels of uptake in each pathway implies that the pathways are spatiotemporally different from each other.

Additionally, Baizer, Ungerleider and Desimone (1991) and Morel and Bullier (1990) injected different tracers in the inferior parietal (M pathway) and inferotemporal (P pathway) region in the macaque monkeys. They found only a little overlap between the two pathways. The overlapped areas included area V4 and the cortex at the bottom of the anterior superior temporal sulcus.

Similar to the case in macaque monkeys, using cytochrome oxidase (CO) staining, blobs, interblobs (Horton & Hedley-Whyte, 1984), thick, thin and pale stripes (Hockfield & Tootell, 1987) were also observed in human striate cortex.

Using 1,1'-dioctadecyl-3,3,3',3'-tetramethylindocarbolyamine perchlorate and CO, Burkhalter and Bernardo (1989) found a projection from V2 to layer 4B in humans. The projection is similar to the magnocellular projection in monkeys.

2.5 Psychophysical Evidence for the Parallel Visual Pathways

Because of the difference in receptive fields, dendritic fields, axons and soma size, the two parallel visual pathways are different in terms of their spatiotemporal properties (Bassi & Lehmkuhle, 1990). Generally speaking:

1) P / X pathway is colour sensitive whereas M / Y pathway is "colour-blind" (Derrington & Lennie, 1984). [Although the M pathway does not support colour perception, it is significant to the effect of colour filters in dyslexics (e.g., see Rock-Faucheux, LeCluyse & Williams, 1993; Solman & Cho, 1991) that it only responds to a restricted range of wavelengths (not including short wavelengths) (e.g., Schwartz, 1995; Burr, Morrone & Fiorentini, 1996; Morrone, Porciatti, Fiorentini & Burr, 1994)]

2) P pathway is more tonic whereas M pathway is more phasic (Purpura, Tranchina, Kaplan & Shapley, 1990).

3) P pathway has a slower conduction velocity than M pathway (Kaplan & Shapley, 1982; Marrocco, 1976).

4) P pathway is less sensitive to luminance contrast than M pathway (Sclar, Maunsell & Lennie, 1990; Shapley, 1986). Hence, M pathway has lower contrast thresholds (Kaplan & Shapley, 1982; Derrington & Lennie, 1984).

5) P pathway is more sensitive to high spatial frequencies (Merigan & Eskin, 1986; Derrington & Lennie, 1984; Kaplan & Shapley, 1982) and hence has better visual acuity for form analysis (Livingstone & Hubel, 1987, 1988). On the other hand, M pathway is more sensitive to low spatial frequencies (So & Shapley, 1979).

6) P pathway is more sensitive to low temporal frequencies whereas M pathway is more sensitive to high temporal frequencies (Merigan & Eskin, 1986; Kaplan & Shapley, 1982).

7) P pathway has poorer temporal resolution or critical flicker fusion than M pathway (Derrington & Lennie, 1984; Marrocco, 1976). Hence, M pathway is

better in motion and flicker analysis (Duffy & Wurtz, 1991; Livingstone & Hubel, 1987, 1988).

8) M pathway has shorter visual latencies (usually 15 ms shorter) than P pathway (Marrocco, 1976).

9) The summation of P pathway is linear whereas that of M pathway is non-linear (Enroth-Cugell & Robson, 1966).

10) P pathway inhibits the activity of M pathway and vice versa (Green, 1984; Breitmeyer, 1980).

11) M cells are evenly distributed throughout the retina while P cells are concentrated in the fovea. Thus, relative to the distribution of M cells, P cells are more concentrated in the fovea whereas relative to the distribution of P cells, M cells are more concentrated in the periphery (DeMonasterio, 1978; Kaplan et al, 1990).

12) P pathway is also called the sustained system because it responds throughout the duration of the stimulus. M pathway is also called the transient system because it elicits bursts of activity at stimulus on / offset (Marrocco, 1976).

In fact, Cleland, Dubin and Levick (1971) argued that the sustained and transient cells also corresponded in their response properties to Enroth-Cugell and Robson's (1966) X and Y cells in cats. Thus, generally speaking, the X cells in cats, the P cells in primates and the sustained cells are roughly equivalent whereas the Y cells in cats, the M cells in primates and the transient cells are roughly equivalent in terms of their response properties.

2.6 *Incomplete Segregation and Interaction of the Parallel Visual Pathways*

It should be noted that the two parallel pathways are not completely segregated. Interactions occur and there is always overlap in a range of abilities. This is further illustrated using: 1) anatomical; 2) chemical; and 3) psychophysical findings.

Anatomical Findings

Although the two pathways are completely segregated up till the level of LGN, the segregation is far from complete at higher levels (Merigan & Maunsell, 1993). For instance, in V1, the P pathway divides into P-blob and P-interblob streams that in turn project via the thin and pale stripes of V2 to V4 and from there to inferotemporal cortex. From V1, the M pathway projects via V3 and the thick stripes of V2 to MT and subsequently to the parietal cortex. Interaction exists between the two pathways: besides projecting to MT, V3 also projects to V4 and in addition projects to the inferotemporal cortex. V4 is also anatomically linked to MT and parietal areas (Desimone & Ungerleider, 1989; DeYoe & Van Essen, 1988). Nonetheless, the P-cell / temporal cortex stream and the M-cell / parietal cortex stream have a convergence in the blobs (DeYoe & Van Essen, 1988). The thin stripes in V2 also receive inputs from both pathways and, moreover, the M pathway projects to the inferotemporal cortex, a region which the P pathway also projects to (Merigan & Maunsell, 1993).

Chemical Findings

In V2, the thin and thick stripes are directly connected (Livingstone & Hubel, 1984a) and both are labeled following the injection of wheatgerm agglutinin conjugated to horseradish peroxidase (WGA-HRP) in dorsomedial visual area which relays to MT and PP (Krubitzer & Kaas, 1990), or the pulvinar (Livingstone & Hubel, 1982). The integrative areas of MT and PP allow color and motion perception (Krubitzer & Kaas, 1990). It is suggested that more connections occur between the two pathways at even higher levels (Merigan & Maunsell, 1993).

Psychophysical Findings

The two pathways also overlap in terms of their psychophysical properties:

In terms of contrast sensitivity, although the M pathway (V1 layer 4B and V2 thick stripes) has a higher contrast sensitivity (Blasdel & Fitzpatrick, 1984), the P pathway can be as sensitive as the M pathway, provided that a lot of input from the insensitive P-cells are summed (Watson, 1992a). For example, Hubel and Livingstone (1990) found that the contrast sensitivity in V1 blobs and interblobs were comparable to that in the M pathway.

In terms of spatiotemporal resolution, although the M pathway is more responsive to high temporal and low spatial frequencies in monkeys (Derrington & Lennie, 1984), the difference is only 15% in peak and cut-off temporal frequency, and peak spatial frequency (Blanckensee 1980; Sherman, Schumer & Movshon, 1984). Moreover, the two pathways have the same spatial resolution given the same eccentricity and there is only a little difference between the two pathways in the size of their receptive field centers (Crook, Lange-Malecki, Lee & Valberg, 1988).

The spatiotemporal interaction also affects contrast sensitivity. For example, contrast sensitivity in the P pathway is enhanced under high spatial frequencies and is reduced when the gratings are moved or counterphased (Derrington & Lennie, 1984). Conversely, contrast sensitivity at low spatial frequencies (M pathway dominant) is enhanced when the gratings are moved or counterphased (Kulikowski & Tolhurst, 1973).

Even though the M pathway is dominant in layer 4B and V2 thick stripes, the existence of some colour sensitivity in layer 4B suggests some contribution from the P pathway (Merigan & Maunsell, 1993). Note that via the ganglion cells, the M pathway also receives some input from the cones, cells which are adapted for colour vision (Shapley, 1990; Grosser & Spafford, 1992; Kaplan et al, 1990).

Livingstone and Hubel (1987, 1988) once proposed that the M pathway is dominant in stereopsis and motion perception while the P pathway is dominant in form and colour analysis. However, DeYoe and Van Essen (1988) argued that the M pathway does not enjoy a dominant role in stereopsis. Rather, the P-interblob stream, besides supporting colour and form vision, also plays a role in high-resolution stereopsis. Evidence for DeYoe and Van Essen (1988) has been provided by Schiller, Logothetis and Charles (1990), who demonstrated that coarse shape discrimination and stereopsis can be supported by either pathway. In addition, the P pathway was found to be essential for the perception of fine stereopsis and to support flicker and motion perception at low temporal frequencies. This indicates that the M pathway does not entirely dominate all aspects of stereopsis, flicker and motion perception.

Further, Breitmeyer (1993a) suggested that the transience and the sustainedness of the two pathways are influenced by some stimulus parameters. For example, Saito and Fukuda (1986) found that at scotopic levels, Y cells acted more like X cells by showing linear luminance summation across their receptive fields. While Maunsell (1987) used suprathreshold stimuli and found that the M cells had shorter visual response latency than the P cells, Lennie (1980) eliminated the response latency differences between X and Y cells using near-threshold stimuli.

2.6.1 Overlap of the Two Pathways or the Existence of a Third Pathway?

Recently, Casagrande (1994) identified a third pathway (K pathway) "that could be traced from the retina to the visual cortex" (p.305). This pathway projects to layers III and I of area V1. In some primate species, the K pathway projects to the blobs in Layer III and terminates in layer III. In addition, the K pathway remains anatomically, physiologically and neurochemically distinct from the P and M pathways. Nonetheless, the K pathway may be responsible for colour perception, object recognition and eye movement. The first two functions are regarded as the responsibility of the P pathway while the last one is regarded as the responsibility of the M pathway.

Similarly, Tyler (1990) also identified "three parallel processing streams in the lateral geniculate / primary cortex structure: a magno / interblob stream for motion and transient information; a parvo / interblob stream for high spatial frequency, static information; and a parvo / blob stream for chromatic and low spatial frequency information" (p.1877). Obviously, the parvo / blob stream combines the function of that of the P pathway (chromatic analysis) and the M pathway (low spatial frequency analysis). Functionally, this corroborates DeYoe and Van Essen (1988) that the P-cell / temporal cortex stream and the M-cell / parietal cortex stream converge at the blobs.

Furthermore, although the third pathway possesses the functional properties of both P and M pathways, it remains unanswered whether its function is distinct or results from an overlap / interaction between the functions of the P and M pathways. Further research is necessary.

2.7 *Summary of the Parallel Visual Pathways*

In sum, anatomical and psychophysical findings suggest segregation of two parallel visual pathways in cats, monkeys and humans. Although the two pathways function differently in terms of their physiological and spatiotemporal properties, their segregation is far from complete and some functional interaction occurs between them. Recent research suggests the existence of a third pathway which functionally possesses the properties of both pathways. Furthermore, it is uncertain whether the functional properties of this pathway remains distinct or results from an overlap or interaction of the two pathways.

2.8 *The Role of the Parallel Visual Pathways in Reading*

(N.B.: For the sake of simplicity, the X / P pathway will be denoted as the sustained system and the Y / M pathway will be denoted as the transient system, as explained in section 2.5)

Reading is a dynamic process that requires precise timing to acquire information distinctly and sequentially from successive fixations (Lehmkuhle, 1995). It involves saccades to integrate information from successive fixations (Badcock & Lovegrove, 1981).

A fixation usually lasts for 200-250 ms in skilled readers (Rayner, 1978; Rayner, Inhoff, Morrison, Slowiaczek & Bertera, 1981; Pirozzolo & Rayner, 1988). About 10-15% of fixations are regressions (Rayner & Sereno, 1994). As details are extracted from the text for further processing in fixations, it is believed that the sustained system (P pathway), which has better spatial resolution and visual acuity (Livingstone & Hubel, 1988), will be mainly responsible for this analysis.

A saccade is a rapid, jerky eye movement which functions to change a fixation from one location to another. It usually lasts 25 ms (Pirozzolo & Rayner, 1988) or less than 1/10 of a second (Sekuler & Blake, 1990) and is believed to be a function of the transient system (M pathway). A reader usually saccades forward about eight character spaces (Morrison & Rayner, 1981).

In general, when text is difficult, readers make longer fixations, shorter saccades and more regressions (Rayner, Sereno, Morris, Schmauder & Clifton, 1989). Moreover, during the process of reading, the sustained system extracts information during fixations and the transient system guides eye movement and integrates information across fixations (Lovegrove, 1991).

Saccadic suppression partially results from the inhibition which the transient system exerts on the activity of the sustained system (Singer & Bedworth, 1973; Breitmeyer, 1980, 1992, 1993b). Singer and Bedworth (1973) proposed that the slowly decaying, trailing activity of the sustained system during one fixation is suppressed by the transient activity generated by abrupt and rapid image displacements accompanying a saccade. Hence the prior sustained activity is prevented from persisting across the saccade as a form of noise to the sustained activity generated in the following fixation. In this way the afferent sustained systems are cleared of activity between fixations, resulting in a series of temporally segregated frames of sustained activity, with each frame corresponding to the pattern information in a given fixation period (Breitmeyer, 1993a,b).

Hence, with its visual masking effect, saccadic suppression reduces the visual sensitivity during saccades (Matin, 1974; Chekaluk & Llewellyn, 1993) and ensures that pattern information carried by the sustained system from a prior fixation will not be carried over and mask the pattern information picked up by the same system during the succeeding fixation. In short, saccadic suppression expedites the pick-up of information during foveal scanning of reading material to obtain a series of clear, unmasked, and temporally segregated frames of sustained activity (Breitmeyer, 1980, 1992, 1993a,b; Lovegrove et al, 1986a).

Therefore, a weakened saccadic suppression will result in "a partial temporal overlap, rather than clear temporal segregation, of successive frames of retinotopic sustained activity from successive fixations" (Breitmeyer, 1993b, p.21). A hypothetical response sequence of sustained and transient systems and their interactions during reading is illustrated in Figure 2-2.

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Figure 2-2: A hypothetical response sequence of sustained and transient channels during three 250-msec fixation intervals separated by two 25-msec saccades (Panel 1). Panel 2 illustrates response persistence of sustained channels acting as a forward mask from preceding to proceeding fixation intervals. Panel 3 shows the activation of transient channels shortly after each saccade which exerts inhibition (arrows with minus signs) on the trailing, persisting sustained activity generated in prior fixation intervals. Panel 4 shows the resultant sustained channel response after the effects of transient on sustained inhibition have been taken into account.
Source: Breitmeyer, B.G. (1980). Unmasking visual masking: a look at the "why" behind the veil of the "how". Psychological Review, 87(1), 52-69.

On the other hand, Burr, Morrone and Ross (1994) and Ross, Burr and Morrone (1996) argued that the transient system during saccades was selectively suppressed, while the sustained system was functionally unimpaired, or even enhanced. Moreover, the suppression seems to occur at an early stage (in the LGN) and is confined to the transient system. Nevertheless, Burr and Morrone (1996) suggested that saccadic suppression was mediated by contrast gain control mechanism occurred in the transient system. Methodological differences [response impulse summation technique adopted by Burr and Morrone (1996) vs metacontrast study adopted by Breitmeyer (1980)] might explain the discrepancy. Nevertheless, both researchers conclude that saccadic suppression is mediated by the transient system and the physiological properties of the two visual systems well-adapt their functions in reading: detail analysis by the sustained system in fixation and movement by the transient system in saccades. It is of no doubt that the inability to compromise between the two systems can be related to reading difficulty. However, if we assume normal saccade accompanies weak transient activity and strong sustained activity as hypothesised by Burr and colleagues, we have to assume reading difficulty is accomplished by strong transient activity and weak sustained activity during saccades. Unfortunately, most research evidence does not favour Burr et al's (1994) view (e.g., see Lovegrove et al, 1986). Hence, more weight should be given to Breitmeyer's theory.

2.9 Summary

The human visual system, like that of cats and monkeys, consists of two parallel systems with different spatiotemporal properties. However, the two pathways are not so distinctly segregated and interaction between the two systems has functional significance in reading. In particular, it has been argued (Breitmeyer, 1980, 1992, 1993b) that the transient inhibition exerted on the sustained activity ensures clear, unmasked successive fixations in reading.

Chapter 3: Parallel Auditory Pathways

3.1 Introduction

Similarly, it is argued that the auditory system comprises two parallel pathways. However, much less supporting evidence is provided for this conclusion in audition. Furthermore, evidence will be cited mainly from morphological as well as psychophysical research.

3.2 The Process of Hearing

The process of hearing starts when sound wave passes through the pinna (which helps detecting the sound source) and is channelled down the auditory canal to the ear drum. The ear drum vibrates and passes the vibration to the ossicles (which consist of hammer, anvil and stirrup) and to the oval window. This middle ear is responsible for impedance matching and overload protection (via the Eustachian tube). Then, the vibration is passed to the fluid-filled cochlea for frequency analysis. The organ of corti, situated inside the cochlear duct, transforms the mechanical vibration to neural messages via the fluid vibration in the inner / outer hair cells on the basilar membrane. The auditory nerves then send the neural messages to the cochlear nucleus. All auditory inputs go via the cochlear nucleus to: 1) the superior olive and auditory cortex for sound localisation; and / or 2) the inferior colliculus, the medial geniculate nucleus (MGN) and the auditory cortex for sound identification (Sekuler & Blake, 1990).

3.3 Segregation of the Parallel Auditory Pathways

In line with vision, the auditory system can be roughly divided into two parallel subsystems. However, in terms of anatomical findings, the segregation is less distinctive than that in vision. Evidence will be cited from morphological and psychophysical research.

3.3.1 Morphological Evidence for the Parallel Auditory Pathways

Anatomical Segregation

In line with the two types of receptor cells (rods and cones) in vision, the organ of corti contains two types of hair cells. The inner hair cells (IHC), numbering about 3500 and forming a single row, are situated on the basilar membrane close to where the tectorial membrane is attached to the wall of the cochlear duct. On the other hand, the outer hair cells (OHC), numbering about 12000, line up any where from three to five rows on the basilar membrane. However, only 5 to 10% of the auditory nerve fibres are connected to OHC while the remaining are connected to the IHC (Sekuler & Blake, 1990).

The cochlear and the auditory nerve fibres are similar to the retinal ganglion cells in that they are frequency-selective (Sekuler & Blake, 1990; Moore, 1986, 1989). In general, high frequency tones produce travelling waves that peak near the base of the basilar membrane whereas low frequency tones produce travelling waves that peak near the apex. As the auditory nerve fibres are connected to hair cells on the basilar membrane, fibres originating from the base are more sensitive to high sound frequencies while those originating from the apex are more sensitive to low sound frequencies (Sekuler & Blake, 1990).

Goldstein, Hall and Butterfield (1968) found a group of cells which were sensitive to on / offsets in the primary auditory cortex of cats. These neurons respond briskly and transiently to the onset of a steady stimulus, irrespective of its duration (Phillips, 1985). In addition, the neurons are sensitive to the carrier frequency and its rise time (Phillips, 1988) and the brevity of the response is determined by inhibition and neural adaptation (Eggermont, 1991). In fact, these neurons also exist in the cochlear nerve (Rhode & Smith, 1986). Galaburda and Livingstone (1993) argued that this auditory "transient" pathway also runs along the MGN. Using dysphasics and magnetic resonance imaging (MRI) techniques, Tallal et al (1991) suggested that the same pathway runs along areas in superior parietal, prefrontal and temporal cortices, and diencephalic and caudate nuclei. Further, in a study involving adult dyslexics and positron emission tomography (PET) techniques, Hagman, Wood, Buchsbaum, Tallal, Flowers and Katz (1992) also suspected the involvement of the medial temporal lobe in the auditory "transient" pathway.

On the other hand, the auditory "sustained" system is a "periodic, steady-state" system which is responsible for pitch perception and not segregation in the time domain. However, little is known about it except that the system still functions well under primary auditory cortex lesions (Phillips, 1993).

Functional Segregation

Like that in vision, excitatory-inhibitory interaction also occurs in audition. For example, in the auditory nerves of cats, signal's offset suppresses the firing of neurons below the baseline rate (Kiang, 1965). Similar interaction also occurs in the cochlear nucleus (Gerstein, Butler & Erulkar, 1968), inferior colliculus (Rose, Greenwood, Goldberg & Hind, 1963) and medial geniculate (Nelson & Erulkar, 1963).

For instance, most of the neurons in the cochlear nucleus have spike discharges that are sustained throughout the duration of the tones (Pfeiffer, 1966; Rose, Galambos & Hughes, 1959), while the rest respond with an initial peak followed by a slow decay (Gerstein et al, 1968). More specifically, neurons which produce the former type of responses are situated around the anteroventral cochlear nucleus (Winter & Palmer, 1990; Rhode & Smith, 1986) and those that have clear transient responses are more concentrated in the dorsal cochlear nucleus (Sullivan, 1985; Hewitt & Meddis, 1995). In fact, Gersuni (1971) regarded the former type of response, the "long-time constant response", as long latent, slow summating and tonic, whereas the latter type of response, the "short-time constant response", as short-latent, rapidly summating and phasic.

Moreover, the two types of responses occur at each level of the auditory system, for example, in the cochlear nucleus, inferior colliculus, medial geniculate body (Oonishi & Katsuki, 1965) and primary auditory cortex (Vardapetian, 1967). Similar results are also found in other species: namely, in the cochlear nucleus of rats (Moller, 1969), in the auditory nerve fibres of monkeys (Nomoto, Suga & Katsuki, 1964), and in the dorsal medullary nucleus of frogs (Hall & Feng, 1991).

3.3.2 Psychophysical Evidence for the Parallel Auditory Pathways

While Gersuni (1971) regarded the two types of auditory responses as short-time and long-time responses, psychophysicists like to term them change and level (or integrative) detectors respectively.

Burbeck and Luce (1982) measured the reaction times (RT) in which subjects had to detect the offset of tones masked by some noise. The hazard functions of the RT distributions showed that auditory detection was best described in terms of parallel functioning of both a change and a level detector. The change detector (CD), on one hand, "is sensitive to abrupt changes in the signal and responds transiently to such changes" (p.117). However, though it responds quickly to a change, it "is less persistent in that, once the change has receded sufficiently into the past, it is unlikely to initiate a response" (p.117). The level detector (LD), on the other, "is sensitive to the absolute level of the signal. The level detector may be a bit slow to respond to change, but, since it tracks the level of the signal, it remains capable of reporting the changed signal intensity long after the change is completed" (p.117).

Green and Smith (1982) also required their subjects to detect a weak 1000 Hz sinusoidal signal presented in noise. They found that the hazard function for the 1000 ms signal rose slowly and reached a plateau after 600 to 700 ms, whereas the one for the 50 ms signal rose much sooner than that of the 1000 ms signal, peaked at about 400 to 500 ms, and then diminished quickly. The former resembles the LD whereas the latter resembles the CD. Moreover, stronger signals favoured a more transient rise in the short duration and not the long duration case.

When subjects detected the increments or decrements in the amplitude of a signal presented in noise, tone or a tone with noise masker, Macmillan (1971, 1973) found that detection involved both an integrative detector (ID) and a nonintegrative change detector (CD). CD responds more quickly to on / offset and is insensitive to the direction of change. ID accumulates information over time to identify the signal (Macmillan, 1973). Further, CD is more important in detecting changes in short-duration stimuli because ID is less reliable. The converse is true for ID for long duration stimuli (Macmillan, 1971).

Wynn (1977) measured the simple reaction time of subjects to auditory clicks. The reaction time distributions varied from a Gaussian to a skew distribution. "The skew distribution, however, could be separated into two Gaussian components" (p.176). The presence of the two Gaussian components suggests the existence of two auditory pathways conveying information to the brain. The author also suggested a stochastic mechanism responsible for channeling the information into either the slow or fast pathway. For instance, information from high intensity stimuli is more likely to be conveyed via the fast channel while information from low intensity stimuli is more likely to be conveyed via the slow channel. In fact, the fast channel is functionally equivalent to Burbeck and Luce's (1982) change detector whereas the slow channel is functionally equivalent to the level detector.

3.4 Similarities between the Parallel Visual and Auditory Pathways

Hence, the auditory system is similar to the visual system in that both have two parallel pathways. While the parallel pathways in vision are called the transient and sustained systems, the ones in audition are called the change (short-time response) and level / integrative (long-time response) detectors respectively.

3.4.1 Similarities in Properties

The auditory detectors are functionally similar to the two visual systems in that: 1) both the change detector and the transient visual system are nonintegrative, short latency, rapidly summating, phasic, sensitive to abrupt on / offsets, and respond quickly, transiently and less persistently to stimulus changes; and 2) both the level detector and the sustained visual system are integrative, long latent, slow summating, tonic, sensitive to absolute levels, and respond slowly and persistently.

3.4.2 Less Distinctive Segregation at Higher Levels

The initial stages of the auditory system (e.g., up till the cochlear and the auditory nerves), compared to the higher levels of the auditory system (e.g., auditory cortex), are relatively more segregated and more sensitive to frequency selectivity and intensity. Although the neurons in the auditory cortex are less sensitive to sound frequency and intensity, this level is more responsive to abstract features of sound. Similarly, although the initial stages of the visual system (e.g., up till LGN) are more segregated than the higher-level visual cortex, the neurons in the higher levels are more sensitive to abstract features (e.g., depth and perception) of visual stimuli (Sekuler & Blake, 1990). Therefore, the segregation in both modalities is not complete. Further, the segregation in the auditory system, when compared to that in the visual system, is far from complete in terms of anatomical findings.

3.5 Audition and Reading / Language

Language mainly consists of vowels and consonants. Vowels are characterised by a steady-state spectrum whereas consonants are characterised by rapidly changing acoustic parameters (Miller & Tallal, 1995). In hearing, the auditory system converts speech sounds into grapheme-phoneme representation for lexical and semantic analysis. In fact, Pastore and Farrington (1996) regarded the ability to identify the order of onset of components of auditory stimuli as a factor contributing to the perception of voicing contrasts in speech. Moreover, Miller and Tallal (1995) argued that "the ability to process short duration, rapidly presented auditory information appears closely associated with or represents a perceptual prerequisite for the normal acquisition of language" (p.292). Therefore, auditory perception is important for language / reading acquisition. This will be further discussed in Chapters 4 and 5.

3.6 Summary

The auditory system, like that in vision, has two parallel pathways which function analogously to those of the visual system. Nevertheless, the auditory pathways, in terms of anatomical findings, are far less segregated than that in vision. Moreover, the precision and resolution of the auditory system in analysing speech sounds is related to language performance.

Chapter 4: Auditory and Visual Temporal Processing Deficits in Dyslexia and Dysphasia

4.1 Introduction

Dyslexia or specific reading disability (SRD) is defined as a disorder manifested by difficulty in learning to read despite conventional instructions, adequate intelligence, educational and socio-cultural opportunity. It is dependent upon fundamental cognitive disabilities which are frequently of constitutional origin, and is not a result of overt neurological or behavioural disorder (Critchley, 1964). Though the definition has been criticized in terms of its context and practicality to poor readers (e.g., see Siegel, 1989), this definition is still most commonly used.

Dysphasia or language impairment "is defined as a specific dysfunction in the development of speech and language expression and / or reception, in the absence of other causal disabilities such as defects of hearing, peripheral speech structures, mental subnormality, personality disorder, brain trauma, or psychoaffective or psychotic disorders" (Benton, 1964 cited in Tallal et al, 1991, p.363).

Thus, dyslexia is similar to dysphasia on the basis of language difficulty. Furthermore, while dyslexia manifests itself via reading, dysphasia manifests itself via speech and language reception. For example, dysphasics make more errors in discriminating /ba/ and /da/ than dyslexics (Fortin, Dudley & Joanette, 1993). Also, in sequence matching tasks, while younger dysphasics perform equally poorly in both auditory and visual tasks, older dysphasic children only perform worse on the auditory tasks (Tallal, Stark, Kallman & Mellits, 1981). More importantly, while nearly all dysphasics demonstrate temporal processing deficits, not all dyslexics demonstrate a disruption in temporal processing (Miller & Tallal, 1995). For example, Tallal and Stark (1982) found that the temporal processing measures could only differentiate dyslexics with concomitant oral language deficits and not those without concomitant oral language deficits from the controls.

Many people experiencing dyslexia or dysphasia usually have temporal processing deficits in different modalities like vision (Williams & LeCluyse, 1990), audition (Tallal, Stark & Mellits, 1985a,b) and motor coordination (Wolff, 1993; Wolff, Cohen & Drake, 1984; Wolff, Michel, Ovrut & Drake, 1990c; Wolff, Michel & Ovrut, 1990a,b). This chapter will mainly focus on the evidence for auditory and visual temporal processing deficits in the two disorders. Evidence will be cited from experimental as well as anatomical / physiological research.

4.2 General Temporal Processing in the context of Farmer and Klein (1995)

According to Farmer and Klein (1995), temporal processing involves four components: 1) detection or identification of a stimulus event; 2) individuation of two stimuli; 3) temporal order judgment; and 4) sequence matching or discrimination.

Detection involves judgments about the presence or absence of a stimulus. In some cases, it also involves discrimination such as making judgment about the duration, location or stimulus identity. Tasks may involve: 1) reporting the presence or absence of a stimulus after a cue; 2) adjusting the duration of a stimulus to match a target stimulus; 3) localizing a stimulus; or 4) determining the identity of a stimulus (Farmer & Klein, 1995).

Determination of numerosity involves the determination of whether one or more than one item has been presented. The most commonly used task is individuation of two stimuli. Tasks may involve: 1) Fusion tasks which "determine the minimum interstimulus interval (ISI) at which subjects are able to perceive that there are two identical stimuli, rather than one" (Farmer & Klein, 1995, p.465); 2) Gap detection tasks which "determine the minimum ISI required for a subject to perceive that a stimulus has been interrupted by a temporal gap" (Farmer & Klein, 1995, p.465); and 3) Temporal integration tasks (Di Lollo, Hanson & McIntyre, 1983) which "determine the minimum ISI at which subjects perceive two nonidentical stimuli, rather than one integrated form" (Farmer & Klein, 1995, p.465).

In temporal order judgment (TOJ) tasks, the events must be perceived as discrete for their order to be determined (Jaskowski, 1991). Tasks may involve presenting stimuli in different locations and the subject has to identify the location of the leading stimulus. This involves a spatial element. In the case where the spatial element is omitted, the stimulus has to be identified before the judgment is made. Sometimes, subjects have to make same-different judgments for two pairs of stimuli, rather than reporting the order (Farmer & Klein, 1995). Evidence on whether TOJ reflects perceptual processing using the effects of inhibition of return (IOR) remains controversial. Though Maylor (1985), Kwak (1992) and Posner, Rafal, Choate and Vaughan (1985) failed to obtain IOR in the long cue but not short cue lead times conditions and that Gibson and Egeth (1994) found that IOR affected TOJs only in some conditions, these findings suggest that TOJ, at least partially, reflects some form of perceptual processing.

Sequence matching or discrimination is an extention of the temporal order judgment which involves sequences of more than two elements. Pairs of stimulus sequences are presented and the subject has to make a same-different judgment for each pair. The tasks may involve a spatial element. The difference between temporal order judgment and sequence matching is that the latter involves a memory factor, as the first sequence must be remembered in order to match with the second one (Farmer & Klein, 1995).

4.3 Experimental Evidence for Auditory Temporal Processing Deficits in Dyslexia / Dysphasia

As discussed in 4.1, dyslexia is similar to dysphasia in that both appear to involve language difficulties. There is considerable evidence that dyslexics / dysphasics both experience difficulties in auditory temporal processing. Evidence mainly comes from studies of: 1) detection or identification of a stimulus event; 2) individuation of two stimuli; 3) temporal order judgment; and 4) sequence matching or discrimination. The studies are listed in Tables 4-1 to 4-4. The presentation style is based on Farmer and Klein (1995).

4.3.1 Detection or Identification of a Stimulus Event

Results concerning whether dyslexics / dysphasics experience difficulty in auditory detection or identification of stimulus are conflicting. The studies are summarised in Table 4-1.

Table 4-1: Auditory Tasks on Detection or Identification of a Stimulus Event

Author	Sample (Age Range).	Stimuli	Stimulus Duration	Differ from Controls/ between Groups?
Tallal (1978)	Dysphasics (aged 6-9)	Complex tones	75-250ms	No
Tallal (1980)	Dyslexics (aged 8-12)	Complex tones	75ms	No
Tallal & Piercy (1973a)	Aphasics (aged 6-9)	Complex tones	75ms	Differ only when ISI < 428ms
Nicolson & Fawcett (1993a)	Dyslexics (aged 11 & 15)	Tones	-	Differ only when detecting low tones from tone mixture
Steffens et al (1992)	Dyslexics (adult)	Synthetic speech continua	400-450ms	Yes
Godfrey et al (1981)	Dyslexics (aged 10)	Synthesised voiced stop consonants	330ms	Yes
Elliott et al (1989)	Children with language-learning problems (aged 6-11)	Synthesised consonant / vowels	300ms	Yes
Elliott et al (1990c)	Learning-disabled children (aged 8-11)	Monosyllabic words	120ms	Yes
James et al (1994)	Language-disordered children (aged 8-10)	Consonant-vowel-consonant	-	Yes

Although Tallal (1978, 1980) found no difference between the dysphasics / dyslexics and controls in detecting complex tones, Tallal and Piercy (1973a) found that the aphasics performed more poorly than their matched controls on detection, but only when the ISI was less than 428 ms.

Nicolson and Fawcett (1993a) found that dyslexics (n=25, aged 11 and 15) were slower than their chronological-age-matched (C.A.) controls but were equally effective as the reading-age-matched (R.A.) controls in detecting low tones (350 Hz) in a mixture of low and high tones (1400 Hz). However, these dyslexics did not differ from the C.A. controls in a simple reaction task to low tones.

In Steffens, Eilers, Gross-Glenn and Jallad (1992), 18 adult dyslexics and 18 controls were tested on the perception of three synthetic speech continua: 1) /a/-/∂/, "in which steady-state spectral cues distinguished the vowel stimuli" (p.192); 2) /ba/-/da/, in which rapidly changing spectral cues varied; and 3) /sta/-/sa/, in which a temporal cue, silence duration was varied. It was found that dyslexics were less able to discriminate vowels and consonants and required greater silence duration to shift their perception from /sa/ to /sta/. The authors suggested that the dyslexics used the acoustic cues differently from normal readers (after Steffens et al, 1992).

Replicating Steffens et al (1992), Godfrey, Syrdal-Lasky, Millay & Knox (1981) tested 17 dyslexics (mean age 10) and their C.A. controls on tests of identification and discrimination of synthesised voiced stop consonants (ba/da/ga: 330 ms duration) differing in place of articulation. Dyslexics were inferior in identification and discrimination. The results further suggest poor categorical perception by dyslexics of auditory cues in the same and not in different phonological categories. Moreover, a significant relationship was found between speech discrimination and reading.

Elliott and Busse (1987) found that 90% of normal-hearing learning-disabled adults "exhibited fine grained auditory discrimination that was as poor as that of normally-achieving six-year-olds" (Elliott, Hammer & Scholl, 1990a, p.171). Elliott, Hammer and Scholl (1989) measured the smallest acoustic differences that could be discriminated among the consonant-vowel (CV) syllables from 151 children (aged 6 to 11) with language learning problems and 143 controls. The auditory discrimination task involved judging whether two syllables presented sequentially were the same or not. Results showed that language-learning disabled children required larger acoustic differences to discriminate the CV syllables and that the fine-grained auditory discrimination tasks "correctly classified nearly 80% of the 6- and 7-year-olds and nearly 65% of the 8- to 11-year-olds" (p.112). Similarly, Elliott, Scholl, Grant and Hammer (1990c) found that normally achieving children (n=18, aged 8 to 11) identified more monosyllabic words than the learning-disabled children, even though both groups took equally long to identify the words. Moreover, the identification of words at short durations was associated with receptive vocabulary scores in the learning-disabled group. Nonetheless, Elliott et al (1990a) also found that fine-grained auditory discrimination significantly predicted receptive vocabulary (Peabody Picture Vocabulary Test-Revised) and receptive language (Token test for Children). In fact, Elliott, Hammer and Scholl (1990b) said that the temporal deficit is neither specific to auditory and speech perception but also exists in other modalities. Nevertheless, Elliott and her colleagues used a heterogeneous group of language learning disabled children which had a high incidence of reading problems and yet could not be classified as dyslexics. Thus, the nature and the severity of their language deficit is unknown.

James, Steenbrugge and Chiveralls (1994) presented some CVC words and nonsense words and their subjects had to judge whether the two stimuli sounded the same or not. Language-disordered children (n=6, mean age 9) showed poorer phoneme discrimination skills than their C.A. controls. Nevertheless, these subjects also experienced central auditory processing difficulties. So, the relationship between reading and auditory phoneme discrimination deficit is inconclusive.

Thus, the results that dyslexics / dysphasics have difficulty detecting / identifying stimuli are inconclusive. While there is inconclusive evidence suggesting they have difficulty detecting simple stimuli like tones, evidence suggests they have difficulty in choice reaction tasks and in detecting rapidly presenting stimuli and speech stimuli, especially those with similar acoustic cues.

4.3.2 Individuation of Two Stimuli

Lowe and Campbell (1965) presented two 15 ms, 50 dB tones (400 and 2200 Hz) to their subjects and found that the aphasics (n=8, aged 7 to 14) did not take longer to judge the succession. However, other researchers have found the opposite. Table 4-2 summarises the studies.

Table 4-2: Auditory Tasks on Individuation of Two Stimuli

Author	Sample (Age Range)	Stimuli	Stimulus Duration	Differ from Controls/ between Groups?
Lowe & Campbell (1965)	Aphasics (aged 7-14)	Tones	15ms	No
McCroskey & Kidder (1980)	Reading-disabled (aged 7-9) Learning-disabled	Tones	17ms	Yes
Haggerty & Stamm (1978)	Learning-disabled (aged 7-9.5)	Clicks	1ms	Yes
Farmer & Klein (1993)	Dyslexics (aged 14)	Clicks	-	Yes
Ludlow et al (1983)	Language-impaired (aged 8-11) Language-impaired & hyperactive Hyperactive Hyperactive Reading-disabled	Noise	750ms	Yes No No No

Davis and McCroskey (1980) presented 135 normal children (aged 3 to 12) 270 pairs of tones (intensity levels between 20, 40, and 60 dB; duration 17 ms; frequencies 250 to 4000 Hz) and asked them to indicate whether they heard one or two sounds. It was found that: 1) the auditory fusion improved between 3 to 8 years of age (from 23 to

7 ms) and became stable after age 9; 2) stronger intensity minimised the ISI; and 3) the fusion points were similar between 250 to 4000 Hz.

Using the same technique, McCroskey and Kidder (1980) presented 135 children (aged 7 to 9) tone pairs between 250 and 4000 Hz and measured their fusion points. Reading disabled (n=45, mean reaction time 9.9 to 14.7 ms) and learning disabled children (n=45, mean reaction time 12.2 to 14.6 ms) had larger fusion points than normal children (mean reaction time 7.5 to 8.9 ms). However, frequency only differentiated the learning-disabled and not the reading-disabled subjects.

When 1 ms clicks were presented binaurally, Haggerty and Stamm (1978) reported that the learning-disabled subjects (n=24, aged 7 to 9.5), compared to the controls (n=20, aged 7 to 10), needed longer ISIs to identify whether a single stimulus or a pair of stimuli were presented. However, this fusion task probably involves a spatial element as the two clicks are presented dichotically.

Similarly, Farmer and Klein (1993) found that dyslexics (n=20, aged 14) required longer ISIs to segregate two clicks.

Ludlow, Cudahy, Bassich and Brown (1983) presented two 750 ms noise bursts. A short gap of silence was inserted in the middle of one of the two bursts of noise and subjects had to choose which noise burst contained the gap. Results showed that the language-impaired and not the hyperactive reading-disabled boys were deficient on this task.

Thus, the notion that dyslexics / dysphasics are deficient in auditory fusion remains inconclusive because the stimuli used in Lowe and Campbell (1965) are similar to that used in McCroskey and Kidder (1980). Furthermore, more reliable results are obtained when clicks with short durations are used.

4.3.3 Temporal Order Judgment

Studies investigating whether dyslexics / dysphasics are deficient in auditory temporal order judgment are summarised in Table 4-3.

Table 4-3: Auditory Tasks on Temporal Order Judgment

Author	Sample (Age Range)	Stimuli	Stimulus Duration	Differ from Controls/ between Groups?
Efron (1963)	Aphasics	Tone pair	10ms	Yes
Lowe & Campbell (1965)	Aphasics (aged 7-14)	Tone pair	15ms	Yes
Watson (1988)	Learning-disabled	Tone-pair Consonant-vowel	20-200ms	Yes
Watson & Miller (1993)	Learning-disabled	Tone-pair	20-200ms	Yes
Tallal & Piercy (1973a)	Aphasics (aged 6-9)	Complex tones	75ms	Differ only when ISI < 428ms
Tallal & Piercy (1974)	Aphasics	Vowel-vowel Consonant-vowels	250ms 250ms	No Yes
Tallal & Stark (1981)	Aphasics	Vowel-vowel Consonant-vowel	40-80ms	Differ only in 40ms condition
Tallal (1980)	Dyslexics (aged 8-12)	Tone pair	75ms	Differ only when ISI < 305ms
Tallal & Stark (1982)	Dyslexics (aged 7.5-9) (No concomitant language disorder)	Tone-pair	75ms	No
Reed (1989)	Dyslexics (aged 9)	Tones Stop Consonant Vowel Vowels in noise	75ms 250ms 250ms	Yes Differ only with short ISI No No

Table 4-3 (cont.)

Author	Sample (Age Range)	Stimuli	Stimulus Duration	Differ from Controls/ between Groups?
Ludlow et al (1983)	Hyperactive boys (aged 8-11) Hyperactive & reading-disabled Language-impaired Language-impaired & hyperactive	Tone pair	50ms	Yes Yes Yes Yes
Kinsbourne et al (1991)	Severe Dyslexics (adult) Recovered Dyslexics	Clicks	1ms	Yes
Farmer & Klein (1993)	Dyslexics (aged 14)	Tones	-	Yes
Mody et al (1997)	Reading impaired (2nd grade)	/ba/-/da/ /ba/-/sa/, /da/-/ʃa/ synthesised nonspeech sounds	250ms	Yes (errors increase as ISI decreases) No (no errors) performance unaffected by ISI

Efron (1963) presented a high (2500 Hz) and a low (250 Hz) tone (each lasted 10 ms) successively and subjects had to report which tone came first. Aphasics (n=11), compared to other clinical controls (n=5), took longer to judge the order. However, no normal controls were used in the experiment.

Similarly, Lowe and Campbell (1965) presented two 15 ms, 50 dB tones (400 and 2200 Hz) to children and asked them to judge the order. Aphasics (n=8, aged 7 to 14) took longer time to judge the order. The authors said that temporal ordering malfunction contributed to their communication difficulty.

Watson (1988) found that a heterogeneous group of learning-disabled students (n=25) which also included some dyslexics, were impaired in the temporal order judgment of both verbal and nonverbal stimuli. The nonverbal task used 550 and 710 Hz tones with various ISIs while the verbal task used sequences of consonant-vowel with various ISI. Similar results were obtained in Watson and Miller (1993). Furthermore, the heterogeneity of the samples imposes difficulties in concluding a temporal processing deficit in dyslexia.

Tallal and Piercy (1973a) trained subjects "to detect and discriminate varied sequential presentations of two complex steady-state tones with different fundamental frequencies (100 Hz and 305 Hz), and to respond by pressing" (Tallal, Miller & Fitch, 1993, p.28) the appropriate panels. Twelve 6- to 9-year-old aphasics performed more poorly than their matched controls only when the ISI was less than 428 ms.

Tallal and colleagues argued that, as vowels transmit the same acoustic information throughout their spectra and hence are referred to as steady state, and stop consonant syllables have a transitional period during which the frequencies change rapidly over the first 40 ms (after Tallal et al, 1993), dysphasics should be impaired in the latter but not the former case. In fact, when substituting the tone pairs with vowel-vowel and consonant-vowel syllables, Tallal and Piercy (1974) reported that the aphasics could discriminate two 250 ms steady-state vowels /e/ and /æ/ but were impaired in discriminating two 250 ms CV syllables /ba/ and /da/. However, after modifying the stimulus duration, the aphasics were impaired in discriminating vowel-vowel stimuli which incorporated a 40 ms-duration segment, but were unimpaired in processing the CV syllables when the formant transitions were extended to 80 ms. Thus, dysphasics have difficulty integrating "brief acoustic components of information occurring within tens of milliseconds in the ongoing speech stream, regardless of phonetic classification" (Tallal et al, 1993, p.32; Tallal & Stark, 1981).

Tallal (1980) found that twenty dyslexics (aged 8 to 12, with a reading lag of at least a year) were impaired in a temporal sequence and a same-different discrimination task of high and low tones when the ISI was 305 ms or less. Moreover, the degree of auditory temporal processing deficit was highly correlated with the degree of impairment in phonological decoding skills (r = 0.81). However, the dyslexic sample included both SRDs with or without language impairment. Subsequently, Tallal and Stark (1982) investigated 26 dyslexics (aged 7.5 to 9, reading age at least a year below mental age) who did not have concomitant language disorders. These children were found to have normal phonological decoding skills and temporal processing abilities, regardless of the sensory modality (Tallal et al, 1993). Hence, it was concluded that the auditory temporal processing deficit may not relate to dyslexia but to concomitant receptive or expressive language deficits (Tallal & Stark, 1982). However, note that the subjects used by Tallal and her colleagues had milder reading problems. These may conceal the temporal processing deficits in dyslexia found by other researchers (e.g., Efron, 1963; Lowe & Campbell, 1965; Watson, 1988; Reed, 1989; Ludlow et al, 1983).

Reed (1989) required 23 dyslexics (mean age 9) and 23 matched controls to report the order of pairs of stimuli. Dyslexics were impaired in judging brief tones (75 ms duration) and stop consonant syllables (250 ms duration) at short ISI. On the contrary, they had no problems with vowels (250 ms duration) and vowels presented in white noise. This implies that the temporal processing requirement for vowels is different from that for consonants. For instance, in speech, the stop consonants, on one hand, involve most rapid spectral changes (on the order of 40 ms in the time frame). Vowels, on the other, require the least temporal auditory differentiation (Phillips & Farmer, 1990). Further, Reed (1989) argued for a perceptual deficit in processing brief auditory cues in dyslexia and that their results validate Tallal's (1980) and Godfrey et al's (1981) studies.

Ludlow et al (1983) found that the language-impaired, the language-impaired hyperactives, the hyperactive reading-disabled and a group of hyperactive boys whose reading and language were normal were all impaired on temporal order judgment of tones when compared to their age-matched normal controls.

Kinsbourne, Rufo, Gamzu, Palmer and Berliner (1991) showed that the severe adult dyslexics (n=23) were also impaired in auditory temporal order judgment.

Further, in a temporal order judgment task with high / low tones, Farmer and Klein (1993) found that dyslexics (n=20, aged 14) were less accurate at perceiving the order of the tone pair.

In Mody, Studdert-Kennedy and Brady (1997), 20 second-grade reading impaired children (reading grade five months below grade level) were tested on TOJ of synthetic /ba/-/da/. The reading-impaired performed poorly and their errors increased as ISI decreased. However, no such trends were observed when dissimilar syllables (e.g., /ba/-/sa/, /da/-/ʃa/) or synthesised nonspeech stimuli were used. The authors argued for difficulty in identifying similar syllables "rapidly stem from independent deficits in speech and nonspeech discriminative capacity" (Studdert-Kennedy & Mody, 1995, p.508). Note that the long duration of the nonspeech stimuli may not be sensitive enough to test for the temporal processing deficit.

In sum, whether dyslexics / dysphasics are deficient in judging the order of two tones is inconclusive, even though the deficit is more apparent with stimuli of short duration and ISI. Moreover, dyslexics / dysphasics also have difficulty judging the order of speech stimuli, with the deficit mainly confined to consonants rather than vowels. The effect is more apparent when the speech sounds are short and similar to each other. In general, it seems that dyslexics / dysphasics are impaired in the auditory temporal order judgment of both verbal and nonverbal stimuli, especially those with small duration, ISIs or rapid acoustic changes.

4.3.4 *Sequence Matching or Discrimination*

Dyslexics / dysphasics also experience difficulty in auditory sequence matching. Table 4-4 summarises the relevant studies.

Table 4-4: Auditory Tasks on Sequence Matching or Discrimination

Author	Sample (Age Range)	Stimuli	ISI	Differ from Controls/ between Groups?
Zurif & Carson (1970)	Dyslexics (grade 4)	Seashore Rhythm Test	500-1000ms	Yes
Newman et al (1991)	Dyslexics (mean age 8.7)	Seashore Rhythm Test (rhythm & pitch)	500-1000ms	Yes
McGivern et al (1991)	Reading-disabled (aged 6-12) Learning-disabled	Seashore Rhythm Test	500-1000ms	Yes
Tallal & Piercy (1973b)	Aphasics (aged 6-9)	75ms tone sequence 250ms tone sequence	428ms 428ms	Yes Yes
Tallal et al (1981)	Aphasics (aged 5-9)	Tone sequence	500ms	Yes
Bryden (1972)	Poor readers (aged 9-10)	Tone sequence	500-750ms	Yes
Robin et al (1989)	Speech and language impaired children (aged 8-10)	Six-element (tone) temporal pattern	-	Yes
Corkin (1974)	Inferior readers (aged 6-11) Prereaders (aged 4-5)	Digits	1s	Yes
Gould & Glencross (1990)	Reading-disabled (aged 10-12)	Hebbs digits	W.A.I.S. procedures	Yes
Farmer & Klein (1993)	Dyslexics (age 14)	Tone sequence	40-360ms	No

The Seashore Rhythm Test involves sequences of 5 to 7 beats with long (1 s) and short (500 ms) intervals and subjects have to judge whether pairs of rhythmical patterns presented are the same or not. Using this test, Zurif and Carson (1970) found that dyslexics (n=14) were deficient in dealing with the temporal aspects of nonverbal auditory information. Moreover, reading skills and temporal processing were correlated to each other.

Similarly, Newman, Wright and Fields (1991) administered the rhythm and pitch sections of the Seashore test to 462 schoolchildren (mean age 8.7). They found that dyslexics (n=52) who had poorer reading and spelling scores compared to their intellectual abilities performed poorly on these nonverbal auditory perceptual tasks.

Additionally, McGivern, Berka, Languis and Chapman (1991) also found that both reading-disabled and learning-disabled subjects (N=59, aged 6 to 12), when compared to the normal controls, were impaired in their ability to discriminate patterned pairs of tones as well as right-left orientation in the Seashore test.

Tallal and Piercy (1973b) found aphasics to be worse than the controls on matching tasks using 3, 4, or 5 tones of 75 ms duration with ISI's of 428 ms. However, with tones of 250 ms duration, the aphasics were impaired only when 4 or 5 tones were used. Hence, increasing stimulus duration improved the serial memory performance of the aphasics. Therefore, apart from demonstrating deficits on tasks requiring the processing of stimulus information that is brief and followed in rapid succession by another stimulus (Tallal et al, 1993), the deficit observed in the aphasics is also influenced by total signal duration rather than just ISIs (Miller & Tallal, 1995). In addition, Tallal et al (1981) also found that 5-9 year-old aphasics were worse than controls in remembering the order of the auditory stimuli.

Also, Bryden (1972) found that poor readers (aged 9 to 10) were impaired on a tone sequence of 3 to 7.

In fact, Robin, Tomblin, Kearney and Hug (1989) argued for a perceptual learning difficulty such as a temporal processing deficit in children with speech and language impairments. They required children (4 with language impairment and 4 matched controls, aged 8 to 10) to listen to six-element temporal tonal patterns and to judge the temporal proximity of two of the elements. Although the language-impaired subjects' performance improved with repeated exposures, their best performance was still poorer than their matched controls who had only one exposure to the task (after Robin et al, 1989).

Corkin (1974) examined normal (n=24, aged 6 to 11), inferior (n=24, aged 6 to 11) and pre-readers (n=8, aged 4 to 5) on an auditory serial-ordering task. The task involved subjects repeating a string of digits. Inferior readers performed worse on this task, especially when a delay (e.g., 6 sec delay) or a doublet which increased the memory load was introduced.

Similarly, Gould and Glencross (1990) compared nineteen reading-disabled children (aged 10 to 12) with their matched controls on a repeated digits task of Hebb (1961). The reading-disabled had a digit span significantly worse than that of the normal subjects, showing a specific deficit in verbal serial organisation.

However, Farmer and Klein (1993) presented two sets of four high / low tones and subjects had to judge whether the tone sequences were the same or not. The dyslexics (n=20, aged 14) were not impaired on this task. The authors speculated that the dyslexics might have been processing the sequences holistically rather than sequentially. Therefore, negative results were obtained.

It is relatively clear that dyslexics / dysphasics are impaired in auditory tasks requiring sequence matching but the effect seems to be apparent only when sequential rather than holistic processing is involved. However, as stressed by Farmer and Klein (1995), the sequence matching tasks may not just involve temporal processing but also memory, as shown in Corkin (1974). So, at first glance, it is unknown whether the deficit is temporal or memory in nature. Furthermore, experiments which produce positive results are those using ISIs of about 500 ms, but Farmer and Klein (1993) were unable to replicate this result using shorter ISIs! The point is, if temporal processing deficit is evident, at least in auditory sequence matching, then shorter stimulus duration or ISIs should produce more positive results. However, this is not supported. Nevertheless, note that the ISIs used in auditory sequencing tasks (e.g., 500 ms) is much longer than the stimulus durations / ISIs used in auditory temporal order judgment (e.g., 100 ms) and fusion tasks (e.g., 20 ms). It can be argued that the stimulus duration used in auditory fusion and TOJ tasks is more likely to tap into the function of temporal processing whereas the ISIs used in auditory sequencing is more likely to tap into memory. Hence, it is likely that the differential effect obtained in auditory sequence matching tasks may reflect memory rather than temporal processing. This issue will be further discussed in the next chapter.

4.4 Anatomical / Physiological Evidence for Auditory Temporal Processing Deficits in Dyslexia / Dysphasia

Tallal and Newcombe (1978) demonstrated that damage to left cerebral hemisphere disrupted the temporal resolution of two tones presented with short but not long ISIs. The authors reasoned that the left hemisphere is critical for successful discrimination of rapidly changing acoustic spectra (regardless of whether the stimuli are verbal or not), and the resolution is within 10s of milliseconds (Miller & Tallal, 1995). Moreover, rapid auditory processing was highly correlated with language comprehension ($r = 0.83$).

In fact, areas responsible for language and auditory temporal processing can be further confined to the parietal, temporal and frontal areas (Fiez, Tallal, Miezin, Dobmeyer, Raichle & Petersen, 1992). In Fiez et al's (1992) PET study, healthy normal adults listened to four sets of sounds: 1) speech stimuli that either did (e.g., syllables or words) or did not (e.g., vowels) incorporate rapidly changing acoustic spectra; and 2) nonverbal complex acoustic stimuli that did or did not incorporate temporal changes. Activity decreased in the parietal lobe but increased in both left and right frontal and temporal cortex for all sets of stimuli. In particular, the left frontal area (Brodmann 45) which leads to aphasia after damage, was activated by both verbal and nonverbal stimuli that incorporated rapid acoustic change (Tallal et al, 1993).

Corroborating Tallal and Newcombe (1978) and Fiez et al (1992), Tallal et al (1991) studied 20 dysphasics and 12 controls (aged 8 to 10) using MRI and volumetric measurement of brain structures. The authors identified abnormalities "in superior parietal, prefrontal, and temporal cortices, as well as diencephalic and caudate nuclei" (p.363). These areas are consistent with the multimodal and behavioural profile of dysphasics.

Additionally, Neville, Coffey, Holcomb and Tallal (1993) tested twenty-two dysphasics and twelve controls (aged 8 to 10) and showed that subjects who experienced rapid auditory temporal processing deficits exhibited lower event-related potential

(ERP) amplitudes and increased ERP latencies in the superior temporal gyrus (perisylvian area).

Nonetheless, Hagman et al (1992) suggested dysfunction in the perisylvian regions in dyslexia. In their study, ten adult dyslexics and their matched controls underwent a PET scan while performing an auditory syllable discrimination task. The stimuli were comprised of brief duration formant transitions. Dyslexics were impaired in the discrimination task and had higher metabolism along the anterior-posterior gradient in the medial temporal lobe. In addition, while a lack of relationship between glucose uptake in the left hemisphere's cortical and diencephalic areas was found in the dyslexics, a strong positive relationship between glucose uptake and these areas was found in the controls, and for both groups in the right hemisphere (Miller & Tallal, 1995).

Wood, Flowers, Buchsbaum and Tallal (1991) investigated the left temporal functioning of dyslexics using regional cerebral blood flow (rCBF), combined auditory evoked responses (AERs) and PET. They found that dyslexics (n=10) performed more poorly on a continuous auditory phonemic discrimination task. Moreover, while normal controls showed positive correlation between left temporal rCBF and orthographic accuracy, and negative correlation between phonemic accuracy and left temporal rCBF near Heschl's gyrus, dyslexics showed positive correlation between phonemic accuracy and Heschl's gyrus activation (by PET and rCBF). Nevertheless, this study did not examine the relationship between orthography and right temporal rCBF.

Besides, during a cognitive auditory task, the left caudate metabolism of the dyslexics was correlated with the left inferior parietal lobule while the left caudate metabolism of the controls was correlated with the left temporal lobe (Flowers, 1993).

Thus, dyslexics demonstrated left hemispheric dysfunction. Flowers (1993) also suggested that the temporal lobe "subserves a process in common with the accurate analysis of both orthography and phonology, requiring fine auditory discrimination, whereas the inferior parietal area is associated with the higher order process of word meaning" (p.579) or comprehension. Thus, the abnormality identified in the temporal area is consistent with the behavioural profile of the dyslexics.

In Rumsey, Andreason, Zametkin, Aquino, King, Hamburger, Pikus, Rapoport and Cohen (1992), rCBF was measured with PET while fourteen adult dyslexics (mean age 27) and their matched controls performed an auditory phonologic task (rhyme detection) and a tone-detection task. While the control group "activated left temporoparietal cortex during rhyme detection but not during the nonphonologic attentional task" (p.527), dyslexics failed to activate the left temporoparietal regions during rhyme detection but did not differ from the controls during rest or the attentional task (after Rumsey et al, 1992). Thus, the inability of the dyslexics to activate the left temporoparietal regions during phonological task supports the hypothesis of left temporoparietal dysfunction in dyslexia.

In a subsequent study, Rumsey, Andreason, Zametkin, King, Hamburger, Aquino, Hanahan, Pikus and Cohen (1994a) examined the ability of dyslexics to activate right temporal cortex. rCBF was measured during rest and during a tonal memory task. While the matched-controls (n=18) "showed significant activation of several right frontotemporal regions as well as of left temporal cortex" (p.171), dyslexics (n=18) activated fewer right frontotemporal regions but "showed normal activation of left mid to anterior temporal cortex" (p.171). Hence, the rapid temporal processing deficits experienced in the dyslexics possibly involve both right and left temporal cortex.

In Rumsey, Zametkin, Andreason, Hanahan, Hamburger, Aquino, King, Pikus and Cohen (1994b), subjects listened to pairs of sentences and had to judge whether the sentences had the same meaning or not. PET using oxygen 15 was used to measure the cerebral blood flow during rest and during the sentence comprehension (syntax) task. It was found that during rest, dyslexics (n=15, mean age 27) showed reduced blood flow in the left parietal region near the angular / supramarginal gyri. During sentence comprehension, dyslexics and controls (n=20) exhibited similar cerebral blood flow in the left middle to anterior temporal and inferior frontal cortex. Hence, these results, together with Rumsey et al's (1992) report of failure of dyslexics to activate left temporoparietal cortex during phonological processing, argue for a dysfunction of left cortical language areas restricted to posterior language regions in dyslexia (after Rumsey et al, 1994b).

Stefanatos, Green and Ratcliff (1989) obtained steady-state auditory evoked responses to frequency modulated tones from two groups of developmental dysphasics (n=12) and their normal controls. Results show that dysphasics with expressive language impairment produced responses similar to the controls, whereas those with receptive language impairment produced diminished responses. The authors argued that analysis of rapid formant transition is carried out via frequency modulation analysis in the temporal lobes. For instance, indirect support has been provided by Kershner, Hadfield, Kershner and Cooke (1985). In their timed letter naming task, voice output was filtered by exaggerating high frequencies and attenuating low frequencies. Twelve reading-disabled children (aged 6.5 to 15), with or without central auditory dysfunction, increased their letter naming speed during frequency modification. Hence, combining Tallal's and Stefanatos et al's (1989) work, it can be argued that frequency modulation which attenuates rapid formant transition improves auditory temporal processing and letter naming.

In Brunswick and Rippon (1994), subjects were given a dichotic listening test which "involved the simultaneous presentation of different consonant-vowel syllables to each ear" (p.268-269), and were asked to report both of the syllables. Auditory evoked potentials (AEP) were taken. Dyslexics (n=15, aged 7 to 11) compared to controls (n=15, aged 8 to 10), were significantly worse on the phonemic awareness task particularly with rimes rather than onsets. In addition, the controls had significantly greater N100 amplitudes in the left temporal region during dichotic listening than dyslexics who displayed equivalent levels of amplitude bilaterally. Moreover, AEP lateralisation indices were significantly related to phonemic awareness performance (after Brunswick & Rippon, 1994): the greater the hemispheric asymmetry measured at the temporal, the better the performance on the rime condition of the phonemic awareness test.

Eleven Hebrew dyslexics and their matched controls (mean age 10) detected either high tones embedded within the low tones or "PA" embedded within the "DA". ERPs were taken during the tasks. Erez and Pratt (1992) found that: 1) P3 peak amplitude was more attenuated in the dyslexics in response to verbal compared to nonverbal stimuli; and 2) P3 apex orientation, which pointed in an upward-posterior direction, tilt to left in normal controls and to the right in dyslexics.

Mason and Mellor (1984) also found that language-impaired children displayed early cortical sensory potentials (N1 and P2) that were larger over the left than the right hemisphere regardless of the ear of stimulation whereas controls revealed contralateral dominance on stimulation in both ears.

On the other hand, 91 male Caucasians aged 8 to 11 were classified into: 1) reading disabled (n=24); 2) attentional deficit disorder with hyperactivity (n=23); 3) attentional deficit disorder without hyperactivity (n=21); and 4) normal controls (n=23). They were asked to respond to a low probability tone. Results showed that late components like P3b, slow wave and Pc were smaller in the clinical groups. However, unlike the parallel visual session (Holcomb, Ackerman & Dykman, 1985), P3 latency did not differentiate among the groups (Holcomb, Ackerman & Dykman, 1986).

Subsequently, Ackerman, Dykman, Oglesby and Newton (1994) measured the electroencephalogram (EEG) of the dyslexics (n=42) during verbal processing. Tasks administered were: 1) judging whether a pair of words rhymed with each other; and 2) reading some words or letters silently. Results showed that dyslexics had lesser power at the parietal and midline sites for the low beta band. Also, they had lesser low beta at the left than right temporal site. More alpha suppression was found in word strings relative to letter strings in the dyslexics. Additionally, "greater low beta and less theta power significantly predicted better reading and spelling" (p.619).

Miller and Tallal (1995) argued that "separate neural systems may exist for the processing of short duration information presented in rapid succession, within 10s of milliseconds, as compared with information presented within 100s of milliseconds" (p.292). This is consistent with the hypothesis of separate physiological representations for the transient and sustained processing systems in the auditory modality as has been discussed. Examining the brains of five dyslexics (mean age 34.2) and five nondyslexics (mean age 40), Galaburda and Livingstone (1993) found that the auditory "magnocellular" pathways in the MGN, of dyslexics, were different from those of the controls in two ways: 1) the dyslexics had a relative paucity of large neurons and relative excess of small neurons. The relative paucity of large cells in left MGN of the dyslexics may prevent "lateralisation of rapid processing to the left hemisphere, which is likely to represent an important factor in language lateralisation" (p.79); and 2) there was an asymmetry in the proportion of large cells in the direction of the left MGN in the controls and in the direction of the right MGN in the dyslexics. Note that the differences are only seen in the left but not the right MGN, suggesting relevance to language laterality (Galaburda, Menard & Rosen, 1994).

In addition, dyslexics were found to have anomalous cerebral asymmetry of the planum temporale (Galaburda & Kemper, 1979; Galaburda, Sherman, Rosen, Aboitiz & Geschwind, 1985). This area, which normally has "large pyramidal neurons and rich intracortical myelination, may form part of the fast components of the auditory system" (Galaburda & Livingstone, 1993, p.80). Furthermore, the small sample size, the wide age range of the subjects, the poorly documented dyslexic population and control samples used in the experiments make firm conclusions from this work difficult (Semrud-Clikeman, Hynd, Novey & Eliopulos, 1991).

Contrary to Galaburda and Kemper (1979) and Galaburda et al (1985) who found dyslexics having symmetric plana, Leonard, Voeller, Lombardino, Morris, Hynd, Alexander, Andersen, Garofalakis, Honeyman, Mao, Agee and Staab (1993) failed to replicate their results. Their MRI study showed that dyslexics (n=9, aged 15 to 65), the unaffected relatives (n=10, aged 6 to 63) and controls (n=12, aged 14 to 52) all "had left-sided asymmetry for the temporal bank of the planum and right-sided asymmetry for the parietal bank" (p.461). It has been documented that leftward asymmetry in the temporal bank is associated with functional localisation for language while rightward asymmetry in the parietal bank of the fissure is associated with nonverbal or visuospatial processing (Steinmetz, Rademacher, Jancke, Huang, Thron & Zilles, 1990; Witelson & Kigar, 1992). Indeed, dyslexics had exaggerated asymmetries, owing to a shift of right planar tissue from the temporal to parietal bank (after Leonard et al, 1993). The discrepancy between Leonard et al (1993) and Galaburda et al (1985) may be attributed to different measurement techniques. For instance, Galaburda et al (1985) did not distinguish between the temporal and parietal banks and included both of them in the measurement of the planum. Therefore, symmetry was found due to the enlarged right planum. On the other hand, Leonard et al (1993) distinguished between the temporal and parietal banks and hence their results differed. For instance, when the planum was defined using Galaburda et al's (1985) method, Leonard et al (1993) also found that the total planum was symmetrical. Furthermore, both Galaburda et al (1985) and Leonard et al (1993) drew their attention to the right plana.

Roncagliolo, Benítez and Pérez (1994) measured the brainstem auditory evoked potentials (BAEPs) from 48 developmental dysphasics (aged 4 to 9) and 20 healthy children (aged 4 to 8). Dysphasics showed overall lower absolute latency values. There were no differences in the central conduction time of the auditory pathway but there were differences with the auditory nerve discharge. The authors explained the results in terms of "a reduction in the control mechanisms of the sensory inputs at the peripheral level, or a disturbance in the inhibitory mechanisms of cortico-subcortical modulation" (p.31). Their results are compatible to Galaburda and Livingstone (1993) who found a deficient auditory "magnocellular" pathway which results in weak inhibition.

Furthermore, Grøntved, Walter and Grønborg (1988) recorded the auditory brain stem responses (ABR) of twenty-four severely constitutionally dyslexics (mean age 14) and found that their response latencies did not differ from those of the matched controls. However, the authors analysed the data using the non-parametric Mann-Whitney test. The lack of statistical power of the test may explain why there is no difference between the two groups. On the other hand, Ayres (1972) and Stillman, Moushegian and Rupert (1976) found abnormal ABR in learning-disabled children (including dyslexics). Nevertheless, the heterogeneity of the sample makes the result inconclusive.

In sum, there is a strong anatomical / physiological evidence supporting language and auditory temporal processing deficits in dyslexia / dysphasia. The area of interest is focused on the left hemispheric regions like the parietal, frontal and temporal cortices, and on more specific regions like the perisylvian area, planum temporal, Heschl's gyrus and diencephalic and caudate nuclei. In fact, these are the areas responsible for auditory and language function. For example, "the cortical structures devoted to auditory processing are found in the temporal bank of the sylvian fissure. Heschl's gyrus receives auditory projections from the medial geniculate and relays them to the secondary auditory cortex of the planum temporale and superior temporal gyrus. This is a site where auditory phonemes could be mapped onto visual graphemes relayed from parieto-occipital cortex" (Leonard et al, 1993, p.461). Phillips (1993) argued that the temporal resolution of the cortical auditory neurons can support behavioural performance for up to 2 to 3 ms in auditory fusion and up to 20 ms in auditory temporal order judgment (Hirsh, 1959). Moreover, the 20-ms perceptual threshold for identifying the order of onset for components of auditory stimuli is a factor contributing to the perception of voicing contrasts in speech (Pastore & Farrington, 1996). Similar resolving power also exists in other modalities and this resolution is consistent with the limits of the dyslexics / dysphasics who suffer from auditory as well as other temporal processing deficits.

4.5 Summary of Auditory Temporal Processing Deficits in Dyslexia / Dysphasia

Thus, there is experimental and anatomical / physiological evidence suggesting that dyslexics / dysphasics experience some form of temporal processing deficit in the auditory modality. Moreover, the temporal processing deficit is more apparent in auditory fusion and TOJ than in auditory sequence matching. Similar deficits exist in the visual modality and this will be discussed in 4.6 and 4.7.

4.6 Experimental Evidence for Visual Temporal Processing Deficits in Dyslexia / Dysphasia

As stressed in 4.1, there is considerable evidence that dyslexics / dysphasics experience difficulties in visual temporal processing. Similar to 4.3, types of studies include: 1) detection or identification of a stimulus event; 2) determination of numerosity; 3) temporal order judgment; 4) sequence matching or discrimination; 5) masking; and 6) contrast sensitivity. Furthermore, most evidence is cited from studies of dyslexia. The studies are listed in Tables 4-5 to 4-10. The presentation style is also based on Farmer and Klein (1995).

4.6.1 Detection or Identification of a Stimulus Event

The evidence that dyslexics / dysphasics are having difficulty in visual detection / identification of stimuli is conflicting. The studies are summarised in Table 4-5.

Table 4-5: Visual Tasks on Detection or Identification of a Stimulus Event

Author	Sample (Age Range)	Stimuli	Stimulus Duration	Differ from Controls/ between Groups?
Mason (1980)	Poor readers (College age)	Letters	20-130ms	No
Morrison et al (1977)	Poor readers (aged 12)	Circular array of stimuli	150ms	No (only when cued 0 to 300ms)
Blackwell et al (1983)	Learning-disabled (aged 8-12)	Letters	150ms	No
Gross-Glen & Rothenberg (1984)	Dyslexics (aged 11-15)	Single letter Double letters	2-180ms	Yes Yes
Bouma et al (1975)	Dyslexics (aged 8-12)	Long words	100ms	Yes
Bouma et al (1976)	Dyslexics (aged 8-12)	Long words	100ms	Prolonged & temporal separation improved recognition
Shapiro et al (1990b)	Dyslexics (aged 10-14)	One-syllable word Two-syllable word Three-syllable word	100ms 300ms 3000ms	Yes
Brannan & Williams (1987)	Poor readers (aged10) Good readers (aged 9) Adults	Letters	30ms	Yes

Mason (1980) found that poor readers performed as well as good readers in identifying letters exposed from 20 to 130 ms. Similarly, good and poor 12-year-old readers were equally good at identifying a circular array of stimuli, but only when the stimulus was cued 0 to 300 ms (but not 500 ms and after) after the array (Morrison, Giordani & Nagy, 1977). Blackwell, McIntyre and Murray (1983) found no difference between the learning-disabled and controls in detecting an "T" or an "F" displayed for 150 ms.

On the other hand, Gross-Glen and Rothenberg (1984) found that dyslexics (aged 11 to 15) needed longer time to identify single or double letters. However, their stimuli were presented monocularly and peripherally.

Bouma, Legein and van Rens (1975) found that tachistoscopic (100 ms) recognition of long words (word length > 6 characters) presented foveally was poor in dyslexics but not in controls. In addition, recognition improved with prolonged presentation time. So, Bouma, Legein and van Rens (1976) presented the words either spatial or temporally separated. Results showed that spatial separation did not improve the recognition of long words in dyslexics (n=12). On the contrary, prolonged presentation and temporal separation improved recognition. This indicates simultaneous processing difficulties in dyslexics. Presumably, dyslexics read a long word by segmenting it into parts and processing the parts successively. When the first part is recognised, it has to be retained while the second part is processed. Thus, prolonged presentation is required in order to keep the second part available (Bouma et al, 1975).

Shapiro, Ogden and Lind-Blad (1990b) required 15 dyslexics, 15 age-matched and 15 reading-matched controls (aged 10 to 14) to identify one- and two-syllable words displayed for 100, 300 or 3000 ms. Dyslexics performed as well as the controls with short words which required one fixation and with long words when there was insufficient time to make a second fixation. However, they performed poorer on the two-syllable, 300 ms condition, a condition which had sufficient time to allow a saccade (Farmer & Klein, 1995).

Brannan and Williams (1987) required subjects to detect "S" or "N" presented 2° to the left or to the right of a fixation target in the center of the visual field. A cue to target presentation and location was provided. Results showed that poor readers (n=6, aged 10) were unable to make use of the cue that predicted the location of the target to the right of the fixation point, a crucial part of the visual field for information processing in reading (Garzia & Nicholson, 1990). Moreover, they could not utilise the cue if it preceded the target by less than 50 ms, whereas the controls (n=6, aged 9) could utilise such information at shorter intervals (Williams & LeCluyse, 1990).

The fact that dyslexics have visual temporal processing deficits has led most researchers to attribute this to the dysfunction of the magnocellular visual pathway or the transient visual system (e.g., Lovegrove et al, 1986a; Galaburda & Livingstone, 1993). The methodology used in Gross-Glen and Rothenberg (1984), Shapiro et al (1990b) and Brannan and Williams (1987) is supportive of this. For instance, the difference between the dyslexics and controls was most obvious when Gross-Glen and Rothenberg (1984) presented the stimuli in the periphery and when Shapiro et al (1990b) and Brannan and Williams (1987) presented the words or letter that needed a saccade to identify. On the other hand, the failure by Mason (1980), Morrison et al (1977) and Blackwell et al (1983) to find a difference may be attributed to: 1) Mason (1980) and Blackwell et al (1983) presented letters for a relatively long duration and the mode and the duration of presentation did not stimulate the transient visual system well enough; and 2) Morrison et al's (1977) task is more likely a test for memory processes rather than temporal processing mechanisms. Thus, it seems that the reduced ability of the dyslexics / dysphasics to detect the stimulus can only be identified using tasks that tap into the transient system functioning.

4.6.2 Determination of Numerosity

As discussed in 4.2, determination of numerosity involves the determination of whether one or more than one item has been presented (Farmer & Klein, 1995). Many researchers show that dyslexics experience difficulty determining numerosity in visual tasks. In this section, evidence mostly comes from studies of individuation of two stimuli. The studies are summarised in Table 4-6.

Table 4-6: Visual Tasks on Determination of Numerosity

Author	Sample (Age Range)	Stimuli	Stimulus Duration	Differ from Controls/ between Groups?
Lovegrove & Brown (1978)	Reading disabled (mean age 8 & 11)	+, square N, O	20ms	Yes
Slaghuis & Lovegrove (1985)	Dyslexics (aged 9)	Sine-wave gratings	60-300ms	Yes
Lovegrove et al (1980)	Dyslexics (aged 8)	Sine-wave gratings	-	Yes
Howell et al (1981)	Dyslexics (aged 10-14)	Sine-wave gratings	20ms 100ms	No
Slaghuis & Lovegrove (1984)	Dyslexics (aged 12)	Sine-wave gratings	300ms	Yes
Chase & Jenner (1993)	Dyslexics (aged 17-22)	Figures Shapes Colour change	D.V.	Yes No
Talcott et al (1997)	Dyslexics (mean age 27.6)	Flicker	D.V.	Yes
Di Lollo et al (1983)	Dyslexics (aged 8-14)	Vertical lines Dot matrices	20ms plotting interval	Yes No
Arnett & Di Lollo (1979)	Poor readers (aged 7-13)	Dot matrices	plotting interval	No
Hogben et al (1995)	Dyslexics (mean age 9)	Dot matrix	20ms/ half matrix	No
Stanley & Hall (1973b)	Dyslexics (aged 8-12)	Words Figures	20ms	Yes

Table 4-6 (cont.)

Author	Sample (Age Range)	Stimuli	Stimulus Duration	Differ from Controls/ between Groups?
Stanley & Hall (1973a)	Dyslexics (aged 8-12)	Letter array	40-6000ms	Yes Poor recall at 40ms condition
Martos & Marmolejo (1993)	Dyslexics (aged 7-14)	Vertical lines &/or Horizontal lines	-	Yes
Winters et al (1989)	Dyslexics (aged 18-37)	4 sides of a square	2ms	Yes
Farmer & Klein (1993)	Dyslexics (aged 14)	Flashes	-	No

Lovegrove and Brown (1978) measured visual information store duration of their subjects using a temporal separation task of two components of a stimulus (+ and a square; N and O). Subjects had to say whether the two parts of the stimulus were presented simultaneously or successively. Reading-disabled children (n=16, mean age 8 and 11) had longer separation thresholds than the controls.

Slaghuis and Lovegrove (1985) presented vertical sine-wave gratings of 1, 2, 4, 8 and 12 c/d and measured the visible persistence (VP) or temporal separation thresholds of their subjects. Relative to the controls (n=14, mean age 9.1), dyslexics (n=12, mean age 9) had a smaller increase in VP with increasing spatial frequency and showed longer VP at low spatial frequencies and shorter VP at high spatial frequencies (Lovegrove, Heddle & Slaghuis, 1980). The authors reasoned that VP was an index for the sustained system activity and that the increased VP at low spatial frequencies implied a weak transient inhibition. However, Howell, Smith and Stanley (1981) failed to replicate this finding with 10 dyslexic boys and their matched controls. The failure to replicate the difference may be attributed to: 1) Lovegrove et al (1980) used a tachistoscope whereas Howell et al (1981) used a cathode ray oscilloscope (CRO) which eliminated the transient artifacts during stimulus presentation (Slaghuis & Lovegrove, 1986); 2) "catch" trials occupied 50% of the trials in Lovegrove et al (1980) whereas they occupied 12.5% of the trials in Howell et al (1981); and 3) Lovegrove et al (1980) used a block trials procedure whereas Howell et al (1981) used a staircase method.

Additionally, Slaghuis and Lovegrove (1984) demonstrated that a 6 Hz uniform field flicker (UFF), which decreases the transient system inhibition on the sustained system, did not alter the VP in dyslexics at low spatial frequencies, but increased the VP at high spatial frequencies. Similarly, UFF did not alter the contrast sensitivity at low spatial frequencies but it decreased that at high spatial frequencies. (Martin & Lovegrove, 1988). Reduction of the transient system activity by UFF masking eliminated VP differences between the two groups.

Chase and Jenner (1993) compared visual processing speed in the magno- (transient) and parvocellular (sustained) layers in 7 adult dyslexics and 8 controls (aged 17 to 22) using flicker fusion threshold tasks. Tasks examining M cells involved either: 1) the stimuli being presented spatiotemporally such that the fused image resulted in an overlapped composite image (after Chase & Jenner, 1993); or 2) shape discrimination or apparent motion. Subjects determined the point where the display no longer flickered. Tasks examining P cells required subjects to determine the point when a square changed from red / green to brown / yellow. Dyslexics showed higher fusion thresholds in the M but not the P tasks. This is consistent with the transient system deficit hypothesis.

Similarly, Talcott, Hansen, Willis-Owen, McKinnell, Richardson and Stein (1997) found that adult dyslexics (n=18, mean age 27.6) exhibit lower critical flicker fusion (CFF) frequencies (the highest temporal frequency that can be detected at full contrast) than the controls.

Di Lollo et al (1983) tested 10 dyslexic boys aged 8 to 14. The temporal integration tasks consisted of a gap-detection and a matrix-integration task. In the former task, one of each pair of test trials consisted of two vertical lines separated by an ISI. The other consisted of a single line. Subjects had to report in which of the two trials the ISI occurred. Dyslexics needed longer ISIs to report which of the two trials contained the ISI. In the latter task, subjects were presented two 5x5 square dot matrices with the pairs of dots plotted sequentially in each cell of the matrix (25 plotted frames). One dot was missing from one of the cells and subjects had to report which cell had the missing dot. Duration of the plotting interval corresponding to 75% performance level was recorded. However, this task failed to discriminate the dyslexics from the controls. Furthermore, Di Lollo et al (1983) said that the effect was most evident when sequential stimuli impinged on the same retinal location and dyslexics took longer to recover from the aftereffects of neural activity evoked by an inducing stimulus.

Using the same dot matrix-integration technique, Arnett and Di Lollo (1979) also failed to find a difference between 24 poor readers (aged 7 to 13) and their controls in visible persistence. Reasons for this replication failure may include: 1) the employment of dyslexics who were just a year behind in the expected reading grade level as compared to those who were admitted with a stricter criteria (e.g., Stanley's and Lovegrove's; Di Lollo et al, 1983); and 2) the use of the median plotting interval as the dependent variable compared to the use of the mean ISI at which two sequentially presented portions of a composite display appear to separate as the dependent variable (after Arnett & Di Lollo, 1979) in other studies.

Hogben, Rodino, Clark and Pratt (1995) modified the matrix-integration technique in Arnett and Di Lollo (1979) and Di Lollo et al (1983). In this temporal integration task, a 4x4 dot matrix with a missing dot was presented in two frames: 8 dots in the first frame and 7 dots in the second, each frame being presented for 20 ms with an intervening ISI (after Hogben et al, 1995). Then a full matrix was presented and subjects had to point to the place where the dot was missing. Confirming Arnett and Di Lollo (1979) and Di Lollo et al (1983), results showed no difference in visible persistence between the dyslexics (n=12, mean age 9, reading lag of 1.5 year) and controls (n=12, mean age 9) even when a two-frame procedure instead of the plotting interval procedure was used. Thus it seems that temporal integration tasks using dot matrices are just generally insensitive in detecting differences in visible persistence.

Stanley and Hall (1973b) presented two parts of a stimulus with 20 ms duration and varying ISI. They found that dyslexics (n=33, aged 8 to 12) needed longer ISIs to report a display as not consisting of a composite figure and to identify the stimulus. Also, Stanley and Hall (1973a) presented a letter array for 40 to 6000 ms. Dyslexics recalled less in the array especially after brief exposures like 40 ms.

Martos and Marmolejo (1993) examined their subjects on a temporal integration and a gap detection task. The temporal integration task involved presenting a vertical and a horizontal line successively and establishing the longest ISI at which subjects could still see the "+". The gap detection task involved presenting a "-" twice and establishing the shortest ISI at which subjects could distinguish a double flash from a single display (after Martos & Marmolejo, 1993). Confirming Lovegrove et al (1986a) and Di Lollo et al (1983), dyslexics (n=30, aged 7 to 14) showed longer VP and VP decreased with increasing age. The authors argued for a maturational lag in dyslexia.

Winters, Patterson and Shontz (1989) presented subjects with the four sides of a square and asked them to judge whether the sides were presented simultaneously or sequentially. Dyslexics (n=8, aged 18 to 37) required longer ISIs only when parts of the test stimuli were presented to adjacent retinal areas.

However, Farmer and Klein (1993) failed to replicate the finding that dyslexics needed longer ISIs to segregate two flashes. They reasoned that the range of ISIs they used may have been too broad, and the tracing steps too gross, to capture the difference (after Farmer & Klein, 1993).

Thus, although Farmer and Klein (1993) and Arnett and Di Lollo (1979) failed to show that dyslexics have longer temporal separation thresholds, most researchers confirm that dyslexics are impaired in visual numerosity tasks which require temporal resolution. Negative results are often produced when temporal integration tasks employing dot matrices are used. This may relate to the spatial frequency content of the stimuli. Since the distance between the dots within a matrix is small, it is possible that only the high spatial frequency content of the stimuli is tested. Therefore, little difference is found between the reading groups as the differential effect is mainly found in low spatial frequency stimuli.

4.6.3 Temporal Order Judgment

Studies investigating whether dyslexics / dysphasics are impaired in visual temporal order judgment are summarised in Table 4-7.

Table 4-7: Visual Tasks on Temporal Order Judgment

Author	Sample (Age Range)	Stimuli	Stimulus Duration	Differ from Controls/ between Groups?
Efron (1963)	Aphasics	Lights	5ms	Yes
Kinsbourne et al (1991)	Severe dyslexics (adult) Recovered dyslexics	Flashes	3ms	Yes
May et al (1988b)	Poor readers (3rd/4th grade) Good readers Adults	Words	100ms	Yes
Brannan & Williams (1988a)	Poor readers (aged 8-12) Good readers	Words Symbols	900ms	Yes
Tallal & Piercy (1973b)	Aphasics (aged 6-9)	Flashes	75ms	No
Reed (1989)	Dyslexics (aged 9)	Figures	83ms	No
Farmer & Klein (1993)	Dyslexics (aged 14)	Symbols	-	suggestive trend

Efron (1963) found that left-hemisphere-damaged aphasics (n=5) had higher visual temporal order judgment thresholds than their normal controls when judging the order of green and red lights.

Similarly, Kinsbourne et al (1991) showed that severe adult dyslexics (n=23) were impaired in visual temporal order judgment.

In May, Williams and Dunlap (1988b), third and fourth grade children reported the order of two words (BOX and FOX) presented to the left and right or above and below a fixation point. Poor readers (n=7, reading lag of at least a year) required longer SOAs than good readers (n=7), who in turn required longer SOAs than adults (n=7) to report the order of the words or to report the position which the first word appeared. Moreover, poor readers exhibited longer SOAs than the other two groups especially in the word condition.

Using the same paradigm as May et al (1988b), Brannan and Williams (1988a) required subjects to report the order of two stimuli (BOX, FOX or #, &) presented 1° either to the left or to the right of a fixation point. Regardless of stimulus type, poor readers (n=15, aged 8 to 12) took longer to make accurate temporal order judgments. Moreover, the magnitude of difference did not lessen with age. Hence, the authors argued for a fundamental perceptual deficit rather than a developmental lag in dyslexia.

Nevertheless, not all studies show visual temporal order judgment deficits in dyslexia and dysphasia. For instance, Tallal and Piercy (1973b) found that language-impaired children did not differ from controls (6 to 9 years old) in judging the order of two 75-ms green flashes with ISIs of 30 to 428 ms. Their failure to replicate may be attributed to the use of long stimulus duration (75 ms) for flashes, as compared to the short ones (5 and 3 ms) used in Efron (1963) and Kinsbourne et al (1991). Furthermore, Tallal et al (1981) noticed that it was more likely for the younger aphasics (5 to 6 year-old) than for the older ones (7 to 8 year-old) to be impaired on these visual tasks. So, the inability to find a difference could also relate to subject selection.

Reed (1989) presented 10 dyslexics (aged 9) and their matched controls brief visual figures (ϕ and <, with a duration of 83 ms) and asked them to report the order of the stimuli. The ISIs were 400, 300, 150 and 50 ms respectively. However, no difference was found between the dyslexics and controls. The author reasoned that an ISI of 10 ms, which is most sensitive to group difference, was not presented. This may explain the failure to replicate.

Similarly, Farmer and Klein (1993) failed to replicate the finding that dyslexics (n=20, aged 14) were impaired in visual temporal order judgment, even though there was a suggestive trend that they were less accurate at ordering two symbols. The failure to find the difference may be attributed to the use of unfamiliar, less meaningful and less verbally-codable stimuli. In fact, experiments using stimuli that are hard to "verbalise" or "label" are less likely to uncover the relationship between temporal processing and reading (see Wagner & Torgesen, 1987). For instance, Nicolson and Fawcett (1993a) demonstrated that tasks involving both phonological and nonphonological components were processed slower than those involving just a nonphonological component by dyslexics. They reasoned that the slowness of dyslexics results from two factors: a general deficit in stimulus classification speed and a linguistic deficit (Nicolson & Fawcett, 1994). This argument is consistent with May et al (1988b) but not with Brannan and Williams (1988a), as May et al (1988b) found a longer SOA in the word condition whereas Brannan and Williams (1988a) found no difference regarding the stimulus type. Thus, it is possible that verbal stimuli which leads to verbal mediation may enhance the role of visual temporal processing in reading.

Similar to the results in visual numerosity tasks, dyslexics / dysphasics are generally impaired in visual temporal order judgment. The failure to replicate the findings may be attributed to the use of conditions which are not sensitive enough to transient system function. Also, other factors may include the use of long stimulus duration / ISIs, types of stimuli used and differences in subject selection.

4.6.4 Sequence Matching or Discrimination

Studies investigating whether dyslexics / dysphasics are impaired in visual sequence matching are summarised in Table 4-8.

Table 4-8: Visual Tasks on Sequence Matching or Discrimination

Author	Sample (Age Range)	Stimuli	ISI	Differ from Controls/ between Groups?
Zurif & Carson (1970)	Dyslexics (grade 4)	Seashore Rhythm Test (flashes)	500-1000ms	Yes
Bakker (1967)	Severe dyslexics (aged 9-15) vs mild dyslexics	Nonsense figures Meaningful figures Letters Digits	4s	No Yes Yes No
Rudel & Denckla (1976)	Learning-disabled (aged 7-12)	Flashes / dots	500-1500ms	Yes
Eden et al (1995a)	Reading-disabled (aged 10-12)	Dots	200-400ms	Yes
Bauserman & Obrzut (1981)	Dysphonetic dyslexics Dyseidetic dyslexics Alexic dyslexics (aged 11-12)	Flashes / dots	500-1500ms	Dyseidetic and normal readers performed better than alexic and dysphonetic readers
Poppen et al (1969)	Aphasics (aged 5-9)	Light	800ms	Yes
Farmer & Klein (1993)	Dyslexics (aged 14)	Flashes	50-250ms	Yes
Corkin (1974)	Inferior readers Pre-readers	Knox Cubes Test	-	Yes
Tallal et al (1981)	Language-impaired (age 5-9)	Symbols	500ms	Yes
Tallal & Piercy (1973b)	Aphasics (age 6-9)	Flashes	428ms	No
Bryden (1972)	Poor readers (age 9-10)	Flashes Dots	500-750ms	No No
Gould & Glencross (1990)	Reading-disabled (age 10-12)	Corsi blocks	1s	No
Bell (1990)	Dyslexics (age 11-14)	Visual sequential memory subtest Stanford-Binet 10-piece form board	- -	No Yes

Zurif and Carson (1970) had 28 grade 4 boys perform a visual version of the Seashore Rhythm Test. Subjects saw two sets of flashes and decided whether the two sets were the same or not. Dyslexic boys performed worse on this task and the authors interpreted this difference as incomplete cerebral dominance.

Bakker (1967) presented sequences of four stimuli to severe and mild reading-disabled children aged 9 to 15. The stimulus types included nonsense figures, meaningful figures, letters and digits. Group differences were only found in sequences of meaningful figures and letters but not in sequences of nonsense figures and digits. Note that the author just compared the severe with the mild reading-disabled and not with normal controls. This may make the group difference less apparent in the nonsense figure and digit conditions. Also, the use of verbal stimuli may have enhanced the role of temporal processing in reading, as discussed in previous section.

Rudel and Denckla (1976) presented sequences of light flashes and asked their subjects (N=51, aged 7 to 12) to match them with sequences of flashes (a temporal-temporal TT task) or spatially arranged patterns of dots (a temporal-spatial TS task). The learning disabled group (n=23), which mainly consisted of reading disabled subjects, performed much poorer than the controls.

Eden, Stein, Wood and Wood (1995a) required thirty-nine normal and twenty-six reading disabled children to perform a temporal and a spatial dot counting task. For the temporal dot counting task, subjects had to count the dots as they sequentially flashed up in the same location whereas for the spatial dot counting task, subjects had to count the dots in space (after Eden et al, 1995a). Reading disabled children performed worse on the temporal dot counting task, but were only mildly impaired on the spatial dot counting task. The authors concluded that dyslexics performed worse in tasks requiring rapid, sequential processing.

Bauserman and Obrzut (1981) compared the spatial and temporal matching abilities of: 1) dysphonetic dyslexics (dyslexics who have difficulty reading nonsense words and not irregular words, n=13); 2) dyseidetic dyslexics (dyslexics who have difficulty reading irregular words and not nonsense words, n=16); 3) alexic dyslexics (n=20); and 4) normal readers (n=18). The task, identical to that used in Rudel and Denckla (1976), consisted of printed dot patterns (spatial stimuli) and light flashes (temporal stimuli). Four tasks were administered: 1) spatial-spatial (SS); 2) spatial-temporal (ST); temporal-spatial (TS); and 4) temporal-temporal (TT). Results indicated that normal and dyseidetic readers were better than dysphonetic and alexic readers in matching purely temporal information. Additionally, matching abilities were found to be more related to the ability to sequence temporal information than to integration ability.

Poppen, Stark, Eisenson, Forrest and Wertheim (1969) required aphasic children (n=6, aged 5 to 9) "to press three panels in the same order in which light had flashed on those panels" (p.288). The sequencing ability of the aphasics was inferior to that of the controls, especially when a delay was introduced.

Also, Farmer and Klein (1993) presented two sets of 4 light flashes sequentially and found that the dyslexics (n=20, aged 14) were impaired in the sequence matching task.

Corkin (1974) compared normal (n=24), inferior (n=24) and pre-readers (n=8) on a visual serial-ordering task. The visual serial-ordering task was a modified version of Knox Cubes in which subjects had to tap the cubes in the same order as the examiner did (after Corkin, 1974). Inferior readers were impaired in this task, especially when a delay or a doublet which increased the memory load was introduced. However, Corkin (1974) arranged five blocks in one single column. It is possible that subjects might have used verbal mediation (Gould & Glencross, 1990) and hence the deficit is more related to reading (see Wagner & Torgesen, 1987).

Though Tallal et al (1981) demonstrated that language-impaired children aged 5 to 9 were impaired in matching sequences of 3 to 7 symbols, Tallal and Piercy (1973b) found that their aphasics (aged 6 to 9) were not impaired in matching sequence of flashes.

Similarly, Bryden (1972) asked subjects to match sequences of flashes or dots. Poor readers (aged 9 to 10) did not differ from the controls in both tasks.

Gould and Glencross (1990) administered the Corsi Blocks test (Milner, 1971) to 19 reading-disabled subjects (aged 10 to 12). Subjects had to tap out the sequence in the order it was presented (after Gould & Glencross, 1990). Their block span did not differ from that of the controls. The result does not support a general deficit in serial organisation but it does support a specific deficit in verbal serial organisation in reading disability because the same subjects had poorer digit span, as stated in 4.3.4.

In Bell (1990), forty-two dyslexic and forty-two normal readers were given the Visual Sequential Memory subtest of the Illinois Test of Psycholinguistic Abilities (Kirk, McCarthy & Kirk, 1968). Test items ranged from four to seven elements. Subjects looked at the sequence of chips to be remembered and had to reproduce the sequence using the figure chips (after Bell, 1990). No difference was found between groups. In a second study, subjects were given the 10-piece form board from the Stanford-Binet Intelligence Scale. They were briefly shown the complete board before the pieces were removed and had to complete the board as quickly as possible (after Bell, 1990). Dyslexics were significantly slower on this task. The author argued that since dyslexics and ordinary readers performed equally in the first task and that short-term memory was not a feature of the second task, "short-term memory problems were unlikely to be a feature of dyslexics' performances on rapid sequential processing tasks" (p.1155). However, note that the items used in the second task are easier to "label" or "verbalised" than the ones used in the first task. This may enhance the differences between the reading groups (see Wagner & Torgesen, 1987).

Even with the negative results presented, it seems that at least some dyslexics / dysphasics are impaired in some visual sequence matching tasks. This is consistent with some research that not all dyslexics have visual deficits (e.g., Borsting, Ridder, Dudeck, Kelley, Matsui & Motoyama, 1996; Gross-Glenn, Skottun, Glenn, Kushch, Lingua, Dunbar, Jallad, Lubs, Levin, Rabin, Parke & Duara, 1995). The failure to replicate the results may be attributed to the use of inappropriate group comparison or meaningless figures. In general, results using flashes and dots as stimuli are inconclusive. Furthermore, differential effects are more likely to obtain when longer ISIs are used. In addition, nonsense / meaningless figures or figures that are hard to "label" or "verbalise" are likely to produce negative results and the reasons have been explained before. Note that the effect of memory is more influential in some visual tasks, especially when a delay is introduced (e.g., Poppen et al, 1969). Further, similar to audition, the sequence matching tasks may not just involve temporal processing but also memory (Farmer & Klein, 1995). At first glance, experiments which emphasise block and pieces manipulation (e.g., Corkin, 1974; Gould & Glencross, 1990; Bell, 1990) are more sensitive to memory, whereas experiments which use dots and flashes (e.g., Zurif & Carson, 1970; Rudel & Denckla, 1976) are more sensitive to temporal processing. Furthermore, note that the differential effect is obtained only when longer ISIs are used. If the temporal processing deficit hypothesis is supported, at least in visual sequence matching, then a differential effect should be obtained with shorter ISIs. Nevertheless, this is not supported by much of the data. However, note that the ISIs used in visual sequencing (e.g., 500 ms) is much longer than the stimulus durations used in visual temporal order judgment and fusion tasks. It can be argued that the stimulus durations used in visual fusion and TOJ are more likely to tap into the function of rapid temporal processing mechanisms whereas the ISIs used in visual sequencing are more likely to tap into memory functions. Hence, it is quite likely that the differential effect obtained in visual sequence matching is due to memory rather than temporal processing. The argument is similar to that of 4.3.4. Furthermore, this issue will be further discussed in the next chapter.

4.6.5 Masking

Masking refers to a process whereby a detectable stimulus (target) is made difficult or impossible to detect by the presentation of a second stimulus (mask) in close temporal or spatial proximity to it (Reber, 1985). Dyslexics / dysphasics generally show a weaker masking effect. Table 4-9 summarises the studies.

Table 4-9: Masking Studies

Author	Sample (Age Range)	Stimuli	Masking Stimulus	Differ from Controls/ between Groups?
Di Lollo et al (1983)	Dyslexics (aged 8-14)	Letter Matrix with a missing dot	Letter portion Full matrix	Yes Yes
Lovegrove & Brown (1978)	Reading-disabled (aged 8 & 11)	U, O	Dots	Yes
Stanley & Hall (1973b)	Dyslexics (aged 8-12)	Letters	Dots	Yes

Table 4-9 (cont.)

Author	Sample (Age Range)	Stimuli	Masking Stimulus	Differ from Controls/ between Groups?
Williams et al (1989)	Poor readers (aged 8-11) Good readers Adults	Diagonal lines	Square	Yes
Williams et al (1990)	Poor readers (aged 8-14) Good readers Adults	Diagonal lines	Square	Yes
Williams & LeCluyse (1989, 1990)	Disabled readers	Letter	3 letter mask to form a word	Yes
Arnett & Di Lollo (1979)	Poor readers (aged 7-13)	Matrix with a missing dot	Full matrix	No
Gross-Glenn et al (1995)	Dyslexics (aged 39)	Horizontal sine wave gratings	Vertical square wave gratings	No

In backward masking, the mask is presented soon after the target and hence the target is made difficult to recognise (Reber, 1985). Backward-masking task is widely regarded as an index of the rate of visual information processing (Blake, 1974; Gummerman & Gray, 1972).

Di Lollo et al (1983) tested 10 dyslexic boys (aged 8 to 14) and their C.A. matched controls. Two visual backward masking tasks were used. The first masking task involved presenting subjects a target letter, followed by an ISI, then a mask (an aggregate of portions of alphabets) and a probe. Subjects had to report whether the target letter was the same as the probe presented after the mask at 75% accuracy interval. The second task involved presenting subjects two 5x5 square dot matrices with one central dot missing from either matrices, followed by an ISI and then a mask (2 full matrices). Subjects had to report which matrix had the dot missing at a 75% accuracy interval. In both tasks, dyslexics were slower in processing visual information.

In a similar study, reading-disabled children (n=16, aged 8 and 11) required longer SOAs to escape the masking effect (Lovegrove & Brown, 1978). Similarly, Stanley and Hall (1973b) found that dyslexics (n=33, aged 8 to 12) required longer ISIs than their controls to identify alphabets under backward masking.

"Metacontrast is a form of backward masking in which the contrast and contour visibility of a briefly flashed target stimulus is suppressed by a temporally following, spatially flanking, briefly flashed mask stimulus" (Breitmeyer, 1993a, p.103). Using diagonal lines as targets and squares as masking stimuli, Williams, Molinet and LeCluyse (1989) showed that maximal masking occurred at a shorter delay in dyslexics. Moreover, dyslexics (n=4, aged 8 to 11) experienced almost no metacontrast masking in peripheral vision and weaker masking in central vision compared with controls. Additionally, disabled readers (n=6, aged 8 to 14) also showed prolonged masking in foveal vision, suggesting a longer integration time or visible persistence. Further, they showed enhancement rather than masking effects in the periphery when detecting the orientation of the lines (Williams, LeCluyse & Bologna, 1990). Nonetheless, while normal adult readers exhibited no visual masking when the onset of the target was presented 100 ms before the onset of the mask, disabled readers exhibited interference between the mask and target even at an ISI of 120 ms (Williams & LeCluyse, 1990). The effect was more apparent when the target letters "S" and "N" "were presented either alone, with a three-letter mask that together with the target formed a word, or followed at various delays by the three-letter mask" (Williams & LeCluyse, 1990, p.117; Williams & LeCluyse, 1989). This may indicate the role of a phonological component in slowing the temporal processing (Nicolson & Fawcett, 1993a, 1994).

Williams and colleagues usually used a small sample size and their dyslexics normally had a reading lag of only one year. Further, the type of measure of intelligence in the samples is not clearly specified and sometimes they used disabled readers with organic / behavioural problems (Garzia & Nicholson, 1990). So, the generality of the temporal processing deficit under these conditions remains tenuous.

On the other hand, contrary to Di Lollo et al (1983), Arnett and Di Lollo (1979) used a similar dot-matrix masking technique but failed to show that their poor readers (n=24, aged 7 to 13) were slower in processing information. However, it should be noted that the dependent variable measured was denoted by the median ISI at which the 80% accuracy level was met in the task, compared to the mean ISI measured in Di Lollo et al (1983) and other experiments (e.g., Lovegrove & Brown, 1978; Williams et al, 1989; Stanley & Hall, 1973b). Moreover, Arnett and Di Lollo (1979) used subjects who had a reading lag of only one year, compared to those who had a reading lag of at least two years in Di Lollo et al (1983). The measurement and sampling technique differences may explain the discrepancies between the two experiments.

Gross-Glenn et al (1995) presented horizontal sine wave gratings forwardly masked by vertical square wave gratings. They expected less masking of high spatial-frequency stimuli in the dyslexics (n=18) if they had a weaker transient system. However, the effects of masking of the high and low spatial-frequency stimuli were equal for both dyslexics and controls (n=22). The authors attributed the discrepancies to: 1) the use of high luminance level of 105 cd/m^2. This is in line with Cornelissen, Richardson, Mason, Fowler and Stein (1995) and Martin and Lovegrove (1984) who failed to differentiate dyslexics from the controls using photopic luminance levels. The luminance level may be too high and thus not sensitive enough to test transient function (see Green, 1984; Lovegrove, Garzia & Nicholson, 1990; Stein, 1993); and 2) the use of adults in this study whereas other studies used children or adolescents (e.g., Di Lollo's, Stanley & Hall's, William's and Lovegrove's studies). A developmental difference may exist (Chase & Jenner, 1993; Gummerman & Gray, 1972), at least as measured in masking studies.

In sum, many studies show that reading disabled children have slower rates of visual information processing than controls. They also need longer time to escape the effect of a mask. The inability by a few researchers to replicate the masking effect may be attributed to different methodologies and / or subject selection.

4.6.6 Contrast Sensitivity

Contrast sensitivity refers to the ability to detect some targets which have the minimum amount of contrast (Sekuler & Blake, 1990). Many studies on contrast sensitivity have demonstrated a loss of sensitivity in the magnocellular pathway or the transient visual system in dyslexics compared with controls. The studies are summarised in Table 4-10.

Table 4-10: Contrast Sensitivity Studies

Author	Sample (Age Range)	Stimuli	Stimulus Duration	Differ from Controls/ between Groups?
Lovegrove et al (1982)	Dyslexics (aged 12)	Alternating sine-wave gratings	40-1000ms	Yes
Martin & Lovegrove (1984)	Dyslexics (aged 12)	Counterphased square-wave gratings	350ms	Yes

Table 4-10 (cont.)

Author	Sample (Age Range)	Stimuli	Stimulus Duration	Differ from Controls/ between Groups?
Cornelissen et al (1995)	Reading-disabled	Sinusoidal gratings (static or counterphased)	1000ms	No
Martin & Lovegrove (1987)	Dyslexics (aged 13)	2 c/d sine-wave grating counterphased at 5-25Hz	500ms	Yes
Cornelissen et al (1993)	Reading-disabled (aged 9)	Counterphased sinusoidal gratings	1000ms	Yes
Brannan & Williams (1988b)	Poor readers (aged 8-12) Good readers (aged 8-12) Adults	Flicker	2s	Yes
Borsting et al (1996)	Dysphoneidetic dyslexics (aged 35) Dyseidetic dyslexics (aged 36)	Vertical sine wave gratings	500ms	Yes No
Ridder et al (in press)	Dysphoneidetics (aged 11-54) Dysphonetics (aged 10-25) Dyseidetics (aged 24-50)	Flickering field	500ms	Yes Yes- only severe case No
Gross-Glenn et al (1995)	Dyslexics (aged 39)	horizontal sine wave gratings	1.5s	No

Lovegrove, Martin, Bowling, Blackwood, Badcock and Paxton (1982) presented sine wave gratings with durations ranging from 40 to 1000 ms and alternated with a blank field at 1s intervals for 10s. Dyslexics (n=14, aged 12) showed lower contrast sensitivity to low spatial frequency gratings (1 to 4 c/d), especially between the durations of 150 and 500 ms (Lovegrove et al, 1986a).

Martin and Lovegrove (1984) measured the contrast sensitivity to square wave counterphased gratings and found that at low luminance levels, dyslexics (n=14, aged 12) were less sensitive from 1 to 4 c/d and more sensitive at 8 and 12 c/d. At high luminance levels, dyslexics were less sensitive than controls from 1 to 8 c/d but were equally sensitive at 12 c/d (Lovegrove et al, 1990). Moreover, while dyslexics had reduced contrast sensitivity at mesopic luminance levels, an optimal condition to test the functioning of the transient system, Martin and Lovegrove (1984), Cornelissen et al (1995) and Gross-Glenn et al (1995) failed to replicate this finding at photopic levels, as high luminance level alters the contrast sensitivity function (especially at high spatial frequencies) (see Green, 1984; Lovegrove et al, 1990) and therefore is not sufficiently sensitive to discriminate between the disabled and normal readers.

Martin and Lovegrove (1987) required 13-year-old dyslexics (n=15) to detect a 2 c/d sine wave grating counterphased at 5, 10, 15, 20 and 25 Hz. Their flicker contrast sensitivity was measured. Dyslexics were generally less sensitive to flicker and the difference increased with increasing temporal frequency. In fact, Cornelissen, Mason, Fowler and Stein (1993) also found that dyslexics, especially those who failed the Dunlop Test (Stein, 1993), were less sensitive to flickering gratings. In addition, dyslexics are less sensitive to coherent motion detection (Cornelissen et al, 1995).

Thus, the work of Lovegrove and colleagues demonstrates a sensitivity loss at low spatial frequencies and high temporal frequencies in dyslexia. This in turn implies a transient system deficit and hence a temporal deficit. Indirect support is provided by Grosser and Spafford (1989), who found that dyslexics were more likely to report colours in the periphery than controls. They interpreted their findings as indicating a higher concentration of colour-sensitive cones in the peripheral vision of dyslexics. Since the transient system is more concentrated in the periphery (DeMonasterio, 1978) and it receives inputs from both cones and "colour-blind" rods whereas the sustained system receives inputs from mostly cones (Shapley, 1990), dyslexics will have relatively fewer rods to initiate the response of the transient system, resulting in a weaker transient system to inhibit the sustained system activity (Grosser & Spafford, 1992). Furthermore, Stuart and Lovegrove (1992a,b) argued that the visual deficit reflects abnormality in neural mechanisms rather than photoreceptors.

Based on the work on visible persistence and flicker sensitivity, Lovegrove et al (1986a) argued that 75% of the dyslexics could be differentiated using such visual measures and that this lower visual processing abnormality already exists before children learn to read (Lovegrove, Slaghuis, Bowling, Nelson & Geeves, 1986b). Breitmeyer (1989) suggested that Lovegrove's data were also consistent with a higher-level cortical dysfunction in areas adjacent to the speech and language areas of the brain. Therefore, the transient system deficit "is not necessarily incompatible with a common temporal processing dysfunction encompassing speech-motor, auditory, manual and visual domains" (Share, 1994, p.158). Furthermore, it would not be surprising if a lower level visual system deficit have consequences on higher level perceptual and cognitive functions like reading (Garzia and Nicholson, 1990).

Support for Lovegrove's argument is provided by Brannan and Williams (1988b) who measured flicker-detection thresholds in poor readers, good readers and adults. Poor readers had higher flicker thresholds than good readers and adults. Although the detection thresholds decreased with age, the difference between the good and poor readers did not change, indicating a temporal visual processing deficit rather than a maturational lag.

Furthermore, Borsting et al (1996) measured the contrast sensitivity of nine dyseidetic dyslexics (aged 36), eight dysphoneidetic dyslexics (dyslexics who have difficulty reading both irregular words and nonsense words, aged 35) and nine controls (aged 35) on vertical sine wave gratings (0.5, 1, 2, 4, 8, 12 c/d) drifting at 1 and 10 Hz.

Dysphoneidetic dyslexics had lower contrast sensitivity to low spatial frequencies at high temporal frequency (10 Hz) but the performance of the dyseidetic dyslexics did not differ from that of the controls. In a subsequent study, Ridder, Borsting, Cooper, McNeel and Huang (in press) measured the contrast sensitivity of seven dyseidetics (aged 24 to 50), five dysphonetics (aged 10 to 25) and seven dysphoneidetics (aged 11 to 54). Only the dysphoneidetics and dysphonetics graded as severe exhibited decreased sensitivity to high temporal frequency flickering fields. The authors concluded that the presence of the transient system deficit depends upon the type and severity of dyslexia. Moreover, as the prevalence of dyseidetic dyslexia ranges from 10 to 30% (Flynn & Boder, 1991; Flynn & Deering, 1989), the findings of Borsting et al (1996) and Ridder et al (in press) are consistent with Lovegrove et al (1986a) that 25% of the dyslexics do not manifest a transient system deficit.

In comparison, Gross-Glenn et al (1995) measured the contrast sensitivity of 18 dyslexics (aged 39) and 22 normal readers (aged 38). When using temporally ramped gratings of high and low spatial frequencies, there were no difference between the two groups. When using gratings with abrupt on / offsets, at high spatial frequency (12 c/d), dyslexics had poorer sensitivity at shortest stimulus durations. However, no difference was found for low spatial-frequency (0.6 c/d) stimuli, even though the detection of these stimuli was mediated by the transient system because the low spatial-frequency stimuli were more susceptible to forward masking than were the high-frequency stimuli. Although the results are inconsistent with the transient system deficit hypothesis, the discrepancies may be due to: 1) while Lovegrove and colleagues and Borsting et al (1996) used a mesopic luminance level, Gross-Glenn et al (1995) used a luminance level of 105 cd/m^2, a condition similar to that used in Cornelissen et al (1995) and Martin and

Lovegrove (1984) which is not sufficiently sensitive to detect the subtle transient deficit (Stein, 1993); 2) Gross-Glenn et al (1995) used adults whereas Lovegrove used children and adolescents. Lovegrove's subjects were selected under strict criteria whereas Gross-Glenn et al's (1995) subjects have more variability (e.g., in terms of age and educational attainment). However, with similar experimental parameters, Borsting et al (1996) also used adults but they found the deficit only in dysphoneidetic and not dyseidetic dyslexics. Thus, it is possible that the subjects used in Gross-Glenn et al (1995) are mostly dyseidetics who are less likely to show a transient system deficit; and 3) Gross-Glenn et al (1995) used discrepancy scores to select their dyslexics whereas Lovegrove used a lag in reading age.

In sum, it has frequently been found that dyslexics have poorer contrast sensitivity to stimuli of low spatial and / or high temporal frequencies and are less sensitive to motion and flicker. The characteristics of the stimuli they are insensitive to implicate a dysfunction of the transient system. Furthermore, the presence of the deficit may well depend upon the type and severity of dyslexia and is less likely to accompany dyseidetic dyslexia. Studies which fail to replicate the transient system deficit are those which use high luminance levels or those which use a different sampling technique.

4.6.7 Miscellaneous: The Persistence of the Transient Deficit into Adulthood?

Some data indicates the persistence of a transient system deficit into adulthood (e.g., Chase & Jenner, 1993; Kinsbourne et al, 1991). For example, Winters et al (1989) measured VP in eight adult dyslexics (aged 18 to 37) and eight controls. The VP was longer in the dyslexics only when parts of the test stimuli were presented to adjacent retinal areas. The authors suggested that problems found in childhood dyslexia persisted into adulthood. However, Hayduk, Bruck and Cavanagh (1993) tested seventeen adult dyslexics and eighteen matched controls with counterphased sine wave gratings or annuli and concluded that the deficit would not persist into adulthood. However, this experiment: 1) only presented gratings to the fovea and not to the periphery and rings to the periphery but not to the fovea; and 2) lacked another control condition of high spatial frequency and high temporal frequency in both foveal and peripheral condition. Thus, the "imbalanced" design allows only tenuous conclusions.

4.7 Anatomical / Physiological Evidence for Visual Temporal Processing Deficits in Dyslexia / Dysphasia

Livingstone, Rosen, Drislane and Galaburda (1991) measured the parvocellular and magnocellular layers of the lateral geniculate nucleus in five dyslexic and five control brains. The magno cells were on average 27% smaller in the dyslexics' brains.

In addition, flickering chequerboard patterns were presented to subjects at different rates and contrasts, and the transient (magno-) and sustained (parvo-) visual-evoked potential (VEP) was recorded. Dyslexics attenuated VEPs only when high temporal frequency, low contrast stimuli were presented. Since these stimuli are handled by the magnocellular pathway (Galaburda, 1993), the VEP results confirm the abnormalities found in the magno cells.

However, Victor, Conte, Burton and Nass (1993) failed to replicate the VEP differences observed in Livingstone et al (1991), though they also used low- and high-contrast chequerboard reversed at low and high temporal rates. The discrepancy may be attributed to the rate used to sample the VEP to average a potential. Victor et al (1993) used a sampling rate of 135 Hz while Livingstone et al (1991) used a rate of 100 KHz.

The higher sampling rate used in Livingstone et al (1991) would provide a more sensitive procedure to detect small temporal VEP differences (Baro, Garzia & Lehmkuhle, 1996).

Lehmkuhle, Garzia, Turner, Hash and Baro (1993) measured the VEP of 8 to 11-year-olds. Under a steady background, dyslexics (n=8) had a longer latency of early components (N1 and P1) at low 0.5 c/d. Under a 12 Hz uniform-field-flicker (UFF), the controls (n=13) showed longer latency and decreased amplitude in early component but the dyslexics only showed a decreased amplitude. Further, the two groups did not differ in high spatial frequency (4.5 c/d). Baro et al (1996) further reasoned that the reduction in amplitude indicated a reduced M-pathway contribution to VEP and the absence of the latency shift indicated a temporal deficit. Thus, the M-pathway is intact in the reading-disabled but it behaves more like the P-pathway.

May, Lovegrove, Martin and Nelson (1991) presented subjects sine wave gratings ranging from 0.5 to 8 c/d flickering at 2 Hz. They found that dyslexics had lower amplitudes and shorter latencies for VEP components elicited by stimulus offsets when low spatial frequency gratings were used. In a subsequent study, factor analysis revealed two factors for both the low and high spatial frequency stimuli. Factor II was associated with the latencies of the first onset component (greater transient contribution) and Factor I with the latencies of all components (greater sustained contribution). Discriminant function analysis showed that good and poor readers were best differentiated by the low but not the high spatial frequency factor (May, Dunlap & Lovegrove, 1992).

In Solan, Sutija, Ficarra and Wurst (1990), "pattern-reversal VEPs were elicited by high-contrast chequerboards of 2 and 4 c/d, reversing at 1 and 4 Hz" (Baro et al, 1996, p.195). While, the controls showed larger monocular and binocular VEP amplitudes, dyslexics had smaller P100 amplitudes.

In Mecacci, Sechi and Levi (1983), VEPs were recorded for chequerboard with check size of 3.75 to 90 min of visual angle. Reading disabled subjects (n=16, aged 7 to 12) exhibited smaller VEP amplitudes than the controls (n=8, aged 7 to 11) for all the check sizes and they experienced hemispheric asymmetry.

Similarly, Neville et al (1993) measured the ERP of twenty-two dysphasics and twelve controls (aged 8 to 10) during a visual perceptual task and a visually presented sentence processing task. They found that for dysphasics, the early component of the visual ERP was reduced in amplitude to both language and nonlanguage stimuli.

Holcomb et al (1985) found that while both nonlinguistic symbols and nontarget word stimuli elicited similar P3 and Pc amplitudes in the controls (n=24, aged 8 to 11), words elicited smaller P3 and Pc amplitudes in dyslexics (n=24). The authors interpreted the results as a selective deficit in processing words in dyslexics.

Ortiz and Expósito (1992) measured the EEG of normal (n=34, aged 11 to 14) and dysphonemic dyslexic children (n=24, aged 11 to 14). The EEG was recorded during presentations of single letters, when a simple detection (LD), form discrimination (FD) or rhyme discrimination (RD) was required. LD and FD required a visual code whereas RD required a phonological code. In alpha, the groups differed most over the posterior regions, with the maximal difference found at occipital regions in LD, "parietotemporal in FD, and involving the parietal cortex extending to temporal, occipital, and lateral-central areas in RD" (p.199). In beta 4, the groups differed most in the infero-temporal areas (after Ortiz & Expósito, 1992).

Interestingly, the abnormality identified in the posterior regions by Ortiz and Expósito (1992), and the finding that dyslexics showed little asymmetry over the occipital lobe and a rightward asymmetry of activity in the lingual lobule (Gross-Glenn, Duara, Barker, Loewenstein, Chang, Yoshii, Apicella, Pascal, Boothe, Sevush, Jallad, Novoa & Lubs, 1991) correspond with the reduced structural posterior (perisylvian region) asymmetry observed in Galaburda and Kemper (1979) and Galaburda et al (1985).

In a post-mortem study, Galaburda (1989) analysed the brains (n=8) of developmental dyslexics and found: 1) an absence of ordinary asymmetry in favour of the left hemisphere in the planum temporale, "a language relevant area of the temporal lobe" (p.67); and 2) malformation of the language relevant perisylvian regions of the cerebral cortex. He suggested the symmetry might "represent absence of the necessary developmental pruning of neural networks required for specific functions such as language" (p.67). Symmetrical plana were also found in a group of dyslexics (Hynd, Semrud-Clikeman, Lorys, Novey & Eliopulos, 1990; Larsen, Høien, Lundberg & Ødegaard, 1990).

In sum, there is evidence that the magnocellular pathways which deal with rapid visual temporal processing are impaired in dyslexics and dysphasics. Besides showing abnormal electrophysiological data when processing verbal and nonverbal stimuli, dyslexics and dysphasics also show abnormalities over the parietal, temporal, occipital and frontal regions, planum temporale and angular gyrus. Interestingly, besides coordinating temporal integration, these areas also relate to language function (Hynd & Semrud-Clikeman, 1989; Rosen, Sherman & Galaburda, 1993) and nonverbal or visuospatial processing (Steinmetz et al, 1990; Witelson & Kigar, 1992).

4.8 *Summary of Visual Temporal Processing Deficits in Dyslexia / Dysphasia*

Thus, there is considerable experimental, anatomical and physiological evidence that dyslexics and dysphasics are impaired in visual temporal processing. Most research has been done on dyslexia rather than dysphasia.

4.9 *Crossmodal Nature of Temporal Processing Deficits*

Experimental Findings

In fact, dyslexics and dysphasics who show visual temporal deficits are more likely also to experience auditory temporal deficits and vice versa. This has been demonstrated in some transmodal research (e.g., Efron, 1963; Zurif & Carson, 1970; Kinsbourne et al, 1991; Tallal et al, 1981), though it is not always the case (see Tallal & Piercy, 1973b; Farmer & Klein, 1993; Reed, 1989; Bryden, 1972; Gould & Glencross, 1990). Moreover, some researchers have argued for a general temporal deficit among the dyslexics (e.g., Gardiner, 1987; Stein, 1993). Most research that supports this crossmodal deficit are sequence matching experiments. Of the tasks mentioned below, apart from the detection / discrimination tasks described by Yap and van der Leij (1993), Nicolson and Fawcett (1993b), Katz and Deutsch (1963) and Raab, Deutsch and Freedman (1960), the rest are tasks involving rapid sequential processing. It should be noted that some of these studies are confounded by IQ, memory or phonetic factors. The studies are summarised in Table 4-11. Similarly, the presentation style is based on Farmer and Klein (1995).

Table 4-11: Crossmodal Tasks

Author	Sample (Age Range)	Stimuli	ISI	Differ from Controls/ between Groups?
Yap & van der Leij (1993)	Dyslexics (aged 9-11)	Digits	-	Yes
Nicolson & Fawcett (1993b)	Dyslexics (aged 15)	Tones / flashes	-	Yes (slower learning)
Katz & Deutsch (1963)	48 grade 1-5 subjects, high and low readers was selected from the upper and lower 30% of frequency distribution for each grade	Tones / lights	1.5, 2, 3s	Yes
Raab et al (1960)	Retarded readers (grade 4 & 5)	Tones / lights	-	Yes
Zurif & Carson (1970)	Dyslexics (grade 4)	Clicks / dots	500-1000ms	Yes
Tallal et al (1981)	Language-impaired (aged 5-9)	Tone/Flash	500ms	Yes
Birch & Belmont (1964)	Reading-disabled (aged 9-10)	Taps / dots	500-1000ms	Yes
Sterritt & Rudnick (1966)	Grade 4 boys	Tones / dots	0.2s	Performance related to reading ability
Beery (1967)	Poor readers (aged 8-14)	Tones / dots	0.4-0.9s	Yes
Jorgenson & Hyde (1974)	Grade 1 & 2 readers	Taps / dots	500-1000ms	Performance related to reading ability
Vande Voort et al (1972)	Retarded readers (aged 8-13)	Tones / dots	0.4-0.9s	Yes
Vande Voort & Senf (1973)	Retarded readers (111.9 m.o.)	Tones / dots	500-1000ms	No
Hatchette & Evans (1983)	Learning-disabled (visual) Learning-disabled (auditory) (aged 7-10)	Test series	-	Yes
Badian (1977)	Inferior readers (grade 3-5)	Test series	-	Yes

Table 4-11 (cont.)

Author	Sample (Age Range)	Stimuli	ISI	Differ from Controls/ between Groups?
Bryden (1972)	Poor readers (aged 9-10)	Tones / dots (flashes)	500-750ms	Yes
Poppen et al (1969)	Aphasics (aged 5-9)	Test series	-	Yes

"Intersensory integration is but one aspect of a more general processing of spatial and temporal stimuli" (Rudel & Denckla, 1976, p.175). Yap and van der Leij (1993) required their subjects to compare a spoken digit with a visual digit. Dyslexics (n=21, aged 9 to 11) were slower than the C.A. but not R.A. controls in comparing the digits.

Similarly, Nicolson and Fawcett (1993b) showed that dyslexics (n=11, aged 15) were deficient in a combined task of tone and flash detection. They had more difficulty combining the two skills and showed less learning over the course of the training period (after Nicolson & Fawcett, 1993b), with final performance being slower and less accurate.

Katz and Deutsch (1963) measured the reaction times of grade 1, 3, and 5 children to perceive stimuli preceded by same-modality and different-modality stimuli. Red and green lights and tones of 1200 cps and 400 cps were used. Retarded readers exhibited greater difficulty than normal readers in shifting from one modality to another (after Katz & Deutsch, 1963). Moreover, the modality shifting capacity is not directly related to intelligence. Similar results were obtained when grade 4 and 5 children were tested (Raab et al, 1960).

Zurif and Carson (1970) administered the Seashore Rhythm test and asked subjects to match dot patterns to click patterns. The patterns are sequences of 5 to 7 items with long (1 s) and short (500 ms) intervals. Dyslexics were impaired on this task.

Tallal et al (1981) compared the performance for auditory, visual and cross-modal perception in language-impaired and normal children (aged 5 to 9). As expected, the language-impaired children made more errors in processing rapidly presented auditory, visual and cross-modal information, despite the fact that the performance on the cross-modal task for both groups was better than on either the visual or auditory tasks (Miller & Tallal, 1995). However, Miller and Tallal (1995) commented that auditory and visual stimuli used in this study were not equated in complexity, perceptual saliency or difficulty. Hence, interpretations based on direct comparison between the tasks are tentative.

Besides, using a similar task, Birch and Belmont (1964) argued that reading disabled children (n=150, aged 9 to 10) were generally impaired in auditory-visual integration (AVI). The task required their subjects to choose a visual dot pattern which corresponded to a given auditory pattern. The auditory pattern consisted of a series of taps separated by half-second or one-second intervals; and the visual pattern consisted of rows of dots containing large and small spaces which were analogous to the long and short intervals of the auditory pattern. Although their experiment: 1) failed to make a control of intramodal matching for material involving temporal patterns (Zurif & Carson, 1970); 2) failed to control for memory (Jorgenson & Hyde, 1974); 3) lacked statistical control for IQ effects (Sterritt & Rudnick, 1966; Beery, 1967; Vande Voort & Senf, 1973); and 4) confounded auditory-visual integration (AVI) with temporal-spatial integration (TSI) (Rudel & Denckla, 1976; Sterritt & Rudnick, 1966; Freides, 1974;

after Hatchette & Evans, 1983), further evidence still supports a relation between AVI and reading once these factors are considered. For example, using Birch and Belmont's (1964) method and controlling the effect of IQ, Sterritt and Rudnick (1966) found that the ability to transpose from auditory-temporal to visual-spatial patterns was related to reading. Same results were obtained with a longer version of the test (Beery, 1967). Similarly, controlling the memory factor, Jorgenson and Hyde (1974) found a significant correlation between AVI and reading vocabulary even when IQ was partialled out.

On the other hand, Vande Voort, Senf and Benton (1972) argued for processes common to crossmodal and within-modal integration because retarded readers were inferior in all tasks. Vande Voort and Senf (1973) tested 16 retarded readers and 16 controls on four matching tasks: 1) visual-spatial / visual-spatial (Vs / Vs); 2) visual-temporal / visual temporal (Vt / Vt); 3) auditory-temporal / auditory-temporal (At / At); and 4) auditory-temporal / visual-spatial (At / Vs). Contradicting Birch and Belmont (1964), only the Vs / Vs and At / At but not the At / Vs task discriminated the groups. Instead of supporting the hypothesis that AVI was deficient in the retarded readers, Vande Voort and Senf (1973) argued that "memory and / or perceptual factors might account for performance deficits in retarded readers" (p.170). The inconsistency between Birch and Belmont (1964) and Vande Voort and Senf (1973) may result from: 1) Birch and Belmont (1964) requiring their subjects to choose the correct dot pattern out of the three alternatives whereas Vande Voort and Senf (1973) used a same-different judgment. Thus, Birch and Belmont's (1964) method possibly increased the memory load; and 2) Birch and Belmont (1964) presenting the pencil taps in front of the subjects.

This possibly confounded the visual with the auditory stimuli (Sterritt & Rudnick, 1966).

Hatchette and Evans (1983) compared subjects (N=54, aged 7 to 10) on six pattern-matching tasks which manipulated either the AVI or TSI factor. Subjects consisted of normal readers, learning-disabled readers with a visual processing dysfunction and learning-disabled readers with an auditory processing dysfunction. Although results supported the AVI rather than the TSI deficit in the learning-disabled group, the learning-disabled readers may link up learning disability with AVI rather than linking up reading disability with AVI / TSI. In addition, Hatchette and Evans (1983) argued that neither deficient auditory nor visual memory could account for the poor performance of the clinical groups. In fact, Jorgensen and Hyde (1974) and Birch and Belmont (1965) also showed that short-term auditory memory and visual and auditory sequential memory were generally unrelated to AVI skills. However, in Badian (1977), retarded readers (n=30) were inferior on all AVI tasks and on both verbal and nonverbal short-term auditory memory tasks. The author concluded that deficits in short-term auditory sequential memory might be a major factor in the inferior AVI performance of retarded readers (after Badian, 1977).

Bryden (1972) found that poor readers performed worse on the cross-modal sequence matching tasks, with performance correlated with reading ability. The author argued that the deficit stemmed from verbal coding problems rather than temporal perception per se. In fact, the poor readers used were only 1.5 year behind in reading. In addition, the stimuli were presented slowly, with a stimulus duration of 250 ms and ISI's of 500 to 750 ms. Hence, the task may have been a measure of verbal coding deficit or memory deficit, rather than a measure of temporal processing deficit (Farmer & Klein, 1995).

Besides finding aphasics having inferior visual sequencing performance, Poppen et al (1969) also administered a variety of sequencing tests and concluded that aphasics were deficient in general sequencing ability, especially when a delay which placed a memory burden was introduced. Further, they were more inferior on tasks which required a verbal response and were less inferior on tasks which required visual motor performance.

Anatomical / Physiological Findings

As discussed in 4.4 and 4.7, several groups of researchers have already identified some physiological abnormalities in both visual and auditory modalities of dyslexics / dysphasics. For example, Galaburda and Livingstone (1993) and Livingstone et al (1991) found that the magno cells in the MGN and LGN of dyslexics were relatively smaller. Holcomb et al (1985, 1986) found that dyslexics exhibited smaller P3 components for both visual and auditory stimuli. Similarly, dysphasics showed lower ERPs in Tallal Repetition Test and visual perceptual and sentence processing tasks (Neville et al, 1993). Interestingly, while performing a syllable discrimination task, dyslexics had higher metabolism in the medial temporal area (Hagman et al, 1992), an area in which the visual M-cells project to (Merigan & Maunsell, 1993) and is important for processing motion information (Newsome et al, 1985). Moreover, Fuster (1985) argued that as the prefrontal cortex receives inputs from visual, auditory and somatosensory association cortices, this region is important for cross-modal and temporal integration of ongoing behaviour (Gross-Glenn et al, 1991).

Stein (1993) suggested that the magnocellular visual pathway does have its "counterparts in the somaesthetic, auditory and motor systems: the dorsal column, magnocellular medial geniculate, and the gigantocellular motor pathways, respectively" (p.83). For instance, both vocalic and consonantal continua are perceived similarly in the tactual and auditory modalities (Eilers, Özdamar, Oller, Miskiel & Urbano, 1988). Thus, the generalised neuronal system which is responsible for temporal processing may be impaired in dyslexics.

Furthermore, Neville et al (1993) found some reduced visual ERPs in dysphasics which are independent of the performance of the Tallal Repetition Test. This indicates that visual temporal processing deficits do not necessarily parallel the auditory ones.

Summary of Crossmodal Temporal Processing Deficits

In sum, it seems that some dyslexics and dysphasics have sequential deficits in both transmodal and crossmodal tasks. This leaves the question of whether deficits experienced in the crossmodal tasks are related to auditory-visual integration, temporal-spatial integration or some other factors like IQ, verbal coding or memory. As none of the studies so far has taken into account all these factors, results are inconclusive. Furthermore, from the results concerning sequence matching in auditory and visual modalities, it is highly probable that the differential effect between the dyslexics / dysphasics and controls is due to memory effects, even though there is a small influence of temporal processing in these tasks. Nonetheless, results of the transmodal and crossmodal tasks are suggestive of a general timing deficit hypothesis. This will be further discussed in Chapters 6 and 7. Nevertheless, since there is evidence that temporal processing deficits existing in one modality do not necessarily parallel the one in another modality (Tallal et al, 1981; Neville et al, 1993), it suggests that deficits existing in different modalities may relate to the different reading mechanisms for different types of words. These will be further discussed in Chapters 6 and 8.

4.10 Summary

Both experimental and anatomical / physiological research support the hypothesis that many dyslexics and dysphasics demonstrate auditory as well as visual temporal processing deficits (Tallal, 1981). Moreover, the deficits may stem from a general timing deficit. In fact, Tallal et al (1993) hypothesised that "a generalised pansensory deficit in processing sensory information, which converges in the nervous system in rapid succession" (Miller & Tallal, 1995, p.293), may underlie the psychophysical deficits and language / reading difficulties observed in these subjects. Nevertheless, visual temporal processing deficits do not necessarily parallel the auditory ones (e.g., Tallal et al, 1981; Neville et al, 1993) and temporal processing deficits are more likely to be observed in subjects with concomitant oral language deficits (Miller & Tallal, 1995). Moreover, it is possible that temporal processing deficits which exist in different modalities may affect the different reading mechanisms for different types of words. Besides, most of the sequence matching tasks and crossmodal research examining temporal processing deficits also confound IQ and memory. Therefore, the relationship between temporal processing deficits, reading and other cognitive abilities is complicated and will be further discussed in the next chapter.

Chapter 5: The Role of Temporal Processing in Reading

5.1 Introduction

This chapter will consider the role of temporal processing in reading, with particular attention to: 1) Coltheart's (1978) cognitive model of reading and its implication for temporal processing; 2) the relationship between temporal processing and reading / phonological ability; and 3) possible confounding effects of memory and intelligence on temporal processing in the context of reading.

5.2 Coltheart's (1978) Model of Reading

There is a range of types of models of reading (e.g., Baddeley, 1979; Baddeley & Hitch, 1974; Goswami, 1993). The precise nature of these models is not crucial to this thesis and the argument presented below applies equally to these models. However, I will choose Coltheart's (1978) model for illustrative purposes as it is more central to my research. According to Coltheart (1978), in reading, word recognition involves two, potentially independent processes: a "direct" lexical recognition process (or visual route) and an "indirect" phonological process[1] (sublexical or grapheme-phoneme-correspondence GPC route). The lexical route associates the printed representation of a word with its corresponding acceptable pronunciation. A sight vocabulary is developed (Beech & Awaida, 1992) and the route operates on familiar words such as regular words (words that conform with spelling-sound rules) and irregular words (words that do not conform with spelling-sound rules). The sublexical route segments letter strings into

[1] "Phonological processes refer to linguistic operations that involve utilization of information about the phonological (speech sound) structure of the language" (Felton & Brown, 1990, p.39).

graphemes, decodes individual graphemes into phonemes and then blends the phonemes into pronunciation. This route deals with regular words and regular nonsense words (Baron, 1977). Thus, if regular and irregular words are "matched for factors such as frequency and length, then an advantage for regular over irregular words indicates the use of phonological recoding (sublexical route)" (Stuart & Masterson, 1992, p.170), as regular words can be read via both lexical and sublexical routes while irregular words must be read via the lexical route (Stuart & Masterson, 1992).

In fact, from electrophysiological correlates of dyslexic subtypes, Flynn, Deering, Goldstein and Rahbar (1992) found that dysphonetic dyslexics (those with phonological deficits) adopted visuospatial processing strategies (right occipital-parietal activation) whereas dyseidetic dyslexics (those with orthographic deficits) emphasised phonetic strategies (left temporal-parietal activation) (after Flynn et al, 1992). This adds physiological evidence for the existence of the two routes.

Although it has been assumed that the two strategies are independent and are adopted sequentially, with an initial visual phase followed by the phonological phase (Frith, 1985), current research has argued that sometimes even a reversed order may occur in processing (e.g., Stuart & Coltheart, 1988; Stuart, 1990). Moreover, Barron (1986) pointed out that the sublexical route is inadequate in the sense that children can read by analogy rather than blending the phonemes together (Goswami, 1986, 1993). In addition, the two routes seem to interact and facilitate each other via phonological awareness. i.e., phonological awareness facilitates efficient development of sublexical as well as lexical routes (Stuart & Coltheart, 1988). For example, "phonological analysis skills directly affect the establishment of efficient sublexical procedures by enabling the child to develop subword level orthography-to-phonology mappings. They indirectly affect development of an efficient lexical processing system by allowing a rapid increase in the number of correctly specified entries in the orthographic lexicon" (Stuart & Masterson, 1992, p.184).

5.3 Possible Implications of Temporal Processing for Coltheart's (1978) Model of Reading

Automatisation is a process by which learned skills become more fluent such that they can be executed without any conscious attention (Nicolson & Fawcett, 1993c). Laberge and Samuels (1974) argued that reading depends on the automatisation of subskills so that the reading process is fast and needs little conscious effort. Additionally, Stanovich (1988) argued that the "key processing mechanisms underlying dyslexia are modular systems: i.e., systems that are fast, automatic, informationally encapsulated and that can both operate without direction from higher level structures and fail without disrupting unaffected central processes" (Wolf, 1991a, p.206). Hence, with reference to the phonological (GPC or sublexical) route in reading, how well one reads depends on one's decoding efficiency. On the other hand, with reference to the direct-access (lexical or visual) route, how well one retrieves a word in the process of reading depends on "the time and subprocesses used to access and retrieve a verbal label in the act of naming" (Wolf, 1991a, p.207). Thus, a temporal processing efficiency of some sort, like automaticity (Spring & Davis, 1988), may imply one's decoding and retrieval efficiency and serves as a precursor for reading. In fact, Spring and Davis (1988) considered automaticity in lower level processes (e.g., naming speed) as a prerequisite for accurate performance in higher level reading processes. Their results showed that digit naming speed correlated with reading of both irregular words and nonsense words. Hence, automaticity is essential for both "direct-access and speech-recoding routes of word recognition" (p.315). Additionally, it correlated more with word recognition than with reading comprehension.

Moreover, Fawcett and Nicolson (1992) hypothesised a dyslexic automatisation deficit (DAD) in both cognitive and motor skills. In this model, a slow "central executive" resulted from problems "within the central brain processes, most probably in the hypothetical inner loop for information transmission between different brain modules" (Nicolson & Fawcett, 1993c, p.389), and results in noisy neural networks that produce slow stimuli analyses and output (Nicolson & Fawcett, 1993c). In addition, Frith (1992) also suggested similar connections between various deficits experienced by dyslexics. Therefore, with reference to my thesis, sensory temporal processing efficiency may reflect or influence some degree of automaticity in reading. In fact, some researchers have suggested that temporal processing may be an index of automaticity (e.g., Wolf, 1991a,b). Thus, if automaticity, via naming speed, reflects how well one reads, it is possible that sensory temporal processing is related to reading, as argued in Chapter 4. Nonetheless, the "automaticity in reading" may be a "cousin" which overlaps with sensory temporal processing to some extent and both of them may undergo a general timing mechanism which acts like a "central executive" (CE) in Nicolson and Fawcett's (1993c) and Baddeley's (1979) model. This hypothesis is analogous to Nicolson and Fawcett's (1993c) DAD hypothesis.

As an overview, it is suggested that there exists a general timing mechanism with different components. Some of the components are more sensory while others are more cognitive, like naming. If the visual and auditory temporal processing deficits experienced by the dyslexics and dysphasics are part of a general timing deficit, and if the automaticity implicated by naming speed studies reflects some function of this timing mechanism, then it will be reasonable to conclude a relationship between naming speed and sensory temporal processing. For instance, Kinsbourne et al (1991) have demonstrated a correlation between TOJs and rapid automatised naming (RAN). The argument that visual and auditory temporal processing deficits are parts of a general timing deficit will be more elaborated in Chapter 7.

Recognising the breath of the issues concerning temporal processing, this thesis will directly investigate the relationship between sensory temporal processing and reading. Though I will comment on other possible connections like Nicolson and Fawcett's (1993c) DAD hypothesis and naming speed studies, these issues will not be investigated in this thesis.

5.4 The Relationship between Temporal Processing and Reading / Phonological Ability

Several studies demonstrate a relationship between sensory temporal processing and various reading / phonological measures. The studies are summarised below.

5.4.1 The Relationship between Auditory Temporal Processing and Reading / Phonological Ability

As discussed in Chapter 4, dyslexics and dysphasics are impaired in auditory perceptual tests which require temporal analysis of tones (Tallal, 1980), syllables (Elliott et al 1990a) or synthesised voiced stop consonants (Godfrey et al, 1981). Moreover, these researchers have shown that the degree of auditory temporal processing deficit is correlated with the degree of impairment in phonological decoding skills (Tallal, 1980), receptive language deficit (Tallal et al, 1985a) and receptive vocabulary (Elliott et al 1990a). In addition, Tallal et al (1985b) argued that these perceptual variables correctly identified 98% of the subjects.

Watson and Watson (1993a) used the Test of Basic Auditory Capabilities (TBAC) and found that dyslexic college students (n=20) were significantly impaired in the temporal subtests with respect to controls (n=25) and maths-disabled students (n=10) who did not differ from each other. Although Watson and Watson (1993b) found a relationship between speech perception which included a measure of temporal processing and phonological processing, nonverbal temporal processing was unrelated to phonological abilities independently of intelligence and speech perception (after Watson & Watson, 1993b). Similar findings were also obtained in Watson and Miller (1993).

Watson and Miller (1993) studied the relationships among auditory perception, phonological processing and reading in 94 undergraduates, 24 of whom were reading disabled. It was found that speech perception, which was measured by speech repetition, syllable sequence discrimination, and degraded speech tasks, was strongly related to phonological measures such as short- and long-term auditory memory and phoneme segmentation (after Watson & Miller, 1993). Moreover, these phonological variables were in turn strongly related to reading. However, though the reading-disabled group performed worse than their matched controls on TBAC auditory temporal order judgment, this nonverbal temporal processing measure was unrelated to phonological processing. The results were consistent with Watson and Watson (1993b) in which they found a relationship between phonological measures and speech perception and not nonverbal temporal processing measures. However, the result was inconsistent with

Watson and Watson (1993a) who found at least a relationship between one temporal processing measure and phonological processing. The difference may be due to the fact that Watson and Miller (1993): 1) used a different criteria for subject selection; 2) used a broad range of auditory measures; and 3) used a different structural equation model. Note again the role of verbal stimuli in enhancing the role of temporal processing in reading as discussed in Wagner and Torgesen (1987).

Furthermore, not all studies show a relationship between reading / phonological processing and various temporal processing measures. In Nix and Shapiro (1986), thirty-four dyslexics (aged 7 to 12) who were receiving learning assistance and 36 controls were examined on "auditory discrimination, auditory analysis and synthesis, auditory sequential memory, and phonemic segmentation tasks" (p.92). The dyslexics were significantly impaired on tasks requiring phonemic analysis and synthesis, repeating digits in reverse order, phonemic segmentation and memory of related words. In a subsequent study, Shapiro, Nix and Foster (1990a) administered the same tests to 103 dyslexics and 103 matched controls. A principal components analysis yielded four factors: advanced phonological awareness (e.g., word or syllable segmentation), sequential memory, auditory discrimination and simple phonological awareness (e.g., phoneme segmentation). However, all factors except the auditory discrimination factor could discriminate between the dyslexics and controls. There are two reasons for not finding the differential effect of auditory discrimination. First, different criterion for reading disability is assigned at different ages. Hence, it is difficult to include a homogeneous group of dyslexics. Second, Shapiro used the Lindamood Auditory Conceptualisation Test (LACT) (Lindamood & Lindamood, 1971). This test requires subjects to manipulate coloured blocks to represent speech sounds. The inter-modal transfer between auditory representation to visuo-motor skills may make the test not as sensitive as those which manipulate auditory stimuli directly. Although there is still a close correspondence between tactual and auditory discrimination with the auditory one being superior in terms of precision (Eilers et al, 1988), Eden, Stein, Wood and Wood (1995b) found that LACT was not sensitive enough to differentiate between the controls and the reading-disabled group, even though this test correlated with reading for the entire sample of 93 ($r = 0.5$).

In sum, it seems that impairment of auditory temporal processing (especially speech perception) is significantly related to the degree of reading deficit. Furthermore, the strength of the effect depends on the methodology and sensitivity of the test used.

5.4.2 The Relationship between Visual Temporal Processing and Reading / Phonological Ability

Lovegrove et al (1989) administered a battery of visual tests and showed a relation between the visual measures and phonological sensitivity. In addition, Slaghuis, Lovegrove and Davidson (1993) compared 35 normal and 35 dyslexic subjects aged 7.9 to 14 on: 1) a visual processing score, defined by "the slope of the regression line predicting the duration of visible persistence as a function of spatial frequency" (p.613); 2) a phonological coding score, measured by the ability to read nonsense words; and 3) a comprehension score, measured by the token test. The results showed that the visual processing score was significantly predictive of group membership with 91% of the dyslexics and 20% of the controls having low scores on this measure. The nonword test was a perfect discriminator by indicating that every dyslexic had a phonological coding deficit. Nevertheless, the token test did not discriminate between the groups (after

Slaghuis et al, 1993). Thus, visual and language deficits are concurrent in dyslexia in that study.

As discussed in Chapter 4, May et al (1988b) required their subjects to report the order of two words or to report the position in which the first word appeared. Poor readers had longer word and position SOAs and only the word but not the position thresholds correlated significantly with reading.

As stated in Chapter 4, Eden et al (1995a) found that reading disabled children (n=26, aged 10 to 12) performed worse than normal children (n=39) on a temporal dot task (task in which subjects had to count the dots as they sequentially flashed up in the same area of the screen) and a spatial dot task (task in which subjects had to count the dots in space). Moreover, "a regression model including age, verbal IQ, phonological awareness and visual temporal processing ability, predicted 73% of the variance of reading ability" (p.451).

Further, Rudel and Denckla (1976) presented sequences of light flashes and asked the learning disabled group (which included some reading disabled subjects) and controls to match them with spatially arranged patterns of dots (a temporal-spatial TS task). Task performance was significantly correlated with reading age.

On the other hand, Sterritt and Rudnick (1966) presented sequences of lights to 36 fourth-grade boys (described as highly intelligent and proficient on reading comprehension) and asked them to find the corresponding dot pattern. However, they failed to find a relationship between task performance and reading scores. The inconsistency between Rudel and Denckla (1976) and Sterritt and Rudnick (1966) may be due to: 1) Sterritt and Rudnick (1966) adopted Birch and Belmont's (1964) match-to-sample technique in which subjects had to say which of the three comparison stimuli was the same as the standard. This placed a burden on memory whenever the three choices were not presented at the same time. On the other hand, Rudel and Denckla (1976) used a same-different procedure which reduced the memory load; 2) Sterritt and Rudnick (1966) used a multiple regression technique on the whole sample whereas Rudel and Denckla (1976) used ANOVA and correlations on different groups; 3) the heterogeneous sample used in Rudel and Denckla (1976) made it hard to conclude whether the effect was due to reading disability or not; 4) In Rudel and Denckla (1976), reading age correlated with Digit Span Forward ($r = 0.445$) and temporal-spatial TS task ($r = -0.421$) and the TS task correlated with Performance ($r = -0.638$) and Full Scale IQ ($r = -0.475$). On the other hand, the IQ effect was controlled in Sterritt and Rudnick (1966). Thus, the significant relationship found in Rudel and Denckla (1976) might be due to the confounding / uncontrolled effect of IQ and memory; and 5) Rudel and Denckla (1976) used both normal and learning-disabled subjects whereas Sterritt and Rudnick (1966) used subjects who had no reading problems. So, it is possible that the ability to transpose from a temporal to a spatial dimension is not a skill significantly related to reading level, at least among adequate readers (Vande Voort & Senf, 1973).

In sum, visual temporal processing deficits are concurrent with reading deficits in some subjects and in some cases, are predictive of the variance in reading. Moreover, their relationship is more apparent in poor than normal readers.

5.4.3 The Relationship between Transmodal / Crossmodal Sensory Temporal Processing and Reading / Phonological Ability

Most evidence supporting a correlation between transmodal / crossmodal sensory temporal processing and reading comes from sequence matching studies (e.g., Bakker, 1967, 1972; Groenendaal & Bakker, 1971; Zurif & Carson, 1970; Bryden, 1972; Birch & Belmont, 1964). These studies have been discussed in Chapter 4. In sequence matching studies, as noted in Chapter 4, the apparent relationship between temporal processing and reading is largely "induced" by the effect of memory under the relatively "long" ISI or stimulus duration presentations. For example, Bakker (1967, 1972) and Groenendaal and Bakker (1971) used an ISI of 75 to 4000 ms while Zurif and Carson (1970) and Bryden (1972) used an ISI of 500 to 1000 ms. Nevertheless, some researchers (e.g., Sterritt & Rudnick, 1966; Jorgenson & Hyde, 1974) still demonstrated a relationship between transmodal / crossmodal temporal processing and reading when taking into account IQ and memory.

Further, a more positive demonstration was provided by Kinsbourne et al (1991) who administered a battery of tests on 23 adult dyslexics (severe group), 11 adults who were dyslexics during childhood (recovered group) and 21 matched controls. Results showed that the severe adult dyslexics were impaired in verbal fluency and visual and auditory temporal order judgment. Nonetheless, these test scores strongly predicted the degree of reading impairment. For example, the visual temporal order judgment measure, which "involved resolution of sequential inputs cross-hemispherically" (p.771), significantly correlated with rapid automatised naming (RAN) which in turn correlated with reading and spelling. As this research focuses on TOJ which requires a shorter stimulus duration, it supports the relationship between transmodal / crossmodal temporal processing and reading.

In sum, to a minimum extent, the transmodal / crossmodal tasks support a relationship between multimodal sensory temporal processing deficits and reading deficits. Even though most evidence comes from sequence matching studies which are likely confounded by memory factors, TOJ studies are still supportive of this hypothesis.

5.5 Possible Confounding Effects of Memory and Intelligence on Sensory Temporal Processing in the context of Reading

Meanwhile, some of the temporal processing effects observed in the reading research have been confounded by cognitive abilities like memory and intelligence. Their interaction is shown in the following studies:

5.5.1 Possible Confounding Effects of Memory on Sensory Temporal Processing

Dyslexics exhibit cognitive problems in phonological awareness and working memory (Kean, 1984). Frith (1992) once suggested a cognitive deficit due to affected brain functions can lead to "problems in naming, short-term memory and phoneme segmentation" (p.15). Moreover, Fortin and Breton (1995) argued that working memory contributes to time estimation. In fact, some researchers show that poor readers who experience sensory temporal processing also experience certain memory deficits. In addition, most evidence comes from sequence matching studies because these tasks are more likely to tap into memory functions, as stated in 4.2.

James et al (1994) found that language-disordered children with central auditory processing (CAP) difficulties not only showed poor phoneme discrimination, but also deficits in phonological working memory as indicated by nonword repetition and word recall.

Newman et al (1991) also found some dyslexics who showed difficulties with auditory discrimination and knowledge of grapheme to phoneme rules, were impaired in sequential memory.

Bakker and Schroots (1981) asked their subjects to: 1) repeat a series of nouns spoken by the examiner (wordspan); 2) match the series of nouns with the pictures (picture matching); 3) repeat a story (sentence imitation); and 4) tap the cube in the order demonstrated by the examiner (Knox Cube Test) (Arthur, 1947). Results showed that sentence imitation, Knox Cubes and picture matching best predicted reading ability. The sentence imitation task and the Knox Cubes test imply the interactive nature of serial memory and temporal processing in reading. Hence, it is possible that the deficiencies found can be attributed to serial memory rather than temporal processing difficulties.

Kinsbourne et al (1991) administered a battery of tests and found that, apart from having temporal order judgment and rapid naming and word fluency deficits, adult dyslexics also had memory and verbal deficits and were deficient in associative learning. However, this study has not thoroughly investigated the relationship between the deficits.

Watson and Willows (1995) found that the reading-level-matched older disabled group also showed deficits in phonological coding and visual sequential memory. In addition, both older disabled and high-risk "dyslexic" groups also exhibited deficits in short-term auditory memory and decoding / encoding.

Furthermore, in Pennington, Van Orden, Smith, Green and Haith (1990), while both familial and clinical dyslexic groups exhibited clear deficits in phonemic awareness which accounted for substantial variance in nonsense word reading, only the clinical dyslexics showed short-term verbal memory deficit.

Nevertheless, Birch and Belmont (1964) found that while poor readers were inferior in an AVI task, their deficit was unrelated to short-term auditory memory because there was no difference between the poor readers and controls on Digit Span measures. In addition, significant correlation between the AVI task and reading vocabulary was obtained after controlling the memory factor (Jorgenson & Hyde, 1974).

Consequently, it seems that not all poor readers who experience temporal processing deficits have memory deficits, though most of them do, depending on the type and the severity of their reading problems. Nevertheless, the relationship between temporal processing, reading and memory is inconclusive. There are several reasons for this. First, poor readers are recruited using different criteria and it is difficult to conclude that the effect is absolutely due to dyslexia. Second, it is possible that dyslexia is heterogeneous such that it may or may not co-exist with memory and / or temporal processing deficits, depending upon the severity, type and the source of its origin, and the methodology and type of memory tests used in the experiments. Even in the case where two out of the three factors co-exist, little is known about the directions of their relationship. One way to examine the contribution of memory to reading is to statistically control the effect of temporal processing and intelligence. On the other hand, one can also examine the contribution of memory to temporal processing by statistically controlling the effect of reading and intelligence. More research is needed to deal with this issue. Furthermore, Vernon (1983a,b) argued that better temporal processing ability results from higher intelligence leads to less decay and hence better performance in working memory. Similarly, Watson (1992b) suggested that deficits in short-term or long-term verbal memory and phoneme segmentation (Jorm & Share, 1983; Wagner & Torgesen, 1987; Stanovich, 1986), which may be etiological factors in dyslexia, may result from fundamental deficit in auditory temporal processing.

5.5.2 Possible Confounding Effects of Intelligence on Sensory Temporal Processing

In a longitudinal study, Baddeley and Gathercole (1992) observed a consistent association between intelligence and reading. Similar to the reading research confounded by memory, some research examining the role of temporal processing in reading is confounded by intelligence.

Confounding Effects of Intelligence on Auditory Temporal Processing

It seems that there is a small effect of auditory temporal processing on reading / phonological processing once intelligence is controlled. Further, the effect is less apparent when nonverbal stimuli are used. For example, Watson and Watson (1993b) found a strong relationship between speech perception and phonological processing. However, nonverbal temporal processing was not related to phonological processing independently of intelligence and speech perception. This implicates the role of intelligence in temporal processing as measured in their experiment. In fact, temporal processing efficiency may be considered as part of intelligence influence (Raz, Willerman & Yama, 1987). Several experiments have demonstrated the confounding effect of IQ in accounting for rapid auditory processing, especially in auditory discrimination (Deary, 1980; Raz, Willerman, Ingmundson & Hanlon, 1983; Watson, 1991). It may be that more intelligent brains will have better signal representation and sensory resolution (Raz et al, 1987). Nevertheless, Deary (1995) argued that auditory temporal processing, as indicated by auditory inspection time at age 11, caused later intelligence.

Confounding Effects of Intelligence on Visual Temporal Processing

Many studies investigating the relationship between intelligence and visual temporal processing are visual inspection time studies. Inspection time refers to the time required to discriminate between two stimuli (Whyte, Curry & Hale, 1985). The most common method used is to measure the time required to discriminate between two lines of different lengths. Whyte et al (1985) measured the time at which subjects could discriminate between two lines with different lengths. Dyslexics (n=7, aged 9 to 11) had longer inspection time than normal controls and inspection time was unrelated to nonverbal IQ.

However, many researchers found that visual temporal processing, as indicated by inspection times studies, is generally related to intelligence in adults (Bowling & Mackenzie, 1996). Moreover, visual inspection time correlates more with Performance IQ than with Verbal IQ (Deary, 1993; Stough, Brebner, Nettlebeck, Cooper et al, 1996). Nevertheless, not all subjects show a relationship between visual inspection time and IQ. For example, Mackenzie, Bingham, Cumming, Doyle, Turner, Molloy, Martin, Alexander and Lovegrove (1989) found that subjects who did not perceive apparent motion in an inspection time display showed a significant correlation between visual inspection time and nonverbal IQ, whereas those who perceived the motion did not. Thus, it is possible that visual temporal processing and intelligence undermine each other, as least in normal adults. Furthermore, their relationship in the context of reading disability remains inconclusive.

Confounding Effects of Intelligence on Crossmodal Temporal Processing

Birch and Belmont (1964) found that retarded readers performed poorer on a series of AVI tasks. Although the AVI scores related to reading, they also related to IQ as subjects who performed poorly on the AVI task also had lower IQ. Therefore, the authors only compared subjects who had an IQ score of 100 or more. Results showed that the AVI difference between the retarded and normal readers still remained even when IQ was controlled.

Similarly, Sterritt and Rudnick (1966) found that the auditory-temporal rhythm perception or the ability to transpose from auditory-temporal to visual-spatial patterns was related to reading when general intelligence was taken into account.

Additionally, Katz and Deutsch (1963) showed that the impaired modality shifting capacity of their retarded readers was not directly related to intelligence.

Hence, it seems that the auditory-visual integration deficit still persists even after IQ is controlled.

Studies with No Control on Intelligence

However, there are still some studies which underestimate the effect of intelligence and hence have not properly controlled it during analysis.

For instance, Birch and Belmont (1965) found that as age increased in a group of children (N=220, aged 5 to 12), the correlation between the perceptual AVI measures and reading decreased while the correlation between IQ and reading increased. The authors interpreted their results as suggesting that in acquiring reading skill primary perceptual factors were most important for initial acquisition but more general intellectual factors were needed for later elaboration (after Birch & Belmont, 1965).

However, this experiment did not further explore the relationship between the AVI measures and reading with intelligence being controlled.

Rudel and Denckla (1976) examined subject's ability to match sequential flashes of light to another sequence of light or to a spatial dot pattern. They found that matching from sequence to pattern correlated with reading age (r = -0.421) among the learning-disabled who also included reading-disabled. Additionally, this task also correlated with Performance IQ (r = -0.475) and FS IQ (r = -0.457). However, the experiment did not examine whether there was a correlation between the matching task and reading age with IQ controlled.

Summary of Confounding Effects of Intelligence

Although the auditory perceptual measures are less related to reading achievement once IQ is controlled, the relationship between the AVI measures and reading performance still remains under this condition.

5.6 Summary

Reading involves two fairly independent routes: a lexical and a sublexical route. How well one reads depends on the efficiency in decoding and retrieval in the routes. In fact, automaticity within these processes has been implicated in naming speed studies. Moreover, temporal processing which bears a relationship with reading, may be an index for automaticity (Wolf, 1991a,b). Furthermore, the relationship between reading and temporal processing is not so clear such that the temporal processing deficits observed may be confounded with other cognitive processes like memory and intelligence. Some researchers suggest that temporal processing deficits are only concurrent and are not necessarily and sufficiently causal to reading disability (Lovegrove et al, 1989; Watson, 1992b; Ludlow et al, 1983).

On the evidence so far, temporal processing ability is related to reading. For example, Miller and Tallal (1995) and Lovegrove et al (1989) found that the ability to process rapidly presented auditory and visual stimuli was related to language impairment and phonological ability. Galaburda et al (1985, 1994) identified abnormalities in the transient visual and auditory pathways which are responsible for processing rapidly presented stimuli in dyslexics. Farmer and Klein (1995) suggested a generalised temporal processing mechanism and that temporal processing deficits in different modality may result in different dyslexic subtypes. This is related to the rationale of my thesis, as will be discussed in Chapter 6.

Chapter 6 : Rationale for the Present Study

On the basis of the evidence discussed in previous chapters showing that many dyslexics and dysphasics were impaired in both auditory and visual temporal processing tasks (e.g., Kinsbourne et al, 1991; Tallal et al, 1985b; Farmer & Klein, 1993) and the finding of similar temporal processing deficits in motor coordination (e.g., Wolff et al, 1984, 1990c), a generalised pansensory deficit in processing sensory information has been hypothesised (Miller & Tallal, 1995; Galaburda et al, 1985, 1994; Farmer & Klein, 1995; Stein, 1993).

Moreover, Miller and Tallal (1995) argued that "separate neural systems may exist for the processing of short duration information presented in rapid succession, within 10s of milliseconds, as compared with information presented within 100s of milliseconds" (p.292). The former refers to a fast system whereas the latter refers to a slow system. In fact, anatomical and psychophysical evidence confirms the existence of a fast and a slow system - the transient and sustained systems in both vision and audition (e.g., Livingstone & Hubel, 1987, 1988; Kulikowski & Tolhurst, 1973; Burbeck & Luce, 1982; Goldstein et al, 1968; Gersuni, 1971).

Thus, the first question this thesis aimed to answer is:

1) Is there a common temporal sensory processing mechanism? This question includes the following more specific questions:

a) Is there a common temporal processing mechanism within vision?

b) Is there a common temporal processing mechanism within audition?

c) Is there a common transmodal temporal processing mechanism?

d) Given the framework of temporal tasks, whether within and / or across modality, it is possible to differentiate the transient and sustained systems in vision and audition.

In order to answer the first question, different temporal processing measures will be obtained in vision and audition. For vision, tasks included flicker sensitivity, visual temporal order judgment, visible persistence (based on the judgment of a blank and a flicker) and flicker fusion. For audition, measures included auditory fusion and auditory temporal order judgment. These tasks were chosen because they are the most common and effective temporal processing tasks used in reading research. Moreover, the tasks were chosen such that there was an analogue between the visual and auditory versions. For example, visible persistence is analogous to auditory fusion while visual TOJ is analogous to auditory TOJ. To differentiate between the sustained and transient visual systems, different experimental parameters were used for each visual measure. For example, the sustained visual system is sensitive to high spatial frequencies and low temporal frequencies whereas the transient visual system is sensitive to low spatial frequencies and high temporal frequencies (Baro et al, 1996). Therefore, for flicker sensitivity, 2 and 12 Hz were used to test the sustained and transient systems respectively. For visual TOJ, 1 and 7 c/d were used to test the transient and sustained systems respectively. For visible persistence and flicker fusion, 2 and 12 c/d were used to test the transient and sustained systems respectively. However, with limitations in methodology, it is hard to differentiate the auditory system into its transient and sustained systems by just varying stimulus duration (Phillips, 1985). Nevertheless, short and long duration stimuli were assigned to each auditory measure. Thus, 15 and 100 ms noise bursts were used for auditory fusion while 15, 75 and 200 ms tones were chosen for auditory TOJ. So, for question 1, the relationship between the measures will be evaluated within each and between both modalities. Table 6-1 illustrates the tests used within each modality.

Table 6-1: Temporal Tasks used in both Visual and Auditory Modalities

Vision	Audition
Flicker Sensitivity (2 and 12 Hz)	Auditory Fusion (noise: 15 and 100 ms)
Visual Temporal Order Judgment (1 and 7 c/d)	Auditory Temporal Order Judgment (tones: 400 and 2200 Hz)
Visible Persistence (blank: 2 and 12 c/d)	
Visible Persistence (flicker: 2 and 12 c/d)	
Flicker Fusion (2 and 12 c/d)	

Livingstone et al (1991) and Lehmkuhle et al (1993) found abnormality in the transient visual system and Galaburda et al (1985, 1994) found a similar deficit in the auditory MGN in dyslexics. These are compatible with the visual and auditory temporal processing deficits observed in dyslexics and dysphasics (e.g., Tallal & Piercy, 1973a,b; Tallal & Stark, 1981; Badcock & Lovegrove, 1981; Lovegrove et al, 1980, 1982, 1986a). Further, these researchers observed that the degree of temporal processing deficit was related to the severity of language deficit (Tallal et al, 1985a; Lovegrove et al, 1989). In fact, Breitmeyer (1993a,b) and Lovegrove et al (1986a) argued that the transient visual system deficit constituted a source of noise impeding or masking efficient pick-up of sequentially scanned information. Support is provided by Hill and Lovegrove (1992) who showed that dyslexics were impaired in the regular text condition - a condition in which integration of central and peripheral information was required (Farmer & Klein, 1995). In this condition, the transient visual system is involved. On the other hand, dyslexics were not impaired in sequential spatial presentation or rapid serial visual presentation (RSVP), conditions which involved primarily the sustained system. Hence, theoretically, there may be a relationship between the transient and sustained visual systems and different types of text presentation.

Farmer and Klein (1995) suggested that individuals with visual but not auditory temporal processing deficits would likely present as dyseidetic dyslexics (dyslexics who have problems reading irregular words) whereas individuals with auditory but not visual temporal processing deficits would likely present as dysphonetic dyslexics (dyslexics who have problems reading nonsense words). Hence, different temporal processing modalities may be related to the processing of different types of words.

Thus, the second question this thesis aimed to answer is:

2) What is the relationship between the temporal processing mechanism(s) and reading in normal adult readers[2]? This question includes the following more specific questions:

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[2] The author is interested in studying the normal readers rather than the dyslexics for various reasons. Firstly, though the research background is based on the work of dyslexia and dysphasia and argues for a relationship between temporal processing deficits and reading, the author is interested to see how the "normal" temporal processing mechanism(s) function(s) under "normal" reading performance before investigating how the same mechanism(s) (e.g., with respect to different mode of text presentation) function(s) differently in normal and reading-impaired subjects. Secondly, with reference to the methodological considerations, this research is a "large-scale" study which involves big sample sizes. The author experienced difficulty obtaining enough reading-disabled subjects. Thus, normal readers served as a second resort. The justification and weaknesses of the approach will be further discussed in Chapter 10.

a) The relationship between the visual and auditory temporal processing measures and various reading measures:

i) whether there is a relationship between the two visual systems and text presentation mode; and

ii) whether there is a modality effect on different types of words.

b) How well do the temporal processing measures discriminate:

i) "irregular word" and "nonsense word" readers; and

ii) good and normal readers.

To answer question 2a, tasks used in question 1 will be used for this study. Further, non-verbal reasoning skills were measured for each subject using the Advanced Raven's Progressive Matrices. In addition, various reading measures were obtained. These required subjects to read both nonsense words and irregular words. The words were presented either singly or continuously. The word type was used to investigate question 2a ii) while the presentation mode was used to investigate 2a i). The relationship between various measures and reading will be evaluated. Table 6-2 illustrates the reading task.

Table 6-2: Types of Words and their Presentation Mode used in the Reading Task

Type of Words	Presentation Mode
Irregular Words	Single
Irregular Words	Continuous
Nonsense Words	Single
Nonsense Words	Continuous

With reference to question 2b, the powerful predictors for the reading measures will be analysed. The aim is to find out how good these predictors are in differentiating: i) "irregular word" and "nonsense word" readers; and ii) good and normal readers. Table 6-3 illustrates the types of subjects compared.

Table 6-3: Types of Subjects compared

	Subjects	
"Irregular Word" Readers	vs	"Nonsense Word" Readers
Good Readers	vs	Normal Readers

Chapter 7: Study 1

The Relationship between Visual and Auditory Temporal Processing

7.1 Rationale

As stated in Chapter 6, the generalisation of temporal processing deficits of dyslexics and dysphasics in different modalities (e.g., Kinsbourne et al, 1991; Tallal et al, 1985a,b; Tallal & Stark, 1982; Farmer & Klein, 1993; Badcock & Lovegrove, 1981; Lovegrove et al, 1980, 1982, 1986a,b; Wolff et al, 1984, 1990c; Wolff, 1993) has led to the hypothesis of a generalised pansensory deficit in processing sensory information (Miller & Tallal, 1995; Galaburda et al, 1985, 1994; Farmer & Klein, 1995; Stein, 1993).

In addition, anatomical and psychophysical evidence suggests the existence of two separate neural systems - a fast transient system and a slow sustained system in both vision and audition (e.g., Livingstone & Hubel, 1987, 1988; Kulikowski & Tolhurst, 1973; Burbeck & Luce, 1982; Goldstein et al, 1968; Gersuni, 1971). Extensive evidence suggests that dyslexics and dysphasics are impaired in the former but not the latter (e.g., Livingstone et al, 1991; Lehmkuhle et al, 1993; Galaburda et al, 1985, 1994; Badcock & Lovegrove, 1981; Lovegrove et al, 1980, 1982, 1986a). Consequently, a generalised pansensory deficit in processing sensory information hypothesised by Miller and Tallal (1995), Galaburda et al (1985, 1994), Farmer and Klein (1995) and Stein (1993) may be just equivalent to a hypothesis of a generalised transient system deficit. Investigation of a generalised sustained system is beyond the scope of my thesis.

Therefore, this study aimed to investigate whether there is a common sensory temporal processing mechanism. This question includes the following more specific questions:

a) Is there a common temporal processing mechanism within vision?

b) Is there a common temporal processing mechanism within audition?

c) Is there a common transmodal temporal processing mechanism?

d) Given the framework of temporal tasks, whether within and / or across modality, it is possible to differentiate the transient and sustained systems.

There were three stages in this study. Although intelligence may be related to temporal processing as stated in Chapter 5, I did not attempt to include IQ in this study because I wanted to use a "cleaner" paradigm to determine the differential effect among the visual and auditory measures. In other words, I wanted to investigate the "sole" relationship between the measures without taking IQ into account. The three stages are summarised below:

Stage one aimed to investigate the relationship between different visual temporal processing measures. Tasks included flicker sensitivity, visual temporal order judgment, visible persistence (based on the judgment of a blank), visible persistence (based on the judgment of a flicker) and flicker fusion. As the transient and sustained visual systems have different spatiotemporal characteristics, it should be possible to segregate and measure the activity of the two systems psychophysically by selective use of particular stimulus parameters. Therefore, low spatial and high temporal frequency stimuli were presented to test the transient visual system while high spatial and low temporal frequency stimuli were presented to test the sustained visual system (Baro et al, 1996). First, these measures will be compared within each test and between the tests. Then, a principal components factor analysis will be performed to see if, within vision, the temporal processing measures group together as a common mechanism, i.e., whether there is a common visual temporal processing mechanism or whether there is more than one mechanism. Nonetheless, given the framework of visual temporal tasks, it is of interest to determine if this method can differentiate the transient and sustained systems within vision.

Stage two aimed to investigate the relationship between different auditory temporal processing measures. Tasks included auditory fusion and auditory temporal order judgment. Even though the auditory system consists of receptors and pathways that are frequency- and abrupt-gradual-on-offset-specific (Gersuni, 1971), due to equipmental limitations, the segregation is not pronounced enough to be tested psychophysically by simply varying stimulus duration (Phillips, 1985). Consequently, short and long duration stimuli were employed in the auditory tasks. A principal components factor analysis will be performed to see if, within audition, the temporal processing measures group together as a common or multiple mechanisms, i.e., whether there is a common auditory temporal processing mechanism.

Stage three aimed to investigate the relationship between the visual and auditory temporal processing measures. A principal components factor analysis will be performed to see if whether the temporal processing measures group together as a common mechanism or reflected different mechanisms / processes, i.e., whether there is a common temporal processing mechanism for both vision and audition as hypothesised by Miller and Tallal (1995), Galaburda et al (1985, 1994), Farmer and Klein (1995) and Stein (1993). Similarly, given the framework of temporal tasks, it is of interest to see if the transient and the sustained systems can be differentiated transmodally.

7.2 STAGE 1: VISION

This aimed to investigate the relationship between different temporal processing measures in vision. Tasks of flicker sensitivity, visual temporal order judgment, visible persistence (based on the judgment of a blank and a flicker) and flicker fusion were administered. To differentiate between the transient and sustained systems, different experimental parameters were used for each measure. Thus, for flicker sensitivity, 2 and 12 Hz were used to test the sustained and transient systems respectively. For visual TOJ, 1 and 7 c/d were used to test the transient and sustained systems respectively. For visible persistence and flicker fusion, 2 and 12 c/d were used to test the transient and sustained systems respectively. These measures will be compared and evaluated.

Chase and Jenner (1993) measured the flicker fusion rate of seven dyslexics and eight controls (aged 17 to 22) in both magnocellular and parvocellular channels. Although the two groups did not differ in their parvocellular channels, dyslexics had higher magnocellular fusion thresholds or lower flicker fusion rates (mean = 26.1 Hz) than the controls (mean = 38.4 Hz).

Similarly, Talcott et al (1997) found that adult dyslexics had lower critical flicker fusion frequencies (mean = 52.8 Hz) than the controls (mean = 57.1 Hz).

Smith, Howell and Stanley (1982) presented subjects sine-wave gratings of 1, 3, 6, and 10 c/d for either 20 or 200 ms and at a contrast of 0.1 or 0.4. The gratings were presented on a cathode ray oscilloscope (CRO) and subjects judged the discontinuity of the superimposed gratings based on the presence or absence of a "flicker" in the display. Results showed that threshold separation for discontinuity detection increased linearly with spatial frequency. The range of increase was between 10 to 30 ms for 200 ms gratings and between 30 to 150 ms for 20 ms gratings.

Using a tachistoscope, Bowling, Lovegrove and Mapperson (1979) presented sine-wave gratings (1, 2, 4, 8, 12 c/d; duration 50 ms) of 0.1 and 0.4 contrast and measured subject's visible persistence. Subjects were asked to judge the discontinuity / continuity based on the presence of a blank. Again, visible persistence increased with spatial frequency (with a range of 140 to 340 ms).

Thus, integrating the above experiments, the short duration obtained in Chase and Jenner (1993), Talcott et al (1997) and Smith et al (1982) implies a measure of flicker fusion whereas the longer duration obtained in Bowling et al (1979) implies a measure of visible persistence. Although the experiments are similar, the major difference between a flicker fusion task and a visible persistence task is that a flicker fusion task requires subjects to judge the discontinuity-continuity based on a "flicker" whereas the visible persistence task requires subjects to judge the discontinuity based on a blank-field or gap detection. In fact, Long and Sakitt (1984) compared the ISI between a critical-flicker-frequency (CFF) task (task on which the judgment of discontinuity-continuity point was based on the perception of a flicker (Sakitt, 1976)) and a quasi-flicker task (task on which the judgment of the discontinuity-continuity point was based on the perception of a blank interval). Stimuli consisted of high-contrast 1 c/d and 7.5

c/d square-wave gratings of 50 ms duration. Results showed that under both conditions, the 7.5 c/d gratings exhibited longer ISI than the 1 c/d gratings. In addition, the quasi-flicker task exhibited a longer ISI (80 to 330 ms) than the CFF task (10 to 60 ms). The authors argued that both conditions underwent the same process(es). Hence, it follows that from the point of discontinuity to continuity, subjects should see a clear gap or a blank-field first, followed by a flicker and then the continuity.

Moreover, Martin and Lovegrove (1987) presented a 2 c/d sine wave grating counterphased at 5 to 25 Hz to test subjects and measured their contrast sensitivity. In general, contrast sensitivity increased (or the contrast threshold decreased) as temporal frequency increased.

To be consistent with previous findings and the spatiotemporal properties of the transient and sustained visual systems, the visual measures in this study should show that:

1) Visible persistence increases with increasing spatial frequency.
2) Visible persistence based on the judgment of a blank will be longer than that based on the judgment of a flicker.
3) Flicker fusion threshold will increase with increasing spatial frequency.
4) For the flicker sensitivity task, as the transient visual system is more sensitive to temporal properties, subjects will exhibit lower contrast threshold (higher contrast sensitivity) at high than at low temporal frequency stimuli.
5) For the visual TOJ task, as the transient visual system is more sensitive to low spatial frequencies, subjects will exhibit shorter stimulus-onset-asynchrony (SOA) at low than at high spatial frequency gratings.

Further, although it is assumed that the visual measures chosen reflect the function of the sustained or transient system processing (Badcock & Lovegrove, 1981; Chase & Jenner, 1993; Lovegrove et al, 1982; May et al, 1988b), it is uncertain whether these measures absolutely reflect temporal processing. Therefore, it is of interest to see if, within the temporal processing framework, the sustained and the transient components can be differentiated. If the two components can be differentiated, it can be concluded that the sustained measures do not tap into temporal processing. Otherwise, it will be argued that the sustained system has some involvement in temporal processing.

7.2.1 MEASURE 1a: Flicker Sensitivity (FSEN)

Flicker sensitivity (FSEN) refers to the ability to detect a rapidly alternating stimulus (Reber, 1985). It measures the minimum contrast required to see a flickering stimulus. The contrast is defiined as the difference between the light intensity of the lightest part of the stimulus and the light intensity of the dimmest part, divided by the sum of these two quantities, i.e., [Lum(max) - Lum(min)] / [Lum(max) + Lum(min)] (Sekuler & Blake, 1990). In this task, flickering blank fields of high (12 Hz: which should reflect transient system functioning) and low (2 Hz: which should reflect sustained system functioning) temporal frequencies were used. Contrast threshold was measured using Wetherill and Levitt's (1965) procedure with a two-alternative forced choice paradigm. In this method, a staircase begins at a value above the subject's threshold. If the subject makes an error, the value will increase for the next block of three trials. If the subject makes no errors within three consecutive trials, the value decreases. Thus, the trials proceed to find an accuracy level of 79%. A reversal occurs when the value changes from a decrease to an increase or vice versa. The size of increase or decrease in each value depends upon the pre-established stepsize. The initial stepsize was 1.5 dB and on each successive reversal, the stepsize halved until it reached 0.375 dB. Six reversals were included for the flicker sensitivity task but the first two were excluded from analysis so that only those determined with the minimum step size were included. Preliminary analysis demonstrated that thresholds yielded in six reversals were not different from those found using eight reversals. Two interleaving staircases randomly alternate between the trials in each staircase in order to ensure that subjects can not identify the response trend and to minimise their ability to guess the right answer.

Method

Subjects

Subjects were 91 undergraduate students (4 males, 87 females, aged 18 to 54) with normal or corrected to normal vision. None of them had hearing problems, epilepsy or migraine headache. They were recruited from advertisement in the university. Each subject was offered bonus points for participation.

Apparatus / Stimuli

Apparatus included: 1) an IBM compatible computer; 2) an Innisfree Picasso CRT Image Generator, which interfaced with the computer and presented stimuli on a Tektronix 608 X-Y display with a P31 phosphor; 3) a white rectangular board, 83 cm x 70 cm, with lights controlling the space-average-luminance of the stimuli presentation; 4) a circular occluder which fixed the position of the stimuli; 5) a clamp and a chin-rest which fixed subject's viewing distance; and 6) a response box.

The stimulus was a circular field with a sinusoidal flickering field which projected a visual angle of 5°. The viewing distance was 57 cm and the space-average-luminance was 10.3 cd/m^2. The stimulus duration was 1 s. As stated before, the contrast was measured using [Lum(max) - Lum(min)] / [Lum(max) + Lum(min)] (Sekuler & Blake, 1990). The initial contrast for the 2 Hz field was set at 0.05 and that for the 12 Hz field was set at 0.03. These contrast thresholds were chosen because they were above subjects' thresholds during piloting.

Sinusoidal flickering fields were generated on a Tektronix 608 X-Y display with a P31 phosphor. The stimuli were generated by an Innisfree Picasso CRT Image Generator controlled by an IBM compatible computer and C programs. Stimuli were presented at varying contrasts using the up-down-threshold-reversal method of Wetherill and Levitt's (1965) at the 79% level of confidence. Luminance was measured with a Tektronix J6523 one-degree narrow-angle luminance probe and was held constant at 10.3 cd/m^2 across all temporal frequency and contrast changes. The background or room illumination was less than 1 cd/m^2. The white rectangular board, 83 cm x 70 cm, surrounded the X-Y display and was illuminated by adjustable lights in such a way that no extra light fell on the X-Y display screen. The average luminance of the surround was equal to the space-average-luminance of the screen of the X-Y display. Table 7-1 summarises the parameters used in this task.

Table 7-1: Parameters used in Flicker Sensitivity Task

Luminance	10.3 cd/m^2
Viewing	57 cm
	Binocular
Visual Angle	5°
Stimulus	Sinusoidal Flickering Blank Field
High Temporal Frequency	12 Hz
Low Temporal Frequency	2 Hz
Stimulus Duration	1 s
Initial Contrast	0.03 for 12 Hz, 0.05 for 2 Hz
Dependent Variable	Contrast Threshold at 79% Accuracy

Procedure

Subjects were seated at a distance of 57 cm from the X-Y display, which was masked with a circular occluder that subtended 5 deg of visual angle. Subjects' heads were restrained by means of a chin rest. Viewing was binocular throughout.

On each trial, subjects were instructed to fixate on the circular field. On each trial, a high tone beep lasting 2 ms was presented first, followed by either a flickering field or nothing. Then a low tone beep was presented, followed by the remaining stimulus that was not presented with the first beep. A third beep, which was a high tone beep, was presented afterwards to indicate the end of the trial. The subject's task was to indicate whether the flickering field followed the first or second beep. If they thought the flickering field followed the first beep, they pressed "1" on the response box. If they thought it followed the second beep, they pressed "2". Feedback was given and each subject's contrast threshold was recorded. Subjects were given practice before the experimental trials and had to respond to both fields of 2 and 12 Hz. The order of presentation for both conditions was counter-balanced.

7.2.2 MEASURE 1b: Visual Temporal Order Judgment (VTOJ)

Visual temporal order judgment (VTOJ) refers to the ability to detect the order of two rapidly presented stimuli. It measures the minimum stimulus-onset-asynchrony (SOA) required to determine the order of two stimuli (Campbell, 1992). In this task, vertical sine wave gratings of high (7 c/d: which should reflect sustained system functioning) and low (1 c/d: which should reflect transient system functioning) spatial frequencies were used. The SOA was measured using Wetherill and Levitt's (1965) procedure with a two-alternative forced choice paradigm. Eight reversals were used in this task.

Method

Subjects

Subjects who participated in the flicker sensitivity task also participated in this task.

Apparatus / Stimuli

Apparatus was the same as that used in the flicker sensitivity task, except that a different occluder was used in this task.

Stimuli were vertical sine wave gratings. The stimulus was seen through two circles, each with a diameter of 3.2 cm, presented 1° on either side of the fixation point. The viewing distance was 57 cm and the space-average-luminance was 30 cd/m^2. The stimulus duration was 200 ms. The stimulus contrast was 0.3. The initial SOA for the 1 c/d gratings was set at 40 / 50 ms and that for the 7 c/d gratings was set at 160 / 180 ms.

Vertical sinusoidal gratings were generated the same way as in the flicker sensitivity task. Stimuli were presented at varying SOAs using the up-down-threshold-reversal method of Wetherill and Levitt's (1965) at the 79% level of confidence. The setup was equivalent to that of the flicker sensitivity task. Table 7-2 summarises the parameters used in this task.

Table 7-2: Parameters used in Visual Temporal Order Judgment Task

Luminance	30 cd/m^2
Viewing	57 cm
	Binocular
Visual Angle	1° from either side of the Fixation Point
Stimulus	Vertical Sinusoidal Gratings
Stimulus Size	2 Circles, each with a Diameter of 3.2 cm
Contrast	0.3
High Spatial Frequency	7 c/d
Low Spatial Frequency	1 c/d
Stimulus Duration	200 ms
Initial SOA	40/50 ms for 1 c/d, 160/180 ms for 7 c/d
Dependent Variable	SOA

Procedure

Subjects were seated at a distance of 57 cm from the X-Y display, which was masked with the occluder with two circles on it. Subjects' heads were restrained by means of a chin rest. Viewing was binocular throughout.

On each trial, subjects were instructed to fixate on the fixation point. A tone was presented first, followed by 500 ms delay. Then, the first grating was presented on either side of the fixation point. Shortly after, the second grating was presented on the other side of the fixation point. The subject's task was to indicate whether the first grating appeared on the left or on the right side. If they thought the grating appeared on the left side first, they pressed "L" on the response box. If they thought the grating appeared on the right side first, they pressed "R". Feedback was given and each subject's SOA was recorded. Subjects were given practice before the experimental trials and had to respond to both gratings of 1 and 7 c/d. The order of presentation for both conditions was counter-balanced.

7.2.3 MEASURE 1c: Visible Persistence based on the Judgment of a Blank (BLAN)

Visible persistence is defined as "any continued visible response to a stimulus after stimulus offset that is phenomenally indistinguishable from that occurring during the actual presence of the stimulus" (Slaghuis & Lovegrove, 1984, p.527-528). It is measured by determining the minimum ISI at which a blank field is just visible among the repetition of a grating-blank-grating cycle. In this task, gratings of high (12 c/d: which should reflect sustained system functioning) and low (2 c/d: which should reflect transient system functioning) spatial frequencies were used. The ISI was measured using a random staircase method. In this method, the first staircase begins at a value above the subject's threshold. Subjects are asked to report whether a distinct blank interval appears between each grating cycle. If they clearly see the blank interval, the value decreases according to a log step. Otherwise, the value increases according to the log step. The initial stepsize was 1.5 dB and the stepsize halved at each reversal until it reached 0.375 dB. A reversal occurs when the value changes from a decrease to an increase or vice versa. At each reversal, the staircase stops and the next staircase starts with its initial value determined according to the response value obtained in the previous reversal and a previously randomised sequence, usually with one log step decrease or increase in ISI. Seven staircases and reversals were used. For three of the last six staircases, the initial value is set a log step above the ISI which resulted from the previous reversal. The magnitude of the increment will be the current step size operating in the tracking procedure. For the remaining three staircases, the initial value is set a log step below the ISI at which the previous reversal occurred. The order in which the initial value is set above or below the ISI obtained in the previous reversal is randomised. The tracking procedure stops at the seventh reversal. The mean of the last five reversals is taken to be the visible persistence measurement.

Method

Subjects

Subjects who participated in the flicker sensitivity task also participated in this task.

Apparatus / Stimuli

Apparatus included: 1) an IBM compatible computer; 2) a Scientific Prototype four-channel tachistoscope, which interfaced with the computer to present the stimuli; and 3) a response box.

Stimuli were computerised reproductions of vertical square wave gratings that completely filled the 6.74 x 4.53 deg target field. The spatial frequencies used were 2 and 12 c/d. The viewing distance was 129 cm and the space-average-luminance was 4.8 cd/m^2. The stimulus duration of each grating was 200 ms. The initial ISIs set for the 2 c/d and 12 c/d gratings were 300 and 500 ms respectively.

Vertical square wave gratings were presented via the tachistoscope controlled by an IBM compatible computer and C programs. On each trial, the gratings were presented for 200 ms, and were alternated with a variable blank ISI for 10 cycles. The duration of the blank ISI was the dependent variable. The luminance was measured with a Tektronix J6523 one-degree narrow-angle luminance probe and was held constant at 4.8 cd/m^2 across all spatial frequency changes. Table 7-3 summarises the parameters used in this task.

Table 7-3: Parameters used in Visible Persistence Task

Luminance	4.8 cd/m^2
Viewing	129 cm
	Binocular
Stimulus	Vertical Square Wave Gratings
Stimulus Size	6.74 x 4.53 deg target field
High Spatial Frequency	12 c/d
Low Spatial Frequency	2 c/d
Stimulus Duration	200 ms
Initial ISI	300 ms for 2 c/d, 500 ms for 12 c/d
Dependent Variable	ISI

Procedure

Subjects were seated at a distance of 129 cm from the display. Viewing was binocular throughout.

Each trial consisted of a grating-blank-grating cycle repeated 10 times. Subjects were instructed to ignore the flicker (Meyer & Maguire, 1977) and to report the presence or the absence of a clear blank interval between the gratings. Thus, if they saw the blank clearly, they pressed "Y" (=> ISI decreased) on the response box. If they could not see it clearly, they pressed "N" (=> ISI increased). Subjects were given practice before the experimental trials and had to respond to both spatial frequencies of 2 and 12 c/d. The order of presentation for both conditions was counter-balanced and the mean visible persistence for each spatial frequency was recorded.

7.2.4 MEASURE 1d: Visible Persistence based on the Judgment of a Flicker (FLICK)

The experimental procedure is similar to that used in measure 1c. Subjects were presented with grating-blank-grating cycle repeated 10 times. They were instructed to report the presence or the absence of a flicker between the gratings. Vertical square wave gratings of 2 and 12 c/d were used. The initial ISIs set for the 2 c/d and 12 c/d gratings were 30 and 50 ms respectively.

7.2.5 MEASURE 1e: Flicker Fusion (CHAS)

Flicker fusion (CHAS) refers to the point at which a flickering stimulus is no longer perceived as periodic but shifts to continuous (Reber, 1985). It measures the minimum duration of a periodic stimulus required to perceive that stimulus as continuous. In this task, gratings of high (12 c/d: which should reflect sustained system functioning) and low (2 c/d: which should reflect transient system functioning) spatial frequencies were used. The stimulus duration was measured using the random staircase method.

Method

Subjects

Subjects who participated in the flicker sensitivity task also participated in this task.

Apparatus / Stimuli

Apparatus used were the same as that employed in the visible persistence tasks.

The stimulus was a "chequerboard" pattern resulted from alternation between vertical and horizontal square wave gratings. The spatial frequencies used were 2 and 12 c/d. The stimulus completely filled the 6.74 x 4.53 deg target field. The viewing distance was 129 cm and the space-average-luminance was 5 cd/m^2. The initial durations set for the 2 c/d and 12 c/d gratings were 30 and 50 ms respectively.

Vertical and horizontal square wave gratings were presented alternately via the tachistoscope controlled by an IBM compatible computer and C programs. On each trial, the vertical-horizontal grating cycle repeated for 3 sec. The duration of each grating was the dependent variable. The luminance was measured with a Tektronix J6523 one-degree narrow-angle luminance probe and was held constant at 5 cd/m^2 across all spatial frequency changes. Table 7-4 summarises the parameters used in this task.

Table 7-4: Parameters used in Flicker Fusion Task

Luminance	5 cd/m^2
Viewing	129 cm
	Binocular
Stimulus	Vertical Square Wave Chequerboard
Stimulus Size	6.74 x 4.53 deg target field
High Spatial Frequency	12 c/d
Low Spatial Frequency	2 c/d
Initial Stimulus Duration	30 ms for 2 c/d, 50 ms for 12 c/d
Dependent Variable	Stimulus Duration

Procedure

Subjects were seated at a distance of 129 cm from the display. Viewing was binocular throughout.

Each trial consisted of a "chequerboard" pattern resulting from the vertical-horizontal grating cycle which repeated for 3 sec. Subjects were instructed to report whether the "chequerboard" display was flickering or not. Thus, if they saw the pattern flickering, they pressed "Y" (=> duration decreased) on the response box. If they saw no flickering, they pressed "N" (=> duration increased). Subjects were given practice before the experimental trials and had to respond to both spatial frequencies of 2 and 12 c/d. The order of presentation for both conditions was counter-balanced and the mean stimulus duration for each spatial frequency was recorded.

7.3 Results

As most of the visual measures did not have a normal distribution and some of the measures had non-homogeneous variance making comparisons across tasks difficult, a log-transformation was performed on the data and all the statistical analyses were based on the log-transformed data[3]. The data were analysed using SAS statistical package in this thesis. The means and standard deviations of both the original and the log-transformed data are shown in Table 7-5.

[3] As shown in Table 7-5, the means and s.d. of the temporal processing measures varied in a wide range and violated the assumption of homogeneous variance in multivariate tests. Moreover, some measures (FSEN12, VTOJ7, BLAN12, FLICK2 and 12, and CHAS2) did not have a normal distribution and hence violated the assumptions of the above tests. Therefore, the data were log-transformed to suit the assumptions of the statistical model (Tabachnick & Fidell, 1989).

Table 7-5: Means and (s.d.) of the Visual Measures and their Log-transformed Data (N=91)

Task	Original		Log-transformed	
FSEN2	0.047[4]	(0.016)	-3.1	(0.3)
FSEN12	0.015	(0.003)	-4.24	(0.23)
VTOJ1	55.46	(23.05)	3.93	(0.41)
VTOJ7	171.62	(89.2)	5.04	(0.46)
BLAN2	189.31	(65.54)	5.17	(0.43)
BLAN12	282.61	(98.47)	5.59	(0.33)
FLICK2	6.69	(6.3)	1.56	(0.8)
FLICK12	15.69	(12.1)	2.44	(0.84)
CHAS2	16.29	(3.22)	2.77	(0.19)
CHAS12	23.93	(5.34)	3.15	(0.22)

N.B.: FSEN2, FSEN12: Flicker Sensitivity at 2 and 12 Hz respectively
VTOJ1, VTOJ7 (ms): Visual Temporal Order Judgment at 1 and 7 c/d respectively
BLAN2, BLAN12 (ms): Visible Persistence (based on the judgment of a blank) at 2 and 12 c/d respectively
FLICK2, FLICK12 (ms): Visible Persistence (based on the judgment of a flicker) at 2 and 12 c/d respectively
CHAS2, CHAS12 (ms): Flicker Fusion at 2 and 12 c/d respectively

7.3.1 Flicker Sensitivity (FSEN)

The mean contrast threshold at 12 Hz is significantly lower than that at 2 Hz ($t(90) = 39.18$, $p = 0.0001$). Hence, it confirms previous work (Martin & Lovegrove, 1987) showing that subjects are more sensitive to high temporal frequency stimuli than low temporal frequency stimuli.

7.3.2 Visual Temporal Order Judgment (VTOJ)

The mean SOA at 1 c/d is significantly lower than that at 7 c/d ($t(90) = 25.57$, $p = 0.0001$). Hence, it confirms previous findings that low spatial frequency gratings will result in shorter SOA than high spatial frequency gratings.

[4] An initial contrast threshold of 0.05 was chosen for FSEN2 because it was well-above subject's threshold in piloting. However, some subjects exhibited values higher than 0.05 in the experimental session and hence the mean threshold calculated (0.047) was close to the initial contrast.

7.3.3 Flicker Fusion (CHAS)

The mean stimulus duration at 2 c/d is significantly lower than that at 12 c/d ($t(90) = 22.74$, $p = 0.0001$). Hence it confirms previous findings (Smith et al, 1982) that flicker fusion threshold will increase with increasing spatial frequency.

7.3.4 Visible Persistence (based on the judgment of a blank and a flicker) (BLAN, FLICK)

A repeated measures ANOVA was performed on these two measures, using the task type as one factor and spatial frequency as the other factor. There is a main effect of Task type ($F(1,90) = 2160.95$, $p = 0.0001$), indicating that ISI based on the judgment of a blank is significantly longer than that based on the judgment of a flicker. This confirms previous work (Long & Sakitt, 1984) that visible persistence based on the judgment of a blank is longer than that based on the judgment of a flicker. There is a main effect of spatial frequency ($F(1,90) = 434.94$, $p = 0.0001$), confirming previous findings (Bowling et al, 1979) that visible persistence increases with increasing spatial frequency. There is also a significant Task x Spatial Frequency interaction ($F(1,90) = 62.42$, $p = 0.0001$), indicating that the BLAN condition, compared to the FLICK condition, has a larger increase in ISI as spatial frequency increases.

Thus, the results indicate that the visual measures used in this study are reliable because they replicated earlier findings.

7.3.5 Intercorrelations among the Visual Measures

Pearson correlation coefficients among the visual measures are shown in section 7.9.1. This will be discussed in that section.

7.3.6 Factor Analysis among the Visual Measures

In order to find out whether there is a common temporal processing mechanism underlying the various measures of visual temporal processing used, a principal components factor analysis with varimax rotation was performed on the visual measures. Four factors were extracted in the analysis. They are summarised in Table 7-6.

Table 7-6: Factor Analysis on the Visual Measures

	F1	F2	F3	F4	
FSEN2	-	-	-	0.84684	
FSEN12	-	-	-	0.83006	
VTOJ1	-	-	0.89486	-	
VTOJ7	-	-	0.84375	-	
BLAN2	-	0.89571	-	-	
BLAN12	-	0.83111	-	-	
FLICK2	0.74154	0.48361	-	-	
FLICK12	0.73173	0.4758	-	-	
CHAS2	0.86125	-	-	-	
CHAS12	0.87141	-	-	-	
Eigenvalue	3.601	1.635	1.381	1.163	Total = 7.78
Variance Explained	36.01%	16.35%	13.81%	11.63%	Total = 77.8%

N.B.: Loadings below |0.3| not shown

FSEN2, FSEN12: Flicker Sensitivity at 2 and 12 Hz respectively

VTOJ1, VTOJ7: Visual Temporal Order Judgment at 1 and 7 c/d respectively

BLAN2, BLAN12: Visible Persistence (based on the judgment of a blank) at 2 and 12 c/d respectively

FLICK2, FLICK12: Visible Persistence (based on the judgment of a flicker) at 2 and 12 c/d respectively

CHAS2, CHAS12: Flicker Fusion at 2 and 12 c/d respectively

From Table 7-6, four factors are extracted from the visual measures. Together, they account for 77.8% of the variance.

The first factor is weighted on by the visible persistence (based on the judgment of a flicker) and flicker fusion measures. It accounts for 36.01% of the variance explained. Presumably, the factor represents the ability to detect movement / flicker.

The second factor is weighted on by the visible persistence measures. It accounts for 16.35% of the variance explained. The factor represents visible persistence.

The third factor is weighted on by the visual temporal order judgment measures. It accounts for 13.81% of the variance explained. The factor represents visual temporal order judgment.

The fourth factor is weighted on by the flicker sensitivity measures. It accounts for 11.63% of the variance explained. The factor represents contrast sensitivity.

7.4 Stage 1 Discussion

Results indicate that the equipment and procedures used have successfully replicated earlier work, namely: 1) there is a strong spatial frequency effect in the visual temporal order judgment, flicker fusion and visible persistence tasks; 2) there is a strong temporal frequency effect in the flicker sensitivity task; 3) visible persistence based on the judgment of a blank is longer than that based on the judgment of a flicker.

As high and low temporal frequency / spatial frequency measures do not weight on different factors, this implicates that the high spatial frequency and low temporal frequency "sustained" stimuli tap into the functioning of temporal processing. Moreover, results are suggestive of a common mechanism dealing with temporal resolution and also add evidence for the sustained system involved in temporal tasks (e.g., see Schiller et al, 1990), or that the nature of the task is more significant than the stimulus parameters used. This will be further discussed in Chapter 10.

Results in the visible persistence tasks confirm Long and Sakitt (1984) that ISI based on the judgment of a blank is longer than that based on the judgment of a flicker. One interesting point is the significant interaction found in this study. Presumably, the magnitude of increase in ISI as spatial frequency increases is larger when the judgment is based on a blank. This may imply that the BLAN task is more effective than the FLICK task in discriminating various reading measures. Nonetheless, as the BLAN and FLICK measures loaded together on the visible persistence factor, this supports Long and Sakitt's (1984) notion that both tasks reflect the same process(es).

The four factors extracted from the factor analysis may indicate that: 1) there exists more than one temporal processing mechanism in vision; or 2) there exists one temporal processing mechanism in vision but that this mechanism has different components / levels responsible for different stimulus dimensions. At first, the multiple factors extracted may give an impression of multiple temporal processing mechanisms. However, some support for the second suggestion is the role of FLICK2 and FLICK12 in both factors 1 and 2. The overlapping of the FLICK measures in both movement / flicker detection and visible persistence factors may indicate cohesion among different components / levels within a common mechanism. The point is the cognitive-neurological approach can not always provide a precise delineation between different "working areas" of the brain because of the multiple connections in the working brain. In fact, morphologically, it is not uncommon to have an overlap among different parts of the brain during a particular task. Moreover, as the segregation of the two visual pathways becomes less definite in higher cortical levels, it is not unlikely to have a common mechanism or a "central executive" that controls all the information at the end. On the other hand, if we assume the first suggestion, then we have to assume each mechanism has its own "central executive". Then, factors involving multiple mechanisms will have multiple "central executives" directing. The point is: 1) this kind of processing may be uneconomical in terms of resourcing; and 2) it is more likely to end up with confusing communication and domineering problems among the mechanisms. Moreover, it is quite common for dyslexics and dysphasics to experience temporal processing difficulty in more than one modality. Most researchers find that dyslexics / dysphasics who are impaired in auditory temporal tasks may or may not be impaired in visual tasks but it is unusual to find dyslexics / dysphasics impaired in visual and not auditory temporal tasks (Farmer & Klein, 1993; Reed, 1989; Tallal & Piercy, 1973b: Bryden, 1972; Gould & Glencross, 1990). This gives credits to the second suggestion.

Presumably, if a "central executive" exists, it controls both sensory and cognitive information processing. Lower level information processing is more sensory whereas higher level information processing is more cognitive. As the information is passed up and analysed in higher levels, more cognitive and less sensory influence is involved. For instance, information processing in the lower level visual and auditory systems is more frequency-selective and hence more sensory whereas higher level visual and auditory systems respond more to abstract and hence more cognitive features (Sekuler & Blake, 1990). The issue of this "central executive" will be further discussed in Chapter 10.

Jaskowski (1991) argued that judging of successiveness is a prerequisite for TOJ. Gibson and Egeth (1994) also argued that TOJ, at least to some extent, reflects some perceptual / sensory processing. If this is the case, then fusion tasks should be more sensory and less cognitive than TOJ tasks. In addition, Nicolson and Fawcett (1993c) hypothesised the DAD in which a "central executive" may be defective and Frith (1992) also suggested the possibility of a defective central mechanism which results in impairment of both temporal and cognitive skills. The suggested temporal processing model is compatible with the results observed and the suggestions / findings of the above research. For example, the visible persistence factor (factor 2) can be regarded as more sensory whereas the TOJ factor (factor 3) can be regarded as more cognitive, and both factors may undergo a common mechanism. Moreover, this mechanism coordinates the involvement of the sustained and transient visual systems in temporal processing. Therefore, the visual measures used in this study are probably valid measures of the "low-level" transient and sustained visual systems and are also "inferential" measures of the "high-level" "central executive". It is unlikely for the "low-level" transient visual system to coordinate within the temporal framework even though it is largely involved in the tasks. This issue will be further discussed in Chapter 10.

Although the data are suggestive of a common mechanism in vision, the evidence to date is unclear. One way of testing this conclusion is to test the temporal processing measures in another modality and combine them with the visual measures. If those measures load with the visual measures, this gives credit to such a conclusion. Stage 2 is the extention of this suggestion. I will test the auditory measures. Then I will combine both visual and auditory measures to test the pansensory common mechanism hypothesis.

7.5 *STAGE 2: AUDITION*

The second stage of this thesis aimed to investigate the relationship between different temporal processing measures in audition. Tasks of auditory fusion and auditory temporal order judgment were administered. As noted in Phillips (1985), it is difficult to differentiate the transient and sustained auditory systems by simply varying stimulus duration. Short and long stimulus durations were used for both measures. So, 15 and 100 ms noise bursts were chosen for auditory fusion while 15, 75 and 200 ms tones were used for auditory TOJ. These measures will be compared and evaluated.

Hirsh (1959) and Hirsh and Sherrick (1961) found that while 2 to 3 ms is sufficient to separate two sounds (fusion), a longer time of about 20 ms is required to judge their order.

Similarly, Lowe and Campbell (1965) asked both aphasics (n=8) and controls (n=8) to perform a fusion task of two 15 ms 1000 Hz tones and to judge the order of a 400 and 2200 Hz tones. Results showed that while the two groups did not differ in auditory fusion, aphasics took longer time to judge the tone order. In addition, the fusion task yielded a separation time of 18 and 30 ms in both groups whereas the temporal order judgment task yielded a separation time of 36 and 357 ms. This is consistent with Hirsh's (1959) and Hirsh and Sherrick's (1961) results.

Hirsh and Sherrick (1961) argued that perception of simultaneity is not sufficient for correct order identification. Therefore, the mechanism for successiveness judgment is different from that for order discrimination. In fact, Jaskowski (1991) proposed a two-stage model for order discrimination. The first stage is to recognise whether or not the stimuli are successive. The second is to determine the order of the stimuli.

To be consistent with previous findings, the auditory measures should show that:

1) TOJ task will have a longer separation time than fusion task.

2) It is of interest to see if there is an effect of stimulus duration within each task.

7.5.1 MEASURE 2a: Auditory Fusion (AFUS)

Auditory fusion (AFUS) refers to the "ability to distinguish paired acoustic events from single acoustic events" (Davis & McCroskey, 1980, p.75). It measures the smallest time interval (ISI) required to distinguish a paired burst of white noise from a single continuous burst of white noise. In this task, noise bursts of 15 and 100 ms were used. The ISI was measured using Wetherill and Levitt's (1965) procedure with a two-alternative forced choice paradigm. Eight reversals were used in this task.

Method

Subjects

Subjects who participated in Measure 1 also participated in this task.

Apparatus / Stimuli

Apparatus included: 1) an IBM 386 compatible computer; 2) Realistic STA-76 IC/FET AM/FM Stereo receiver; 3) National Semiconductor MM5837 digital noise source; 4) Sony MDR CD250 headphones; and 5) a response box.

Stimuli were a single continuous burst of white noise or paired bursts of white noise separated by a variable ISI. The duration of the paired bursts of noise was 15 and 100 ms in different conditions. The duration of the single continuous burst of noise was the sum of the duration of the paired bursts plus the ISI. The initial ISI set between the two bursts of noise was 75 ms. The intensity level was 60 dB.

The computer was controlled by a 48 channel I/O card with an intel 8254 hardware timer chip. This controlled the timing of stimulus presentation.

Stimuli were generated by a National Semiconductor MM5837 digital noise source. The decibel level was set by placing a 4176 prepolarised microphone cartridge in a 4153 artificial ear and a 2235 Digital sound level meter screwed in the side of the ear. The sides of Sony MDR CD250 headphones were placed on top of the ear and the intensity level was adjusted to 60 dB. The cartridge, ear and the sound level meter were manufactured by Brüel and Kjær. The program for the auditory fusion test was written in C and the hardware timing routines were written in assembler interfaced to C. The apparatus was set up so that the computer was placed in an adjacent room to ensure that noise from the computer fan did not disturb the subject. The parameters used in this task are shown in Table 7-7.

Table 7-7: Parameters used in Auditory Fusion Task

Hearing	Binaural
Stimulus	White Noise
Intensity	60 dB
Stimulus Duration	15 and 100 ms
Initial ISI	75 ms
Dependent Variable	ISI

Procedure

On each trial, subjects heard either two small bursts of noise followed by a single burst of noise, or vice versa. Their task was to indicate in which interval the paired bursts of noise appeared. If they thought the paired bursts of noise appeared in the first interval, subjects pressed "1" on the response box. If they thought the paired bursts of noise appeared in the second interval, they pressed "2" on the response box. The order in which the single burst or the paired bursts of noise was presented first was randomised. Subjects were given practice before the experimental trials and had to respond to noise bursts of 15 and 100 ms. The order of presentation for both conditions was counter-balanced. The mean ISI to distinguish the paired bursts of noise was recorded.

7.5.2 MEASURE 2b: Auditory Temporal Order Judgment (ATOJ)

Auditory temporal order judgment (ATOJ) refers to the ability to locate the order of specific patterns presented one after the other. It measures the minimum stimulus-onset-asynchrony (SOA) required to determine the order of the two stimuli (Campbell, 1992). In this task, tones of low (400 Hz) and high (2200 Hz) frequencies were used and the duration of the tones were 15, 75 and 200 ms respectively. The SOA was measured using Wetherill and Levitt's (1965) procedure with a two-alternative forced choice paradigm. Eight reversals were used in the task.

Method

Subjects

Subjects who participated in Measure 1 also participated in this task.

Apparatus / Stimuli

Apparatus used was similar to that used in the auditory fusion except that the tones were generated by a dual tone generator instead of the National Semiconductor MM5837 digital noise source.

Stimuli were a pair of sine wave tones: a high tone (2200 Hz) and a low tone (400 Hz). The tones had a rise / fall time of 5 ms. The initial SOA set between the tones was 350 ms. The intensity of the tones was 60 dB. The duration of the second tone was 15, 75 and 200 ms respectively. The duration of the first was equal to the sum of the duration of the second plus the SOA.

The stimuli were generated by two Novatech DDS3 Digital Synthesiser boards in the dual tone generator. To ramp the tones, the tones were amplitude modulated by a voltage source from a Digital to Analog board connected to the computer. The set up was similar to that used in the auditory fusion. The parameters used in this task are summarised in Table 7-8.

Table 7-8: Parameters used in Auditory Temporal Order Judgment Task

Hearing	Binaural
Stimulus	Sine Wave Tones
Stimulus Frequency	400, 2200 Hz
Rise / Fall Time	5 ms
Intensity	60 dB
Stimulus Duration of Last Tone	15, 75 and 200 ms
Initial SOA	350 ms
Dependent Variable	SOA

Procedure

On each trial, either the high tone was presented before the low tone or the low tone was presented before the high tone. One of the tones was presented first with the onset of the second occurring at a varying SOA. The offset of both tones occurred simultaneously. Thus, the duration of the second tone was 15, 75 or 200 ms while that of the first was equal to the sum of the duration of the second plus the SOA. The subject's task was to locate whether the high tone or the low tone was presented first. If they thought the high tone was presented first, they pressed "H" on the response box. If they thought the low tone was presented first, they pressed "L" on the response box. The order of presentation of the tones was randomised. Subjects were given practice before the experimental trials and had to respond to stimulus durations of 15, 75 and 200 ms. The order of presentation for the three conditions was counter-balanced. The mean SOA to distinguish the tones was recorded.

7.6 *Results*

A log-transformation was performed on the data in order to achieve normal distribution and homogeneous variance for better comparison. All statistical analyses were based on the log-transformed data. The means and standard deviations of the original and the log-transformed data are shown in Table 7-9.

Table 7-9: Means and (s.d.) of the Auditory Measures and their Log-transformed Data (N=91)

Task	Original		Log-transformed	
AFUS15	4.002	(2.22)	1.29	(0.39)
AFUS100	3.014	(0.66)	1.08	(0.19)
ATOJ15	65	(64.8)	3.84	(0.8)
ATOJ75	87.6	(55.79)	4.28	(0.64)
ATOJ200	128.94	(107.13)	4.65	(0.62)
AFUSM	3.51	(1.36)	1.19	(0.26)
ATOJM	93.84	(64.29)	4.26	(0.6)
AUDDIF	90.34	(63.89)	3.07	(0.56)

N.B.: AFUS15, AFUS100 (ms): Auditory Fusion at 15 and 100 ms respectively
ATOJ15, ATOJ75, ATOJ200 (ms): Auditory Temporal Order Judgment at 15, 75 and 200 ms respectively
AFUSM (ms): Mean of the Auditory Fusion measures
ATOJM (ms): Mean of the Auditory Temporal Order Judgment measures
AUDDIF (ms): Difference between Auditory Fusion and Auditory Temporal Order Judgment

A repeated measures ANOVA was performed on the auditory fusion and auditory temporal order judgment measures. As one of the aims of this study is to find out whether there is any difference among the two auditory fusion measures, and among the three auditory temporal order judgment measures, four a priori contrasts were set. This maximises the efficiency for comparison without the need to correct for the 0.05 α-level (Brown, personal communication, 1993). The four contrasts were: 1) AFUS15 vs AFUS100; 2) ATOJ15 vs ATOJ75; 3) ATOJ15 vs ATOJ200; and 4) ATOJ75 vs ATOJ200. The number beside the task denotes the stimulus duration.

The repeated measures ANOVA showed a significant within-subject effect among the five auditory measures ($F(4,360) = 1385.93$, $p = 0.0001$). The a priori contrasts showed that the ISI of AFUS100 is significantly shorter than that of AFUS15 ($F(1,90) = 38.37$, $p = 0.0001$). The SOA of: 1) ATOJ15 is significantly shorter than that of ATOJ75 ($F(1,90) = 45.61$, $p = 0.0001$); 2) ATOJ15 is significantly shorter than that of ATOJ200 ($F(1,90) = 188.38$, $p = 0.0001$); 3) ATOJ75 is significantly shorter than that of ATOJ200 ($F(1,90) = 41.73$, $p = 0.0001$).

The separation times of the auditory fusion measures are significantly shorter than that of the auditory TOJ ($t(90) = 52.13$, $p = 0.0001$). This confirms Hirsh's (1959) and Hirsh and Sherrick's (1961) results.

7.6.1 Intercorrelations among the Auditory Measures

Pearson correlation coefficients among the auditory measures are shown in section 7.9.1. This will be discussed in that section.

7.6.2 Factor Analysis among the Auditory Measures

In order to find out whether there is a common temporal processing mechanism underlying the various measures of auditory temporal processing used, a principal components factor analysis with varimax rotation was performed on the auditory measures. Two factors were extracted in the analysis. They are summarised in Table 7-10.

Table 7-10: Factor Analysis on the Auditory Measures

	F1	F2	
AFUS15	-	0.8358	
AFUS100	-	0.89496	
ATOJ15	0.89355	-	
ATOJ75	0.81316	-	
ATOJ200	0.8824	-	
Eigenvalue	2.732	1.162	Total = 3.894
Variance Explained	54.63%	23.25%	Total = 77.88%

Table 7-10 (cont.)

N.B.: Loadings below |0.3| not shown

AFUS15, AFUS100: Auditory Fusion at 15 and 100 ms respectively

ATOJ15, ATOJ75, ATOJ200: Auditory Temporal Order Judgment at 15, 75 and 200 ms respectively

From Table 7-10, two factors are extracted from the auditory measures. Together, they account for 77.88% of the variance.

The first factor is weighted on by the auditory TOJ measures. It accounts for 54.63% of the variance explained. This factor represents auditory temporal order judgment.

The second factor is weighted on by the auditory fusion measures. It accounts for 23.25% of the variance explained. The factor represents auditory fusion.

7.7 *Stage 2 Discussion*

Results indicate that the equipment and procedures used have successfully replicated earlier work because auditory temporal order judgment exhibits longer separation time than auditory fusion. Additionally, the results are consistent with Hirsh and Sherrick's (1961) and Lowe and Campbell's (1965) findings. However, although the fusion data is consistent with Hirsh and Sherrick (1961), the TOJ data is much longer than theirs. One explanation is that Hirsh and Sherrick (1961) used tones of 666 and 278 Hz while I used tones of 400 and 2200 Hz. It may be that the SOA is frequency-dependent. On the other hand, the fusion and TOJ thresholds of Lowe and Campbell (1965) is longer than mine. One reason is that Lowe and Campbell (1965) used children as subjects. It is not surprising to find that the motor and cognitive skills of children are less well developed than that of adults and hence they exhibit longer reaction times. Secondly, Lowe and Campbell (1965) used 1000 Hz tones for the fusion task while I used white noise.

Interestingly, visible persistence decreases as stimulus duration increases (Efron, 1970). This is known as the "inverse duration effect" and is normally interpreted as a reflection of sensory mechanisms rather than higher level mechanisms (Coltheart, 1980; Di Lollo, Hogben & Dixon, 1994). An analogue version is found in the auditory fusion tasks which show that the ISI of 15 ms noise burst is longer than that of 100 ms noise burst. On the contrary, an opposite trend is observed in auditory TOJ: the auditory SOA increases as the stimulus duration of the second tone increases. This may imply the increasing cognitive demands required by the task, as it is assumed that TOJ is a higher order task than fusion which involves more cognitive and less sensory processing. It may be that long tones produce greater interference than short tones and hence the task is more difficult.

Two factors were extracted from the factor analysis: auditory fusion and auditory temporal order judgment. This supports Hirsh and Sherrick (1961) and Jaskowski (1991) argument that the mechanism involved in fusion is different from that in temporal order judgment. Nevertheless, it is still unknown whether the fusion mechanism is a prerequisite for temporal order judgment. As with the visual measures, the results make it impossible to conclude whether there exists a common auditory temporal processing mechanism which consists of a fusion and a temporal order judgment component / level, or there exists independent fusion and temporal order judgment mechanisms. Therefore, as suggested in 7.4, Stage 3 aimed to test this possibility.

7.8 STAGE 3: VISION AND AUDITION

Stage 3 aimed to test: 1) whether there exists a common mechanism which controls temporal processing in both vision and audition; and 2) if 1) is true, whether there exists different components / levels for different stimulus dimensions. Therefore, the visual and auditory measures in Stages 1 and 2 will be combined and analysed using Pearson correlation coefficients and factor analysis. The rationale is that if the visual and auditory measures load together, I may conclude that there is a common temporal processing mechanism in both vision and audition. Consequently, I can conclude a common temporal processing mechanism in audition, an unanswered question in Stage 2. Secondly, from the results in Stage 1, it is expected that this mechanism, like that in vision, consists of different components / levels for different stimulus dimensions.

7.9 Results

As the data were already log-transformed in vision and audition, all the statistical analyses were based on the log-transformed data.

7.9.1 Pearson Correlation

Pearson correlation coefficients among the visual and the auditory measures are shown in Table 7-11.

Table 7-11: Correlation Matrix of the Log-transformed Data of the Visual and Auditory Experiments (N=91)

	FSEN2	FSEN12	VTOJ1	VTOJ7	BLAN2	BLAN12	FLICK2	FLICK12	CHAS2	CHAS12	AFUS15	AFUS100	ATOJ15	ATOJ75	ATOJ200
FSEN2	1.0000														
FSEN12	0.4729**	1.0000													
VTOJ1	0.0742	0.1226	1.0000												
VTOJ7	0.2111*	0.1839	0.5484**	1.0000											
BLAN2	0.1434	0.2123*	0.0527	0.0954	1.0000										
BLAN12	0.1926	0.2710**	0.1970	0.2419*	0.6729**	1.0000									
FLICK2	0.2214*	0.2385*	0.0153	0.2005	0.3830**	0.4601**	1.0000								
FLICK12	0.1775	0.2297*	0.0089	0.2028	0.3473**	0.4551**	0.8286**	1.0000							
CHAS2	0.2698**	0.0613	0.0600	0.1901	0.0837	0.2435*	0.5461**	0.5119**	1.0000						
CHAS12	0.2622*	0.1147	-0.0174	0.1453	0.0211	0.1771	0.5279**	0.5175**	0.7037**	1.0000					
AFUS15	0.3266**	0.1759	0.2365*	0.2588*	0.1301	0.2601*	0.1644	0.0652	0.1470	0.1274	1.0000				
AFUS100	0.3224**	0.1900	0.3308**	0.2333*	0.1749	0.2508*	0.1800	0.0793	0.1238	0.1458	0.5571**	1.0000			
ATOJ15	0.2196*	0.0460	0.3107**	0.3224**	-0.0032	-0.0031	0.1363	0.0147	0.2354*	0.0879	0.3208**	0.2133*	1.0000		
ATOJ75	0.2182*	-0.0116	0.4229**	0.2954**	0.1196	0.1198	0.1236	0.0771	0.2852**	0.2274*	0.3312**	0.3166**	0.6538**	1.0000	
ATOJ200	0.2538*	0.0881	0.3528**	0.3980**	-0.0068	0.0646	0.1248	0.0712	0.2476*	0.1151	0.3234**	0.1882	0.7122**	0.6134**	1.0000

*p <.05
**p <.01

N.B.: FSEN2, FSEN12: Flicker Sensitivity at 2 and 12 Hz respectively
VTOJ1, VTOJ7: Visual Temporal Order Judgment at 1 and 7 c/d respectively
BLAN2, BLAN12: Visible Persistence (based on the judgment of a blank) at 2 and 12 c/d respectively
FLICK2, FLICK12: Visible Persistence (based on the judgment of a flicker) at 2 and 12 c/d respectively
CHAS2, CHAS12: Flicker Fusion at 2 and 12 c/d respectively
AFUS15, AFUS100: Auditory Fusion at 15 and 100 ms respectively
ATOJ15, ATOJ75, ATOJ200: Auditory Temporal Order Judgment at 15, 75 and 200 ms respectively

Considering the significant correlations in Table 7-11, FSEN2 correlates with FSEN12 (r = 0.4729), VTOJ7 (r = 0.2111), FLICK2 (r = 0.2214), the flicker fusion measures: CHAS2 (r = 0.2698), CHAS12 (r = 0.2622), and all auditory measures: AFUS15 (r = 0.3266), AFUS100 (r = 0.3224), ATOJ15 (r = 0.2196), ATOJ75 (r = 0.2182) and ATOJ200 (r = 0.2538). The positive correlations among the sensory measures indicate that at low temporal frequency, higher contrast threshold is related to longer SOAs, ISIs, and flicker fusion thresholds. Hence, higher contrast thresholds may relate to poorer timing precision.

FSEN12 correlates significantly with the visible persistence measures: BLAN2 (r = 0.2123), BLAN12 (r = 0.271), FLICK2 (r = 0.2385) and FLICK12 (r = 0.2297). Thus, the high temporal frequency variable is positively related to visible persistence and that higher contrast threshold is related to longer visible persistence.

VTOJ1 strongly correlates with VTOJ7 (r = 0.5484) and correlates moderately with the auditory measures: AFUS15 (r = 0.2365), AFUS100 (r = 0.3308), ATOJ15 (r = 0.3107), ATOJ75 (r = 0.4229) and ATOJ200 (r = 0.3528). Thus, the low spatial frequency variable is positively related to the auditory measures and the longer SOA is related to weaker auditory temporal resolution.

VTOJ7 correlates significantly with BLAN12 (r = 0.2419) and the auditory measures: AFUS15 (r = 0.2588), AFUS100 (r = 0.2333), ATOJ15 (r = 0.3224), ATOJ75 (r = 0.2954) and ATOJ200 (r = 0.398). Similarly, the positive correlations indicate that at high spatial frequency, longer SOAs are related to longer visible persistence and weaker auditory temporal resolution.

BLAN2 strongly correlates with BLAN12 (r = 0.6729) and correlates moderately with other visible persistence measures: FLICK2 (r = 0.383) and FLICK12 (r = 0.3473). It is not surprising to have such correlations because they are all visible persistence measures and they load on the same factor.

BLAN12 correlates significantly with FLICK2 (r = 0.4601), FLICK12 (r = 0.4551), CHAS2 (r = 0.2435), AFUS15 (r = 0.2601) and AFUS100 (r = 0.2508). So, at high spatial frequency, longer visible persistence is related to higher flicker and auditory fusion thresholds.

FLICK2 strongly correlates with FLICK12 (r = 0.8286), CHAS2 (r = 0.5461) and CHAS12 (r = 0.5279). FLICK12 strongly correlates with CHAS2 (r = 0.5119) and CHAS12 (r = 0.5175). The positive correlations indicate that longer ISI in visible persistence is related to high flicker fusion thresholds. Moreover, it is not surprising for these correlated measures because they all deal with flickering stimuli.

CHAS2 strongly correlates with CHAS12 (r = 0.7037) and significantly correlates with the auditory temporal order judgment measures: ATOJ15 (r = 0.2354), ATOJ75 (r = 0.2852) and ATOJ200 (r = 0.2476). The positive correlations indicate that higher flicker fusion threshold at low spatial frequency is related to longer auditory SOAs.

On the other hand, CHAS12 significantly correlates with ATOJ75 (r = 0.2274) This indicates that higher flicker fusion threshold at high spatial frequency is related to longer auditory SOAs.

AFUS15 strongly correlates with AFUS100 (r = 0.5571) and correlates moderately with ATOJ15 (r = 0.3208), ATOJ75 (r = 0.3312) and ATOJ200 (r = 0.3234).

AFUS100 significantly correlates with ATOJ15 (r = 0.2133) and ATOJ75 (r = 0.3166). ATOJ15 strongly correlates with ATOJ75 (r = 0.6538) and ATOJ200 (r = 0.7122). ATOJ75 strongly correlates with ATOJ200 (r = 0.6134). As the auditory measures are more likely to correlate with each other, it is suspected that auditory fusion and auditory temporal order judgment share some common operating mechanism.

7.9.2 Factor Analysis among the Visual and Auditory Measures

A principal components factor analysis with varimax rotation was performed on the sensory measures. Five factors were extracted in the analysis. They are summarised in Table 7-12.

Table 7-12: Factor Analysis on the Sensory Measures

	F1	F2	F3	F4	F5	
FSEN2	-	-	-	0.43882	0.66183	
FSEN12	-	-	-	-	0.85088	
VTOJ1	-	0.73807	-	-	-	
VTOJ7	-	0.70712	-	-	0.34716	
BLAN2	-	-	0.84369	-	-	
BLAN12	-	-	0.83561	-	-	
FLICK2	0.75355	-	0.45171	-	-	
FLICK12	0.74275	-	0.45873	-	-	
CHAS2	0.84266	-	-	-	-	
CHAS12	0.84936	-	-	-	-	
AFUS15	-	-	-	0.77567	-	
AFUS100	-	-	-	0.74007	-	
ATOJ15	-	0.72995	-	0.32272	-	
ATOJ75	-	0.69767	-	0.40019	-	
ATOJ200	-	0.76952	-	-	-	
Eigenvalue	4.397	2.557	1.679	1.241	1.006	Total = 10.88
Variance Explained	29.31%	17.05%	11.2%	8.27%	6.71%	Total = 72.53%

N.B.: Loadings below |0.3| not shown

FSEN2, FSEN12: Flicker Sensitivity at 2 and 12 Hz respectively

VTOJ1, VTOJ7: Visual Temporal Order Judgment at 1 and 7 c/d respectively

BLAN2, BLAN12: Visible Persistence (based on the judgment of a blank) at 2 and 12 c/d respectively

FLICK2, FLICK12: Visible Persistence (based on the judgment of a flicker) at 2 and 12 c/d respectively

CHAS2, CHAS12: Flicker Fusion at 2 and 12 c/d respectively

AFUS15, AFUS100: Auditory Fusion at 15 and 100 ms respectively

ATOJ15, ATOJ75, ATOJ200: Auditory Temporal Order Judgment at 15, 75 and 200 ms respectively

From Table 7-12, five factors are extracted from the visual and auditory measures. Together, they account for 72.53% of the variance.

The first factor is weighted on by the visible persistence (based on the judgment of a flicker) and flicker fusion measures. It accounts for 29.31% of the variance explained. Presumably, this factor represents the ability to detect movement / flicker. This factor is equivalent to factor 1 in Stage 1.

The second factor is weighted on by the visual and auditory temporal order judgment measures. It accounts for 17.05% of the variance explained. The factor is a general temporal order judgment factor. Moreover, as both modalities load together, it is likely that the temporal order judgment in both modalities involves a common mechanism. Thus, the hypothesis for a common temporal processing mechanism across the two modalities is supported with TOJs.

The third factor is weighted on by the visible persistence measures. It accounts for 11.2% of the variance explained. The factor represents visible persistence and is equivalent to factor 2 of Stage 1.

The fourth factor is weighted on by flicker sensitivity at 2 Hz, the auditory fusion and auditory temporal order judgment measures at 15 and 75 ms. It accounts for 8.27% of the variance explained. As the auditory fusion and TOJ measures load together, it is supportive of a common auditory temporal processing mechanism. Moreover, as the visual and auditory measures load together, it also supports the involvement of a common mechanism across modalities. Furthermore, the loading of a low temporal frequency measure (FSEN2) on this factor makes the interpretation of this factor difficult. If FSEN12, instead of FSEN2, loaded on this factor, then this factor could be interpreted as temporal precision which deals with short duration stimuli.

The fifth factor is weighted on by the flicker sensitivity measures and visual temporal order judgment at 7 c/d. It accounts for 6.71% of the variance explained. Although VTOJ7 loads on the same factor, the factor loading is relatively small compared to FSEN measures. Consequently, it indicates that this factor may represent contrast sensitivity.

7.10 Stage 3 Discussion

Since the visual and auditory measures load on the temporal order judgment factor (factor 2), and flicker sensitivity at 2 Hz loads with the auditory fusion and auditory temporal order judgment measures (factor 4), the results are suggestive of the involvement of a common temporal processing mechanism across the visual and auditory modalities. Moreover, as the auditory fusion and TOJ measures load together in factor 4, the results are also suggestive of a common temporal processing mechanism for audition, an unanswered question in Stage 2.

Similar to the results in Stage 1, several factors have been extracted from the sensory measures. This may indicate that the transmodal temporal processing mechanism has different components / levels responsible for different stimulus dimensions. In fact, some of the factors extracted in Stage 1 overlap with those in Stage 3, namely: the movement / flicker detection ability and the visible persistence factor.

Since the auditory fusion measures load with the auditory temporal order judgment measures in factor 4, the result is suggestive of auditory fusion being a prerequisite for auditory temporal order judgment. This is supportive of Hirsh and Sherrick's (1961) and Jaskowski's (1991) argument.

Similar to Stage 1, the high and low temporal frequency / spatial frequency stimuli load on the same factors. This implicates the involvement of the sustained system in temporal processing and also a higher level temporal processing mechanism which coordinates the two systems within the temporal framework, an issue discussed in 7.4.

In line with Stage 1, the TOJ factor (factor 2) may indicate a "higher-cognitive" operating level whereas the visible persistence factor (factor 3) may indicate a "lower-sensory" operating level. Evidence for a "more central" TOJ level can be obtained from May, Martin, MacCana and Lovegrove (1988a) and Burr (1983) who demonstrated that while contrast, intensity and spatial frequency strongly affected temporal processing measures like reaction time and visible persistence, these variables "did not result in a shift in the point of subjective simultaneity" (May et al, 1988a, p.293) in TOJ.

Due to equipment constraints and the availability of subjects, subject recruitment and data collection were carried out over a period of 2 years. Subjects recruited in the first year (about half of the total) were given the visual tests first followed by the auditory tests whereas subjects recruited in the second year were given the auditory tests first followed by the visual tests. Within each session, the order of the tests and the order within each test was counterbalanced. Further analysis showed no effect of the time course on the temporal processing measures (see Appendix C). This ensures the validity of the results due to the merging of data.

7.11 *Summary and Conclusion*

This study aimed to test the possibility of whether there is a common sensory temporal processing mechanism operating in vision, in audition and across both modalities. The study consists of three stages.

Stage 1 tested the above hypothesis in vision. Tasks of flicker sensitivity, temporal order judgment, visible persistence and flicker fusion were administered. Apart from finding the significant spatial frequency or temporal frequency effect on individual task, results are suggestive of the hypothesis of a common mechanism, as there is an overlap between the visible persistence and flicker fusion tasks. Nonetheless, it is likely that this mechanism may have different components / levels responsible for different stimulus dimensions.

One of the aims in Stage 1 was to test whether the "sustained" measures tap into the functioning of temporal processing, or do they absolutely tap into the functioning of the sustained system irrespective of the temporal nature of the tasks. In other words, the study aimed to find whether the transient and sustained visual systems can be differentiated given the framework of various temporal tasks. Factor analysis showed that both high and low temporal frequency / spatial frequency stimuli load together on the same factor. Results confirm the involvement of the sustained visual system in temporal processing and, moreover, are suggestive of a common mechanism dealing with temporal resolution. On the other hand, the results may also indicate that the nature of the task is more significant than the stimulus parameters used. This will be further discussed in Chapter 10.

Stage 2 tested the common temporal processing mechanism hypothesis in audition. In addition, it also aimed at determining if the separation time in auditory fusion is shorter than that in auditory temporal order judgment. Results show that fusion tasks exhibit shorter separation time than temporal order judgment tasks. Moreover, consistent with Hirsh and Sherrick's (1961) and Jaskowski's (1991) argument, the mechanism operating on auditory fusion is different from that operating on temporal order judgment. However, it is unknown whether auditory fusion is a prerequisite for temporal order judgment and whether they belong to a common mechanism.

Therefore, Stage 3 aimed to test whether there is a transmodal common sensory temporal processing mechanism. Results show: 1) the possibility for the existence of a common transmodal temporal processing mechanism, as the visual and auditory measures load together on the temporal order judgment factor and factor 4; 2) factor 4 shows that both auditory fusion and TOJ load together and that they are operated by a common auditory temporal processing mechanism. In addition, fusion may be a prerequisite for TOJ; 3) some of the visual factors found in Stage 1 overlap with those in Stage 3; and 4) similar to Stage 1, the transmodal temporal processing mechanism has different components / levels responsible for different stimulus dimensions.

In conclusion, some results of this study are suggestive of a common temporal processing mechanism operating in both vision and audition. Moreover, this mechanism is likely to be the higher-order "central executive" which consists of different components / levels responsible for different stimulus dimensions. Some levels, for example, indicated by the TOJ factors, are more cognitive whereas others, for example, indicated by the visible persistence / gap detection factors, are more sensory. The influence of cognitive component becomes more relevant when proceeding to higher levels of processing. The issue of this "central executive" will be further elaborated in

Chapter 10. In the next chapter, I will test the relationship between the sensory measures and various reading measures.

Chapter 8: Study 2

The Effect of Temporal Processing on Irregular and Nonsense Words, and the Role of the Transient and Sustained Visual Systems in Various Text Presentation

8.1 Introduction

Study 1 aimed at investigating whether there is evidence for a generalised pansensory mechanism involved in processing sensory information as hypothesised by Miller and Tallal (1995), Galaburda et al (1985, 1994), Farmer and Klein (1995) and Stein (1993). Although Study 1 showed some independent visual and auditory factors, other factors are supportive of a common temporal processing mechanism in vision, audition and across both modalities. As visual and auditory temporal processing is related to reading and language performance (Tallal et al, 1985a; Lovegrove et al, 1989), this study aimed to find out the relationship between visual and auditory temporal processing and various reading measures.

As stressed in Chapter 7, although the temporal processing measures reflect the function of a common mechanism, this mechanism is likely to be the "higher-order" "central executive" which coordinates the "lower-level" transient and sustained visual subsystems. Therefore, relative to the reading measures, the visual measures should be adequate measures of the "low-level" transient and sustained visual systems.

As stated in Chapter 5, Coltheart's (1978) model consists of two routes: a direct lexical or visual route responsible for reading irregular words and an indirect phonological or GPC route responsible for reading nonsense words.

According to Boder and Jarrico (1982), there are three subtypes of dyslexics: dysphonetics, dyseidetics and mixed. Dysphonetic dyslexics "have difficulties with grapheme to phoneme translation and have to rely on their sight vocabulary for word recognition" (Licht, 1994, p.42). In this case, dysphonetics should have the GPC and not the visual route impaired. Consequently, they should have difficulties reading nonsense words and not irregular words. Dysphonetics largely overlap with Licht's (1988) L-type dyslexics and Van der Leij's (1983) "guessers". By contrast, dyseidetic dyslexics "have problems in building a sight vocabulary, and tend to use an analytical spelling strategy" (Licht, 1994, p.42). In this case, dyseidetics should have the visual and not the GPC route impaired. Consequently, they should have difficulties reading irregular words and not nonsense words. Dyseidetics largely overlap with Licht's (1988) P-type dyslexics and Van der Leij's (1983) "spellers". Mixed dyslexics have problems with both reading strategies. Therefore, they have problems in both visual and GPC routes. Consequently, they should have difficulties reading both irregular words and nonsense words.

While there is considerable debate over Boder's dyslexic subtypes (see Watson & Willows, 1995), the recent demonstration by Borsting et al (1996) and Ridder et al (in press) that only some of Boder's subtypes demonstrate transient system deficits makes her subtypes useful for this study[5].

[5] The justification for extending the results of dyslexics to normal readers has already been explained in Chapter 6 and will be further discussed in Chapter 10.

Farmer and Klein (1995) suggested that a temporal processing deficit might affect "either the auditory or the visual pathway, or both" (p.484). Subjects who have an auditory temporal processing deficit but do not appear to have a visual one would likely present as Boder's dysphonetic dyslexics. Conversely, "subjects who have a visual temporal processing deficit but do not appear to have an auditory one would likely present as Boder's dyseidetic dyslexics" (p.485). Where the temporal processing deficit affects both pathways, the pattern would present as mixed (after Farmer & Klein, 1995).

So, the first aim of this study was to investigate a version of Farmer and Klein's (1995) suggestion that the dyslexic subtypes are "modal-specific". If visual temporal processing deficit is related to dyseidetic dyslexia, then there should be a relationship between the visual temporal processing measures and irregular words. Conversely, if an auditory temporal processing deficit is related to dysphonetic dyslexia, there should be a relationship between the auditory temporal processing measures and nonsense words. So, in this study, subjects will read both irregular words and nonsense words. The relationship between the types of words and different temporal processing measures will be examined.

The second aim of this study was to investigate whether the transient and sustained visual measures are differentiated in terms of different modes of text presentation as hypothesised by Lovegrove and colleagues (e.g., Hill & Lovegrove, 1992). According to Breitmeyer (1980, 1992, 1993a,b), saccadic suppression results from the inhibition which the transient system exerts on the activity of the sustained system. Consequently, this suppression reduces the visual sensitivity during saccades (Matin, 1974) and ensures that the pattern information carried by the sustained system from a prior fixation will not be carried over and mask the pattern information picked up by the same system during successive fixations (Breitmeyer, 1993a,b). Thus, the transient system deficit hypothesised by Lovegrove et al (1986a) may weaken the suppression and result in a partial temporal overlap of successive frames of information (Breitmeyer, 1993b). As discussed in Chapter 2, though Ross et al (1996) had an opposite view on the function of the two visual systems during saccades, they confirmed that saccadic suppression was mediated by the transient system. Accordingly, Ross et al (1996) is not necessarily incompatible with the function of the two visual systems in reading. In fact, from the spatiotemporal properties of the transient and sustained visual systems, it is hypothesised that the sustained system mainly extracts details during each fixation (Livingstone & Hubel, 1988) while the transient system mainly guides eye movement and integrates information across fixation (Lovegrove, 1991).

Hence, it follows that if only one word is presented each time, primarily the sustained system would be involved in reading because no saccade is required. An example of this type of text presentation is the rapid serial visual presentation (RSVP) (Juola et al, 1995; Bourne et al, 1986). On the other hand, if several words are presented each time, this "line" presentation will resemble that of ordinary text presentation. Subjects have to saccade from one word to another during reading and hence the transient visual system is more heavily involved. Actually, indirect evidence regarding the involvement of the transient system deficit in ordinary text presentation in dyslexics has been provided by Hill and Lovegrove (1992) who showed that dyslexics were impaired only in the regular text condition - a "condition in which integration of central and peripheral information was required" (Farmer & Klein, 1995, p.484), and not in sequential spatial presentation or RSVP.

Therefore, in this study, normal subjects will read both nonsense words and irregular words presented in two different text presentation modes: single / word condition and continuous / line condition. With reference to the spatiotemporal properties of the transient and sustained visual systems (Baro et al, 1996), it is expected that high spatial frequency and / or low temporal frequency visual measures will be more related to the single word presentation condition, a condition which needs the sustained system primarily. On the other hand, high temporal frequency and / or low spatial frequency visual measures should be more related to the continuous / line condition, a condition which needs both the transient and sustained systems. Moreover, since I am testing the visual measures, the differential effect may be more obvious in irregular words than in nonsense words, as suggested by Farmer and Klein (1995).

In overview, subjects will undergo the same experimental procedure as in Study 1. Measures taken included: flicker sensitivity, visual temporal order judgment, visible persistence based on the judgment of a blank and a flicker, flicker fusion, auditory temporal order judgment and auditory fusion. In addition, irregular words and nonsense words were used. Each type of words would be presented singly and continuously. Subjects were required to read the words aloud. Subjects also had their non-verbal reasoning IQ measured using Advanced Raven's Progressive Matrices.

The sensory measures would be compared. Further, the relationship between these measures and various reading measures would be analysed using correlation, factor analyses and multiple regressions.

8.2 STUDY 2a

Method

8.2.1 Subjects

79 undergraduate students (3 males, 76 females, aged 18 to 54) who were a subset of the original 91 participated in Study 1 participated in this study. The selection criteria were the same as that in Study 1 with the inclusion that all subjects had to be English-speaking. Sensory data collected in Study 1 were used in this study.

8.2.2 MEASURE 1: Advanced Raven's Progressive Matrices (IQ)

This is a standardised test which assesses subject's non-verbal reasoning skills which are independent of specific learning acquired in a particular cultural or educational context. The test consists of 36 two-dimensional matrices. Each item is a large rectangular pattern with a sector removed. The subject's task is to choose the correct sector out of eight alternatives. The task becomes increasingly difficult as the trials proceed. Subjects were given 40 minutes to complete the task and were given 12 practice trials before the experimental trials. Their raw scores were converted into standard scores using the appropriate norms.

8.2.3 MEASURE 2: Irregular Word and Nonsense Word Reading

This task required subjects to read aloud words presented on the screen. The words included both irregular words and nonsense words and they were presented singly and continuously. Naming latencies (RT) and accuracy were recorded.

Apparatus / Stimuli

Apparatus included: 1) an IBM compatible computer which displayed the stimuli and recorded the RT; 2) a microphone which recorded subject's voice to signal the computer; and 3) a tape recorder which recorded the subject's voice.

Stimuli included thirty irregular and thirty nonsense words. For the irregular words, 15 were from Castles and Coltheart (1993) and 15 were from the National Adult Reading Test (NART) (Nelson, 1982). For the nonsense words, 15 were from Castles and Coltheart (1993) and 15 were from Woodcock's Reading Mastery Tests-Revised (Woodcock, 1987) and Woodcock Language Proficiency Battery Test Book (Woodcock, 1984). Both irregular words and nonsense words were matched in word length and syllable length. To avoid ceiling effects in adult readers, multi-syllabic words were used. However, this would probably increase the word length and hence increase the chance of saccades when reading within each word. Therefore, words were chosen such that the word length did not exceed 9 characters, a condition which probably induces saccades within one word reading (Shapiro et al, 1990b).

Procedure

There were two modes of text presentation: single and continuous (line). For the single presentation, on each trial, a single word was presented in the centre of the screen and subject had to read it as quickly as possible via a microphone. The stimulus duration is the duration starting from the beginning of the presentation till voice-onset. The accuracy and naming latency were recorded. There were 30 experimental trials and 12 practice trials. An example of a word condition is presented below:

Trial 1:

dog

Trial 2:

cat

etc...

Thus, the presentation is the same as in RSVP (Juola et al, 1995; Bourne et al, 1986).

For the continuous (line) presentation, on each trial, six crosses were presented from left to right on the screen and each word appeared below each cross successively. Subjects had to follow the crosses and read each word as quickly as possible. Subjects were instructed not to jump to the next cross until the word under that cross appeared. The stimulus duration is the duration starting from the beginning of the presentation till voice-onset. The accuracy and naming latency were recorded. There were 5 experimental trials and 2 practice trials. An example of the "line" presentation is shown below:

Trial 1a:

+	+	+	+	+	+
dog					

Trial 1b:

+	+	+	+	+	+
	cat				

etc...

Both irregular words and nonsense words were presented singly and continuously. Thus, there were four conditions: irregular words presented singly (IWS), irregular words presented continuously (IWL), nonsense words presented singly (NWS) and nonsense words presented continuously (NWL). The order of presentation of the conditions was counter-balanced. Naming latencies and accuracy were recorded.

8.3 Results

A log-transformation was performed on the data in order to achieve normal distribution and homogeneous variance for better comparison. All statistical analyses were based on the log-transformed data. The means and standard deviations of the original and the log-transformed data are shown in Table 8-1.

Table 8-1: Means and (s.d.) of the Visual, Auditory and Reading Measures and their Log-transformed Data (N=79)

Task	Original		Log-transformed	
FSEN2	0.047	(0.015)	-3.09	(0.29)
FSEN12	0.015	(0.003)	-4.24	(0.24)
VTOJ1	55.05	(23.27)	3.92	(0.42)
VTOJ7	173.8	(93.55)	5.04	(0.47)
BLAN2	187.88	(66.54)	5.16	(0.45)
BLAN12	281.89	(103.41)	5.58	(0.34)
FLICK2	6.84	(6.42)	1.59	(0.79)
FLICK12	15.93	(12.25)	2.47	(0.81)
CHAS2	16.51	(3.13)	2.79	(0.17)
CHAS12	23.98	(4.91)	3.16	(0.2)
AFUS15	4.01	(2.29)	1.3	(0.4)
AFUS100	3.01	(0.7)	1.08	(0.2)
ATOJ15	66.67	(67.81)	3.86	(0.81)
ATOJ75	85.46	(55.69)	4.25	(0.64)
ATOJ200	132.09	(113.03)	4.67	(0.64)
IWSA1	77.64	(10.05)	4.34	(0.14)
IWLA1	78.99	(8.74)	4.36	(0.11)
NWSA1	84.43	(9.6)	4.43	(0.13)
NWLA1	83.42	(9.5)	4.42	(0.12)

Table 8-1 (cont.)

Task	Original		Log-transformed	
IWST1	901.15	(268.81)	6.76	(0.29)
IWLT1	871.21	(279.59)	6.73	(0.29)
NWST1	957.44	(295.33)	6.82	(0.29)
NWLT1	925.63	(273.94)	6.79	(0.27)
IQ	110.14	(17.08)	4.69	(0.16)

N.B.: FSEN2, FSEN12: Flicker Sensitivity at 2 and 12 Hz respectively
VTOJ1, VTOJ7 (ms): Visual Temporal Order Judgment at 1 and 7 c/d respectively
BLAN2, BLAN12 (ms): Visible Persistence (based on the judgment of a blank) at 2 and 12 c/d respectively
FLICK2, FLICK12 (ms): Visible Persistence (based on the judgment of a flicker) at 2 and 12 c/d respectively
CHAS2, CHAS12 (ms): Flicker Fusion at 2 and 12 c/d respectively
AFUS15, AFUS100 (ms): Auditory Fusion at 15 and 100 ms respectively
ATOJ15, ATOJ75, ATOJ200 (ms): Auditory Temporal Order Judgment at 15, 75 and 200 ms respectively
IWSA1, IWLA1 (%): Irregular Words Accuracy, Single / Continuous (Line) condition (first session)
NWSA1, NWLA1 (%): Nonsense Words Accuracy, Single / Continuous (Line) condition (first session)
IWST1, IWLT1 (ms): Irregular Words Reaction time, Single / Continuous (Line) condition (first session)
NWST1, NWLT1 (ms): Nonsense Words Reaction time, Single / Continuous (Line) condition (first session)
IQ: Nonverbal Reasoning Skills measured by Advanced Raven's Progressive Matrices

8.3.1 Visual and Auditory Measures

Consistent with previous findings, results using the subset of the original (79 subjects) did not differ from those found in Study 1, namely:

1) There is a main temporal frequency effect in flicker sensitivity, with the contrast threshold at 2 Hz being higher than that at 12 Hz ($t(78) = 37.76$, $p < 0.0001$).

2) The spatial frequency effect in visual temporal order judgment is also significant, with a lower SOA at 1 c/d than at 7 c/d ($t(78) = 23.18$, $p < 0.0001$).

3) In flicker fusion, there is a significantly lower fusion threshold at 2 c/d than at 12 c/d ($t(78) = 21.99$, $p < 0.0001$).

4) For visible persistence, there is a main effect of Task type ($F(1,78) = 1942.38$, $p < 0.0001$) indicating that the ISI based on the judgment of a blank field is significantly longer than that based on the judgment of a flicker. There is a main

effect of spatial frequency ($F(1,78) = 367.06$, $p < 0.0001$), indicating that the ISI at 2 c/d is shorter than that at 12 c/d. There is also a significant Task x Spatial Frequency interaction ($F(1,78) = 50.72$, $p < 0.0001$), indicating that the ISI increase in the BLAN condition is larger across spatial frequency changes.

5) For the auditory measures, there is a significant within-subject effect among the five tasks ($F(4,312) = 1191.45$, $p < 0.0001$). A priori contrasts show that: AFUS15 is significantly longer than AFUS100 ($F(1,78) = 34.34$, $p < 0.0001$). ATOJ15 is significantly shorter than ATOJ75 ($F(1,78) = 33.12$, $p < 0.0001$) and ATOJ200 ($F(1,78) = 165.44$, $p < 0.0001$). ATOJ75 is significantly shorter than ATOJ200 ($F(1,78) = 48.46$, $p < 0.0001$). The fusion measures are significantly shorter than the temporal order judgment measures ($t(78) = 47.3$, $p < 0.0001$).

8.3.2 Reading

A repeated measures ANOVA was performed on reading accuracy and latency separately, using word type as one factor and the presentation mode as the other. In terms of reading accuracy, subjects have significantly higher accuracy scores on nonsense words than on irregular words ($F(1,78) = 22.69$, $p < 0.0001$). However, there is no accuracy difference between presenting the words singly or continuously ($F(1,78) = 0.29$, $p > 0.05$). There is also no significant Word Type x Presentation Mode interaction ($F(1,78) = 2.44$, $p > 0.05$). In terms of reading latency, subjects have significantly longer naming latency for nonsense words than for irregular words ($F(1,78) = 8.17$, $p = 0.0055$). There is no difference between presenting the words singly or continuously ($F(1,78) = 3.38$, $p > 0.05$). There is also no significant Word Type x Presentation Mode interaction ($F(1,78) = 0.05$, $p > 0.05$).

8.3.3 Intercorrelations among the Visual, Auditory and Reading Measures

Pearson correlation coefficients among the visual, auditory and reading measures are listed in Table 8-2. Only some special aspects of the correlation are stressed below.

Table 8-2: Correlation Matrix of the Log-transformed Data of the Visual, Auditory and Reading (first session) Tasks (N=79)

	FSEN2	FSEN12	VTOJ1	VTOJ7	BLAN2	BLAN12	FLICK2	FLICK12	CHAS2	CHAS12	AFUS15	AFUS100	ATOJ15	ATOJ75	ATOJ200
FSEN2	1.0000														
FSEN12	0.4882**	1.0000													
VTOJ1	0.0298	0.1397	1.0000												
VTOJ7	0.1627	0.1921	0.5376**	1.0000											
BLAN2	0.1774	0.2005	0.0794	0.1415	1.0000										
BLAN12	0.2109	0.2687*	0.2047	0.2585*	0.6767**	1.0000									
FLICK2	0.1589	0.2078	0.0144	0.2066	0.3752**	0.4713**	1.0000								
FLICK12	0.1087	0.2346*	-0.0126	0.1922	0.3416**	0.4643**	0.8134**	1.0000							
CHAS2	0.1474	0.0499	-0.0358	0.1076	0.1731	0.3308**	0.6109**	0.5612**	1.0000						
CHAS12	0.1199	0.0491	-0.1102	0.0892	0.0375	0.2186	0.5053**	0.5297**	0.6837**	1.0000					
AFUS15	0.3843**	0.221	0.2261*	0.2463*	0.2098	0.2871*	0.2488*	0.143	0.1877	0.1613	1.0000				
AFUS100	0.2965**	0.1705	0.312**	0.2051	0.2007	0.254*	0.1702	0.0658	0.0881	0.0839	0.5715**	1.0000			
ATOJ15	0.1849	-0.001	0.287*	0.2842*	0.045	-0.0007	0.1542	0.0297	0.1687	0.0049	0.2972**	0.1771	1.0000		
ATOJ75	0.1683	-0.0619	0.41**	0.2731*	0.1185	0.1158	0.1145	0.0541	0.2451*	0.1646	0.3917**	0.3074**	0.6756**	1.0000	
ATOJ200	0.236*	0.07	0.345**	0.3762**	0.0148	0.0409	0.1541	0.07	0.2536*	0.1477	0.3193**	0.1728	0.7256**	0.6488**	1.0000
IWSA1	-0.4163**	-0.3023**	-0.1301	-0.1795	-0.1559	-0.1758	-0.2722*	-0.2911**	-0.167	-0.1325	-0.1596	-0.0346	-0.0254	-0.102	-0.0902
IWLA1	-0.1169	-0.1714	-0.0127	-0.1461	-0.1349	-0.1123	-0.266*	-0.2146	-0.153	-0.1164	-0.0938	0.0491	-0.1689	-0.1076	-0.1086
NWSA1	-0.3109**	-0.1157	-0.1605	-0.2418*	-0.0806	-0.0748	-0.007	0.1011	0.0551	0.0479	-0.3796**	-0.1662	-0.1909	-0.2421*	-0.1608
NWLA1	-0.4566**	-0.1073	-0.0963	-0.1335	-0.0887	-0.0458	-0.1362	-0.0981	-0.0262	-0.0685	-0.3883**	-0.1827	-0.2406*	-0.2724*	-0.283*
IWST1	-0.0456	0.0503	-0.044	-0.0197	-0.0895	0.0219	-0.0178	0.1114	0.0233	0.0293	-0.1021	-0.0499	0.0239	0.0259	-0.0031
IWLT1	-0.0106	0.0299	-0.1493	-0.0819	-0.1497	-0.0806	0.086	0.166	0.0905	0.054	-0.0796	-0.089	-0.0668	-0.1607	-0.03
NWST1	-0.0373	-0.0042	0.042	-0.0084	-0.0621	0.1172	0.051	0.126	0.1329	0.1141	-0.028	0.0006	0.0422	0.0292	0.0964
NWLT1	0.0362	-0.0467	0.0353	0.0125	-0.2094	0.0464	0.0651	0.1571	0.1216	0.0922	-0.0643	-0.0072	0.034	-0.0741	0.0231
IQ	-0.1753	-0.1165	-0.2266*	-0.2845**	0.0158	-0.1693	-0.2795*	-0.2213*	-0.1815	-0.0897	-0.3427*	-0.1058	-0.2566*	-0.2978**	-0.3036**

* p<.05
** p<.01

Table 8-2 (cont.): Correlation Matrix of the Log-transformed Data of the Visual, Auditory and Reading (first session) Tasks (N=79)

	IWSA1	IWLA1	NWSA1	NWLA1	IWST1	IWLT1	NWST1	NWLT1	IQ
IWSA1	1.0000								
IWLA1	0.471**	1.0000							
NWSA1	0.2083	0.153	1.0000						
NWLA1	0.4472**	0.1981	0.7146**	1.0000					
IWST1	0.0572	0.1537	0.0827	0.2238*	1.0000				
IWLT1	-0.0088	0.0541	0.0888	0.0963	0.7288**	1.0000			
NWST1	0.0901	0.2196	0.0087	0.1315	0.7139**	0.5822**	1.0000		
NWLT1	0.0318	0.124	-0.127	-0.0812	0.6378**	0.6188**	0.7837**	1.0000	
IQ	0.2621*	0.454**	0.2547*	0.2678*	0.0384	-0.0673	0.0398	-0.019	1.0000

* $p<.05$
** $p<.01$

N.B.: FSEN2, FSEN12: Flicker Sensitivity at 2 and 12 Hz respectively
VTOJ1, VTOJ7: Visual Temporal Order Judgment at 1 and 7 c/d respectively
BLAN2, BLAN12: Visible Persistence (based on the judgment of a blank) at 2 and 12 c/d respectively
FLICK2, FLICK12: Visible Persistence (based on the judgment of a flicker) at 2 and 12 c/d respectively
CHAS2, CHAS12: Flicker Fusion at 2 and 12 c/d respectively
AFUS15, AFUS100: Auditory Fusion at 15 and 100 ms respectively
ATOJ15, ATOJ75, ATOJ200: Auditory Temporal Order Judgment at 15, 75 and 200 ms respectively
IWSA1, IWLA1: Irregular Words Accuracy, Single / Continuous (Line) condition (first session)
NWSA1, NWLA1: Nonsense Words Accuracy, Single / Continuous (Line) condition (first session)
IWST1, IWLT1: Irregular Words Reaction time, Single / Continuous (Line) condition (first session)
NWST1, NWLT1: Nonsense Words Reaction time, Single / Continuous (Line) condition (first session)
IQ: Nonverbal Reasoning Skills measured by Advanced Raven's Progressive Matrices

From Table 8-2, FSEN2 significantly correlates with the auditory fusion measures AFUS15 ($r = 0.3843$) and AFUS100 ($r = 0.2965$) and also with reading accuracy IWSA1 ($r = -0.4163$), NWSA1 ($r = -0.3109$) and NWLA1 ($r = -0.4566$). On the other hand FSEN12 also correlates significantly with IWSA1 ($r = -0.3023$). This implies that the more sensitive a visual system is at detecting low and high temporal frequencies, the better the reading accuracy is. Higher contrast thresholds are related to longer auditory gap detection thresholds.

The visual temporal order judgment measures also correlate significantly with the auditory measures and IQ: VTOJ1 correlates with AFUS15 ($r = 0.2261$), AFUS100 ($r = 0.312$), ATOJ15 ($r = 0.287$), ATOJ75 ($r = 0.41$), ATOJ200 ($r = 0.345$) and IQ ($r = -0.2266$); VTOJ7 correlates with AFUS15 ($r = 0.2463$), ATOJ15 ($r = 0.2842$), ATOJ75 ($r = 0.2731$), ATOJ200 ($r = 0.3762$), IQ ($r = -0.2845$) and also with NWSA1 ($r = -0.2418$). This implies that the more sensitive the visual system is at detecting low and high spatial frequencies, the more sensitive the auditory system is and the higher the reading accuracy and IQ scores.

Visible persistence measures also correlate significantly with auditory fusion, irregular word reading accuracy and IQ: BLAN12 correlates with AFUS15 ($r = 0.2871$) and AFUS100 ($r = 0.254$). FLICK2 correlates with IWSA1 ($r = -0.2722$), IWLA1 ($r = -0.266$) and IQ ($r = -0.2795$); FLICK12 correlates with IWSA1 ($r = -0.2911$) and IQ ($r = -0.2213$). This implies that poorer high spatial frequency gap detection is related to poorer auditory gap detection. Also, a stronger or more sensitive visual system in detecting flicker will result in better accuracy when reading irregular words.

Flicker fusion significantly correlates with auditory temporal order judgment: CHAS2 correlates with ATOJ75 ($r = 0.2451$) and ATOJ200 ($r = 0.2536$). This indicates that poorer low spatial frequency flicker fusion is related to longer auditory SOAs at long stimulus duration.

Auditory fusion correlates significantly with nonsense word reading accuracy and IQ: AFUS15 correlates with NWSA1 (r = -0.3796), NWLA1 (r = -0.3883) and IQ (r = -0.3427). This indicates that shorter auditory gap detection is related to better nonsense word reading accuracy and IQ.

Auditory temporal order judgment also correlates significantly with nonsense word reading accuracy and IQ: ATOJ15 correlates with NWLA1 (r = -0.2406) and IQ (r = -0.2566); ATOJ75 correlates with NWSA1 (r = -0.2421), NWLA1 (r = -0.2724) and IQ (r = -0.2978); ATOJ200 correlates with NWLA1 (r = -0.283) and IQ (r = -0.3036). This implies shorter auditory SOAs are related to better nonsense word reading accuracy and IQ.

IQ also significantly correlates with reading accuracy: IWSA1 (r = 0.2621), IWLA1 (r = 0.454), NWSA1 (r = 0.2547) and NWLA1 (r = 0.2678). This indicates higher the IQ, the better the reading accuracy.

In sum:

1) The negative correlations between the visual / auditory measures and reading accuracy imply that the better the resolution of the visual / auditory system in processing temporal information, the higher the reading accuracy is.

2) There are more significant correlations between the visual measures and irregular words reading accuracy, whereas there are more significant correlations between the auditory measures and nonsense words reading accuracy.

3) On the other hand, there is no significant correlation between the sensory measures and reading latency. This indicates that naming latency may not be as reliable as accuracy measures in accounting the relationship between the sensory temporal processing measures and reading.

4) The positive correlations between some visual and auditory measures imply that the more sensitive one system is, the more sensitive the other one is also. This is supportive of a generalised timing mechanism in processing rapidly presented information suggested by Miller and Tallal (1995).

5) Nonverbal reasoning skills tend to have more significant correlations with temporal order judgment measures and reading accuracy. It may be that the TOJ and reading measures are more cognitive in terms of my proposed framework and hence a larger influence of IQ is found in this level.

6) Nevertheless, the correlations do not explicitly suggest a differential effect between the transient and sustained visual measures and the mode of text presentation.

7) Interestingly, no significant correlations are found between reading accuracy and latency. This will be further explained in section 8.4.

8.3.4 Factor Analyses of Study 2a

Principal components factor analyses with varimax rotation were performed on the sensory measures with: 1) irregular words single mode presentation (IWS1); 2) irregular words continuous mode presentation (IWL1); 3) nonsense words single mode presentation (NWS1); and 4) nonsense words continuous mode presentation (NWL1) separately. Results are summarised below.

Factor Analysis on Irregular Words Single Mode Presentation (IWS1)

Six factors accounting for 70.66% of the variance were extracted in the analysis. They are summarised in Table 8-3.

Table 8-3: Factor Analysis on Irregular Words Single Mode Presentation (IWS1)

	F1	F2	F3	F4	F5	F6	
FSEN2	-	-	-	0.70244	0.50405	-	
FSEN12	-	-	-	0.73533	-	-	
VTOJ1	0.63295	-	0.4385	-	-	-	
VTOJ7	0.58454	-	0.42729	-	-	-	
BLAN2	-	-	0.75488	-	-	-	
BLAN12	-	0.31369	0.78781	-	-	-	
FLICK2	-	0.77998	0.36059	-	-	-	
FLICK12	-	0.77249	0.37494	-	-	-	
CHAS2	-	0.84902	-	-	-	-	
CHAS12	-	0.82138	-	-	-	-	
AFUS15	0.31426	-	-	-	0.68451	-	
AFUS100	-	-	-	-	0.72428	-	
ATOJ15	0.79107	-	-	-	-	-	
ATOJ75	0.78225	-	-	-	0.32459	-	
ATOJ200	0.81683	-	-	-	-	-	
IWSA1	-	-	-	-0.72951	-	-	
IWST1	-	-	-	-	-	0.90832	
IQ	-0.46847	-	-	-0.35844	-	-	
Eigenvalue	4.658	2.658	1.819	1.338	1.198	1.047	Total = 12.718
Variance Explained	25.88%	14.77%	10.1%	7.43%	6.66%	5.82%	Total = 70.66%

N.B.: Loadings below |0.3| not shown

FSEN2, FSEN12: Flicker Sensitivity at 2 and 12 Hz respectively

VTOJ1, VTOJ7: Visual Temporal Order Judgment at 1 and 7 c/d respectively

BLAN2, BLAN12: Visible Persistence (based on the judgment of a blank) at 2 and 12 c/d respectively

FLICK2, FLICK12: Visible Persistence (based on the judgment of a flicker) at 2 and 12 c/d respectively

CHAS2, CHAS12: Flicker Fusion at 2 and 12 c/d respectively

AFUS15, AFUS100: Auditory Fusion at 15 and 100 ms respectively

ATOJ15, ATOJ75, ATOJ200: Auditory Temporal Order Judgment at 15, 75 and 200 ms respectively

IWSA1, IWST1: Irregular Words Accuracy / Reaction time, Single condition (first session)

IQ: Nonverbal Reasoning Skills measured by Advanced Raven's Progressive Matrices

The first factor is weighted on by the temporal order judgment measures, an auditory fusion measure and IQ. It accounts for 25.88% of the variance explained. The negative loading of IQ indicates that higher TOJ and auditory fusion thresholds are related to lower IQ. The factor is supportive of a common mechanism across vision and audition and also a common mechanism across auditory fusion and TOJ. Moreover, this factor is IQ dependent.

The second factor is weighted on by three visible persistence measures and the flicker fusion measures. It accounts for 14.77% of the variance explained. The factor indicates that higher flicker fusion thresholds are related to longer visible persistence, and possibly that gap detection at high spatial frequency is related to flicker detection. Even though this loading is relatively small, it may imply some role for the sustained visual system in movement detection.

The third factor is weighted on by the visual temporal order judgment and visible persistence measures. It accounts for 10.1% of the variance explained. This implies that poorer gap detection is associated with higher SOAs. Moreover, the results are consistent with Jaskowski's (1991) notion that gap detection may be a prerequisite for TOJ and that both processes may undergo the same mechanism.

The fourth factor is weighted on by the flicker sensitivity measures, irregular words single mode presentation accuracy and IQ. It accounts for 7.43% of the variance explained. The negative loadings indicate that higher reading accuracy is related to higher IQ and lower contrast thresholds, even though the influence of IQ is small, as suggested by the relatively small loading. Nevertheless, the results do not indicate any differential effect of the sustained and transient visual measures and mode of text presentation.

The fifth factor is weighted on by flicker sensitivity at 2 Hz, auditory fusion measures and auditory temporal order judgment at 75 ms. It accounts for 6.66% of the variance explained. Thus, low temporal frequency contrast sensitivity measure is related to auditory measures. This is supportive of a transmodal temporal processing mechanism across vision and audition and also the role of the sustained visual system in temporal processing. Moreover, poorer resolution in one modality is related to poorer resolution in the other.

The sixth factor is weighted on by irregular words single mode reaction time only. It accounts for 5.82% of the variance explained. In general, reading latency may be unrelated to reading accuracy and the sensory processing measures.

In sum, the factor analysis of performance on irregular words presented singly indicates that:

1) There are different independent visual factors which reflect the function of the same visual measures, as shown by factors 2 and 3.

2) Some visual and auditory measures load on the same factors (e.g., factors 1 and 5). This may imply some common sensory timing factors. Moreover, nonverbal reasoning skills may be related to these factors.

3) Irregular word reading accuracy is related to the visual measures at both high and low temporal frequencies. Moreover, this factor is related to IQ (factor 4). Thus, the hypothesis that irregular word performance will be related to visual measures is supported. However, as words presented singly load with both high and low temporal frequency (both transient and sustained visual systems) measures, the hypothesis that single mode presentation will be more related to

low temporal frequency / high spatial frequency measures is partially supported. Nevertheless, this will be further clarified in the multiple regression analyses reported in section 8.3.5.

Factor Analysis on Irregular Words Continuous Mode Presentation (IWL1)

Six factors accounting for 71.09% of the variance were extracted in this analysis and are summarised in Table 8-4.

Table 8-4: Factor Analysis on Irregular Words Continuous Mode Presentation (IWL1)

	F1	F2	F3	F4	F5	F6	
FSEN2	-	-	0.81068	-	-	-	
FSEN12	-	-	0.68963	-	-	-	
VTOJ1	-	0.30444	-	0.80873	-	-	
VTOJ7	-	-	-	0.77208	-	-	
BLAN2	-	-	-	-	0.77211	-	
BLAN12	0.44526	-	-	0.32218	0.60857	-	
FLICK2	0.82166	-	-	-	-	-	
FLICK12	0.84171	-	-	-	-	-	
CHAS2	0.83241	-	-	-	-	-	
CHAS12	0.79342	-	-	-	-	-	
AFUS15	-	0.4022	0.63447	-	-	-	
AFUS100	-	-	0.58804	-	-	0.33074	
ATOJ15	-	0.81886	-	-	-	-	
ATOJ75	-	0.84995	-	-	-	-	
ATOJ200	-	0.79096	-	-	-	-	
IWLA1	-	-	-	-	-	0.85718	
IWLT1	-	-	-	-	-0.66518	-	
IQ	-	-	-	-	-	0.64491	
Eigenvalue	4.616	2.683	1.81	1.351	1.281	1.054	Total = 12.795
Variance Explained	25.65%	14.91%	10.05%	7.51%	7.12%	5.85%	Total = 71.09%

N.B.: Loadings below |0.3| not shown

FSEN2, FSEN12: Flicker Sensitivity at 2 and 12 Hz respectively

VTOJ1, VTOJ7: Visual Temporal Order Judgment at 1 and 7 c/d respectively

BLAN2, BLAN12: Visible Persistence (based on the judgment of a blank) at 2 and 12 c/d respectively

FLICK2, FLICK12: Visible Persistence (based on the judgment of a flicker) at 2 and 12 c/d respectively

CHAS2, CHAS12: Flicker Fusion at 2 and 12 c/d respectively

Table 8-4 (cont.)

N.B.: AFUS15, AFUS100: Auditory Fusion at 15 and 100 ms respectively

ATOJ15, ATOJ75, ATOJ200: Auditory Temporal Order Judgment at 15, 75 and 200 ms respectively

IWLA1, IWLT1: Irregular Words Accuracy / Reaction time, Continuous (Line) condition (first session)

IQ: Nonverbal Reasoning Skills measured by Advanced Raven's Progressive Matrices

The first factor is weighted on by the visible persistence measures and the flicker fusion measures. It accounts for 25.65% of the variance explained. This factor is equivalent to factor 2 of IWS1.

The second factor is weighted on by the visual temporal order judgment at 1 c/d, auditory fusion at 15 ms and the auditory temporal order judgment measures. It accounts for 14.91% of the variance explained. The factor is supportive of a common mechanism operating on both gap detection and TOJ and also a transmodal timing factor across specific aspects of vision and audition. Moreover, better visual temporal resolution is related to better auditory temporal resolution.

The third factor is weighted on by the flicker sensitivity and auditory fusion measures. It accounts for 10.05% of the variance explained. The factor indicates that higher contrast threshold is related to longer auditory gap detection. In addition, this factor is supportive of a specific transmodal process across vision and audition because the better the temporal resolution in one modality, the better the temporal resolution in the other.

The fourth factor is weighted on by the visual temporal order judgment measures and a visible persistence measure at high spatial frequency. It accounts for 7.51% of the variance explained. The factor may imply the role of the sustained visual system in visual TOJ and also the role of gap detection as a prerequisite for TOJ.

The fifth factor is weighted on by the visible persistence measures and irregular words continuous reaction time. It accounts for 7.12% of the variance explained. This supports the relationship between irregular word reading and various visual measures. Moreover, the relationship between the transient visual system and continuous text presentation is implicated.

The sixth factor is weighted on by auditory fusion at 100 ms, irregular words continuous mode accuracy and IQ. It accounts for 5.85% of the variance explained. The factor indicates that better reading accuracy is related to higher IQ and the possible limited influence of auditory / phonological factor in irregular word reading, as shown by the relatively small loading.

In sum, the factor analysis of performance on irregular words presented continuously indicates that:

1) There are different independent visual factors, as shown by factors 1 and 4.

2) Some visual and auditory measures load on the same factors (e.g., factors 2 and 3). This may imply some common sensory timing processes.

3) Irregular word naming latency is related to the visual measures at both high and low spatial frequencies (factor 5), whereas accuracy is related to an auditory fusion measure and IQ (factor 6). Thus, the hypothesis that processing of irregular words will be related to visual measures is partially supported. Moreover, as words presented continuously load with both high and low spatial frequency (both transient and sustained visual systems) measures, the hypothesis that continuous mode presentation will be related to the transient system is supported. This relationship will be further clarified in the multiple regression analyses reported in section 8.3.5.

Factor Analysis on Nonsense Words Single Mode Presentation (NWS1)

Six factors accounting for 70.04% of the variance were extracted in the analysis. They are summarised in Table 8-5.

Table 8-5: Factor Analysis on Nonsense Words Single Mode Presentation (NWS1)

	F1	F2	F3	F4	F5	F6	
FSEN2	-	-	0.82208	-	-	-	
FSEN12	-	-	0.66984	-	0.317	-	
VTOJ1	-	0.36002	-	-	0.69345	-	
VTOJ7	-	-	-	-	0.76562	-	
BLAN2	-	-	-	0.83595	-	-	
BLAN12	0.35952	-	-	0.74215	-	-	
FLICK2	0.81999	-	-	-	-	-	
FLICK12	0.83356	-	-	-	-	-	
CHAS2	0.82667	-	-	-	-	-	
CHAS12	0.79258	-	-	-	-	-	
AFUS15	-	0.44652	0.57865	0.33041	-	-	
AFUS100	-	0.3683	0.41688	0.50898	-	-	
ATOJ15	-	0.808	-	-	-	-	
ATOJ75	-	0.86138	-	-	-	-	
ATOJ200	-	0.77347	-	-	-	-	
NWSA1	-	-	-0.5415	-	-	-	
NWST1	-	-	-	-	-	0.89078	
IQ	-	-	-	-	-0.44875	0.35415	
Eigenvalue	4.604	2.747	1.845	1.298	1.088	1.027	Total = 12.608
Variance Explained	25.58%	15.26%	10.25%	7.21%	6.05%	5.7%	Total = 70.04%

N.B.: Loadings below |0.3| not shown

FSEN2, FSEN12: Flicker Sensitivity at 2 and 12 Hz respectively

VTOJ1, VTOJ7: Visual Temporal Order Judgment at 1 and 7 c/d respectively

BLAN2, BLAN12: Visible Persistence (based on the judgment of a blank) at 2 and 12 c/d respectively

FLICK2, FLICK12: Visible Persistence (based on the judgment of a flicker) at 2 and 12 c/d respectively

CHAS2, CHAS12: Flicker Fusion at 2 and 12 c/d respectively

AFUS15, AFUS100: Auditory Fusion at 15 and 100 ms respectively

ATOJ15, ATOJ75, ATOJ200: Auditory Temporal Order Judgment at 15, 75 and 200 ms respectively

NWSA1, NWST1: Nonsense Words Accuracy / Reaction time, Single condition (first session)

IQ: Nonverbal Reasoning Skills measured by Advanced Raven's Progressive Matrices

The first factor is weighted on by the visible persistence measures and the flicker fusion measures. It accounts for 25.58% of the variance explained. This factor is equivalent to factor 2 of IWS1.

The second factor is weighted on by the visual temporal order judgment at 1 c/d, auditory fusion and temporal order judgment measures. It accounts for 15.26% of the variance explained. The factor implies a common ability in both auditory gap detection and TOJ and possibly the involvement of the transient visual system in auditory temporal resolution, i.e., a common sensory timing factor across vision and audition.

The third factor is weighted on by the flicker sensitivity measures, the auditory fusion measures and nonsense words single mode accuracy. It accounts for 10.25% of the variance explained. The negative loading indicates that higher contrast thresholds and auditory gap detection thresholds are related to lower reading accuracy. In other words, the better the temporal precision, the better the accuracy. Moreover, as nonsense word reading accuracy loads with both visual and auditory measures, the hypothesis that nonsense word reading is related to auditory measures is supported. The results, however, do not clarify the relationship between the sustained and transient visual measures and the mode of text presentation.

The fourth factor is weighted on by the visible persistence measures and the auditory fusion measures. It accounts for 7.21% of the variance explained. This is a general gap detection factor across modality.

The fifth factor is weighted on by flicker sensitivity at 12 Hz, the visual temporal order judgment measures and IQ. It accounts for 6.05% of the variance explained. The negative loading indicates that higher IQ is related to better visual temporal resolution. Moreover, the loading of IQ and VTOJ may suggest the more cognitive nature of TOJ.

The sixth factor is weighted on by nonsense words single mode reaction time and IQ. It accounts for 5.7% of the variance explained. Contrary to what is normally expected, the positive loading indicates that higher IQ is related to longer reading latency. It is possible that reading latency is generally not a reliable reading measure in these tasks.

In sum, the factor analysis of performance on nonsense words presented singly indicates that:

1) There are different independent visual factors and some of them are related to IQ (factors 1 and 5).

2) Some visual and auditory measures load on the same factors (e.g., factors 2 and 4). This may imply some common ability in sensory timing factors.

3) Nonsense word reading accuracy is related to the visual measures at both high and low temporal frequencies and auditory fusion measures (factor 3), whereas naming latency is related to IQ (factor 6). Thus, the hypothesis that nonsense words will be related to auditory measures is supported. However, as words presented singly load with both high and low temporal frequency (both transient and sustained visual systems) measures, evidence for the hypothesis that single mode presentation will be more related to high spatial frequency / low temporal frequency measures is ambiguous. This relationship will be further clarified in the multiple regression analyses reported in section 8.3.5.

Factor Analysis on Nonsense Words Continuous Mode Presentation (NWL1)

Five factors accounting for 65.4% of the variance were extracted in the analysis. They are summarised in Table 8-6.

Table 8-6: Factor Analysis on Nonsense Words Continuous Mode Presentation (NWL1)

	F1	F2	F3	F4	F5	
FSEN2	-	-	0.84205	-	-	
FSEN12	-	-	0.59464	0.30633	-	
VTOJ1	-	0.31783	-	0.78664	-	
VTOJ7	-	-	-	0.75765	-	
BLAN2	-	-	-	-	0.78275	
BLAN12	0.47471	-	-	0.40296	0.53619	
FLICK2	0.83996	-	-	-	-	
FLICK12	0.85707	-	-	-	-	
CHAS2	0.83078	-	-	-	-	
CHAS12	0.77912	-	-	-	-	
AFUS15	-	0.37401	0.60775	-	-	
AFUS100	-	-	0.45726	-	0.34739	
ATOJ15	-	0.81639	-	-	-	
ATOJ75	-	0.8518	-	-	-	
ATOJ200	-	0.79752	-	-	-	
NWLA1	-	-	-0.66708	-	-	
NWLT1	-	-	-	-	-0.62949	
IQ	-	-0.30319	-	-0.32089	-	
Eigenvalue	4.664	2.693	1.813	1.421	1.18	Total = 11.771
Variance Explained	25.91%	14.96%	10.07%	7.9%	6.55%	Total = 65.4%

N.B.: Loadings below |0.3| not shown

FSEN2, FSEN12: Flicker Sensitivity at 2 and 12 Hz respectively

VTOJ1, VTOJ7: Visual Temporal Order Judgment at 1 and 7 c/d respectively

BLAN2, BLAN12: Visible Persistence (based on the judgment of a blank) at 2 and 12 c/d respectively

FLICK2, FLICK12: Visible Persistence (based on the judgment of a flicker) at 2 and 12 c/d respectively

CHAS2, CHAS12: Flicker Fusion at 2 and 12 c/d respectively

AFUS15, AFUS100: Auditory Fusion at 15 and 100 ms respectively

ATOJ15, ATOJ75, ATOJ200: Auditory Temporal Order Judgment at 15, 75 and 200 ms respectively

NWLA1, NWLT1: Nonsense Words Accuracy / Reaction time, Continuous (Line) condition (first session)

IQ: Nonverbal Reasoning Skills measured by Advanced Raven's Progressive Matrices

The first factor is weighted on by the visible persistence and flicker fusion measures. It accounts for 25.91% of the variance explained. This is equivalent to factor 2 of IWS1.

The second factor is weighted on by visual temporal order judgment at 1 c/d, auditory fusion at 15 ms, the auditory temporal order judgment measures and IQ. It accounts for 14.96% of the variance explained. The factor is supportive of a transmodal timing mechanism across aspects of vision and audition and also a common factor or commonality across auditory fusion and TOJ. Moreover, lower IQ is associated with poorer temporal resolution.

The third factor is weighted on by the flicker sensitivity measures, the auditory fusion measures and nonsense words continuous mode accuracy. It accounts for 10.07% of the variance explained. The negative loading indicates that lower contrast thresholds and auditory gap detection thresholds are related to higher reading accuracy. In other words, better temporal resolution across modalities is associated with better reading performance. Further, the results are supportive of the relationship between nonsense word reading and audition.

The fourth factor is weighted on by flicker sensitivity at 12 Hz, the visual temporal order judgment measures, visible persistence at 12 c/d and IQ. It accounts for 7.9% of the variance explained. The negative loading implies that lower IQ is related to poorer visual temporal resolution.

The fifth factor is weighted on by the visible persistence measures, auditory fusion at 100 ms and nonsense words continuous mode reaction time. It accounts for 6.55% of the variance explained. Interestingly, contrary to what is normally expected, the negative loading indicates that shorter gap detection thresholds are related to longer reading latency. Furthermore, the results are supportive of the relationship between nonsense word reading and audition.

In sum, the factor analysis of performance on nonsense words presented continuously indicates that:

1) There are different independent visual factors and that some of them are related to IQ (factors 1 and 4).

2) Some visual and auditory measures load on the same factors (e.g., factor 2) and may be related to IQ. This implies some common sensory timing factors.

3) Nonsense word reading accuracy is related to the visual measures at both high and low temporal frequencies and auditory fusion measures (factor 3), whereas naming latency is related to high and low spatial frequency measures and auditory fusion (factor 5). Thus, the hypothesis that nonsense words will be related to auditory measures is supported. Moreover, as words presented continuously load with both high and low spatial frequency / temporal frequency (both transient and sustained visual systems) measures, the hypothesis that continuous mode presentation will be related to the transient visual system is supported. This relationship will be further clarified in the multiple regression analyses reported in section 8.3.5.

Summary of Factor Analyses of Study 2a

The main findings of the factor analyses are:

1) There are some independent visual factors which may tap into some of the same visual measures of rapid temporal processing and may be influenced by IQ or vice versa. Presumably, higher IQ is related to better visual temporal resolution.

2) Evidence for a general sensory timing mechanism is found by the fact that some visual and auditory measures load on the same factor(s). Similarly, this common mechanism may be influenced by IQ or vice versa. Similarly, higher IQ is related to better temporal resolution.

3) Irregular words are mostly related to visual measures whereas nonsense words are related to both visual and auditory measures as hypothesised in section 8.1. Moreover, some reading measures are related to nonverbal IQ.

4) Although words presented continuously are related to both high and low temporal frequency / spatial frequency (both transient and sustained systems) measures and thus supporting the hypothesis that the transient visual system is involved in reading continuous text, words presented singly also relate to both systems. This is contrary to the expectation that words presented singly should be more related to the sustained visual system. In fact, Hughes, Nozawa and Kitterle (1996) argued that early processes associated with pattern recognition are dominated by the transient visual system. Thus, it is possible for the minimal involvement of the transient visual system in single word reading, at least during early processing.

Therefore, multiple regression analyses will be run in the following section to clarify the relationship between the visual subsystems and the mode of text presentation.

The aims of the multiple regression analyses are: 1) to sort out, relative to both visual subsystems, which system dominates in each text presentation mode; and 2) to further investigate the differential relationship between vision and irregular word reading and between audition and nonsense word reading.

8.3.5 Multiple Regression Analyses of Study 2a

Standard multiple regressions were run on the IWS1, IWL1, NWS1 and NWL1 data respectively. The aim is to evaluate the effects of the sensory measures and IQ on different types of words and text presentation modes. Therefore, the predictors of the model are the sensory measures and IQ while the dependent variable is the reading measure. The reason for adding IQ as the predictor is that it is related to some sensory temporal processing measures and is implicated in reading, as shown by the factor analyses. Outliers were identified and discarded if the absolute value of studentised residuals[6] were greater than 3. Results are summarised below.

Multiple Regression on Irregular Words Single Mode Accuracy (IWSA1)

In this model, one outlier was identified and discarded. Results show that sensory measures and IQ together significantly account for 32.99% of the variance in irregular words single mode accuracy ($F(16,61) = 1.877$, $p = 0.0407$). According to the model, the significant predictor is FSEN2. The results are shown in Table 8-7.

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[6] Studentised residual is the ratio of the residual to its standard error (SAS/STAT User Guide, 1988). Similar to the function of standardised residual and Cook's D, studentised residual identifies multivariate outliers in regression analysis (Tabachnick & Fidell, 1989).

Table 8-7: Multiple Regression on Irregular Words Single Mode Accuracy (IWSA1)

D.V.	R^2	$adjR^2$	F	df	Sig. Predictors	Parameter	Beta	T	p
IWSA1	0.3299	0.1541	1.877	16,61					
					FSEN2	-0.16	-0.38	-2.84	0.0061

N.B.: FSEN2: Flicker Sensitivity at 2 Hz
IWSA1: Irregular Words Accuracy, Single condition (first session)

FSEN2, a low temporal frequency measure, significantly predicts irregular words single mode accuracy. This clarifies previous results and supports the hypothesis that the sustained visual system is dominant in processing words presented singly.

Multiple Regression on Irregular Words Single Mode Reaction Time (IWST1)

In this model, one outlier was identified and discarded. Results show that sensory measures and IQ together account for 14.48% of the variance in irregular words single mode reaction time. The result is not significant ($F(16,61) = 0.645$, $p > 0.05$). It may be that reading latency in this experiment is generally not as reliable and sensitive as reading accuracy.

Multiple Regression on Irregular Word Continuous Mode Accuracy (IWLA1)

In this model, one outlier was identified and discarded. Results show that sensory measures and IQ together significantly account for 41.14% of the variance in irregular words continuous mode accuracy ($F(16,61) = 2.665$, $p = 0.0031$). According to the model, the significant predictors are IQ, FSEN12 and BLAN2. The results are shown in Table 8-8.

Table 8-8: Multiple Regression on Irregular Words Continuous Mode Accuracy (IWLA1)

D.V.	R^2	adjR^2	F	df	Sig. Predictors	Parameter	Beta	T	p
IWLA1	0.4114	0.2571	2.665	16,61					
					IQ	0.32	0.48	4.086	0.0001
					FSEN12	-0.16	-0.38	-2.84	0.0061
					BLAN2	-0.15	-0.49	-3.38	0.0013

N.B.: FSEN12: Flicker Sensitivity at 12 Hz
BLAN2: Visible Persistence (based on the judgment of a blank) at 2 c/d
IWLA1: Irregular Words Accuracy, Continuous (Line) condition (first session)
IQ: Nonverbal Reasoning Skills measured by Advanced Raven's Progressive Matrices

FSEN12, a high temporal frequency measure, and BLAN2, a low spatial frequency measure, significantly predict irregular words continuous mode accuracy. This reinforces previous results that the transient visual system is active in processing words presented continuously.

Multiple Regression on Irregular Words Continuous Mode Reaction Time (IWLT1)

In this model, one outlier was identified and discarded. Results show that sensory measures and IQ nonsignificantly account for 19.14% of the variance in irregular words continuous mode reaction time ($F(16,61) = 0.903$, $p > 0.05$). Similarly, reading latency may not be a sensitive and reliable measure.

Multiple Regression on Nonsense Words Single Mode Accuracy (NWSA1)

In this model, two outliers were identified and discarded. Results show that sensory measures and IQ nonsignificantly account for 27.53% of the variance in nonsense words single mode accuracy ($F(16,60) = 1.425$, $p > 0.05$).

Multiple Regression on Nonsense Words Single Mode Reaction Time (NWST1)

In this model, one outlier was identified and discarded. Results show that sensory measures and IQ nonsignificantly account for 16.04% of the variance in nonsense words single mode reaction time ($F(16,61) = 0.728$, $p > 0.05$).

Multiple Regression on Nonsense Words Continuous Mode Accuracy (NWLA1)

In this model, the results show that sensory measures and IQ together significantly account for 35.62% of the variance in nonsense words continuous mode accuracy ($F(16,62) = 2.144$, $p = 0.017$). According to the model, the significant predictor is FSEN2. The results are shown in Table 8-9.

Table 8-9: Multiple Regression on Nonsense Words Continuous Mode Accuracy (NWLA1)

D.V.	R^2	adjR^2	F	df	Sig. Predictors	Parameter	Beta	T	p
NWLA1	0.3562	0.19011	2.144	16,62					
					FSEN2	-0.19	-0.45	-3.5	0.0009

N.B.: FSEN2: Flicker Sensitivity at 2 Hz
NWLA1: Nonsense Words Accuracy, Continuous (Line) condition (first session)

The prediction of nonsense words continuous mode accuracy by FSEN2, a low temporal frequency measure is partially inconsistent with the hypothesis that the transient visual system is active in processing words presented continuously. However, note that during fixation, the sustained visual system is involved in extracting details from the print. Hence it is also possible for the sustained system to be active in reading continuous text.

Multiple Regression on Nonsense Words Continuous Mode Reaction Time (NWLT1)

In this model, the results show that sensory measures and IQ nonsignificantly account for 20.59% of the variance in nonsense words continuous mode reaction time ($F(16,62) = 1.005$, $p > 0.05$).

Summary of Multiple Regression Analyses of Study 2a

In sum, the results partially support the role of the sustained visual system in single word reading and the role of the transient visual system in continuous word reading. It should be noted that the effect of some of the visual processes is more pronounced in irregular words than in nonsense words. This reinforces the relationship between irregular words and visual temporal processing.

One may ask why a stepwise multiple regression was not run in order to determine the effect of each individual sensory measure on reading performance. The reason is that in general, the sensory measures are not individually very strong predictors and it is hard to find any individual measure to dominate entirely in reading, and hence a stepwise regression may not be an appropriate technique to detect their subtle influences without considering much of the covariate factor among the measures. On the other hand, the sensory measures work better by their co-factor and usually a "synergistic" effect is observed when a combination of them is entered into the equation. In addition, within this model, the relative effectiveness of individual measures among all measures is more pronounced and one can easily pick out, say among all measures, which are the more significant ones.

Given the known effects of phonological awareness and various temporal processing ability on reading performance (e.g., Lovegrove et al, 1989; Tallal et al, 1985a,b; Eden et al, 1995a,b), it is not surprising that the temporal processing measures account for a certain amount of the variance explained in reading. The amount of variance accounted for by the sensory measures, though relatively small, is still statistically significant and probably meaningful in this study.

8.4 Discussion for Study 2a

Consistent with Study 1, the loading of both visual and auditory measures on some factors as shown by the factor analyses is suggestive of a common temporal processing mechanism proposed by Miller and Tallal (1995), Galaburda et al (1985, 1994), Farmer and Klein (1995) and Stein (1993). Moreover, results show that the better the temporal resolution in one modality, the better the resolution in the other. Further, this temporal processing ability may be related to IQ, namely, higher IQ is related to better temporal resolution. In fact, Chapter 5 has already stressed the role of IQ in temporal processing like rapid auditory processing, auditory discrimination and visual inspection time (Deary, 1980, 1993; Raz et al, 1983; Watson, 1991; Bowling & Mackenzie, 1996; Stough et al, 1996). Therefore, it is possible for more intelligent brains to have better signal representation and sensory resolution (Raz et al, 1987) or alternatively, better temporal resolution contributes to intelligence (Deary, 1995).

The factor analyses showed: 1) a relationship between some visual measures and irregular words; 2) a relationship between some visual and auditory measures and nonsense words; and 3) the role of the transient visual system in continuous word reading. Nevertheless, the analyses could not explicitly show the role of the sustained visual system in single word reading.

Consequently, multiple regression analyses were run to reinforce the major conclusions of the factor analyses: namely, the sustained visual system is active in processing words presented singly whereas the transient visual system is active in processing words presented continuously. Moreover, the differential effects of the visual measures are more pronounced in irregular words than in nonsense words. This implies that the two visual systems do not totally work independently. Nevertheless the result is supportive of Farmer and Klein's (1995) suggestion.

Note that the sensory measures, in general, are more influential in irregular word reading and are less predictive for nonsense word reading. It is speculated that the two types of words partially involve different processes. For instance, as irregular word reading relies on the visual route, it may rely more on visual processing, and visual coding is needed to identify the word and to retrieve the correct pronunciation of that word. Therefore, irregular word reading has a stronger relationship with the visual measures. Moreover, the visual effect may depend strongly on the sustained system rather than the transient system as temporal processing deficits occur primarily with subjects who have phonological deficits (Borsting et al, 1996; Ridder et al, in press). Hence, irregular word processing which lacks phonological components should relate more to the sustained visual system. On the other hand, nonsense word reading involves cognitive resources in addition to the visual processes measured. One candidate of these cognitive resources is phonological processing. In fact, the visual configurational information represented in orthographic images "is only a minor part of the representations which also contain phonological information" (Bruck & Waters, 1990, p.167). Thus, it is possible that in reading nonsense words, firstly, visual coding / processing is necessary to identify the physical appearance of the words (i.e., to identify the alphabets / graphemes). Then, phonological processing is involved in retrieving the corresponding phonemes of the graphemes and in blending the phonemes to produce the correct pronunciation. According to Watson and Miller (1993), Watson and Watson (1993a,b) and Tallal et al (1985a), rapid auditory processing mechanisms are involved in phonological awareness. Therefore, it is reasonable to conclude that nonsense word reading is related to both visual and auditory measures and it is highly probably that a large part of the cognitive demands involved in nonsense word reading is phonological in nature.

A point of interest is that the temporal processing measures are more related to accuracy measures than to latency measures. This implies that latency is an unreliable measurement of reading ability in this study. This is not surprising as there are people who can read correctly but may take a longer or shorter time to do so. On the other hand, there are also people who read incorrectly but may also take a longer or shorter time to do so. This may explain why no significant correlations were obtained between reading accuracy and latency in section 8.3.3. Moreover, a consistent relationship is observed between reading accuracies and various temporal processing and IQ measures but the relationship between reading latencies and these measures is contradictary and confusing. Therefore, reading accuracies are better measures in reflecting various reading and temporal processes.

Baddeley and Gathercole (1992) observed a consistent association between nonverbal IQ and reading. In fact, my results also show that nonverbal IQ loads with or predicts some reading measures. There are two possible explanations for this. First, as IQ is related to temporal processing and temporal processing is related to reading, it is possible that the effect of IQ on reading is due to the relationship between IQ and temporal processing. As stated in Chapter 5, IQ is regarded as an index for general speed of processing, at least in visual and auditory inspection time studies (Deary, 1993, 1995). The above studies can strengthen the first argument. Second, as reading involves cognitive processes like phonological processing and word retrieval skills, it is possible that IQ affects reading via these processes. Further, my results are consistent with Rudel and Denckla (1976) who found that reading-age was correlated with a temporal-spatial task which in turn correlated with Performance and Full Scale IQ. In addition, my results are also consistent with Watson and Watson (1993b) who found that nonverbal temporal processing was unrelated to phonological processing independently of IQ.

The presentation mode effect is more pronounced with irregular words than with nonsense words. Apart from the explanation that irregular words are more "vulnerable" to visual processing whereas nonsense words are more "vulnerable" to phonological / auditory processing, the presentation mode may explain the lack of differential effect between words processed singly and continuously. In the continuous mode, the "+" guided the spatial separation between the words and no peripheral information was given during the task. This results in a clearly-segmented presentation and it is assumed that any effect due to the transient system is attributed to the saccades and not to the peripheral information presented in normal reading. As the transient cells, compared to the sustained cells, are more concentrated in the periphery (DeMonasterio, 1978), it is expected that presentation involving peripheral information should enhance the effect of the transient visual system. Since the multiple regression analyses showed that only FSEN2, (a low temporal frequency measure) and not high temporal frequency / low spatial frequency measures significantly predicted nonsense words continuous mode accuracy, a continuous mode presentation involving peripheral information should enhance the role of high temporal frequency / low spatial frequency predictors in nonsense words continuous mode accuracy. Therefore, using the moving window technique of McConkie and Rayner (1975), Study 2b aimed to investigate this possibility. Justification of this technique comes from Hill and Lovegrove (1992) who showed that dyslexics were impaired only in reading ordinary text (text which incorporated central and peripheral information) and not single words or text with sequential spatial presentation.

8.5 STUDY 2b

Study 2b is equivalent to Study 2a except that in the continuous reading tasks, peripheral information was added based on the moving window technique of McConkie and Rayner (1975). In this presentation, a word was presented while to the right of it a row of "X"s was simultaneously presented. The second word was presented 2 "X"s away to the right of the first word and the first word and the first two "X"s were not shown on the second fixation. However, the "X"s to the right of the second word were presented with the second word. Then the third word was presented 2 "X"s away to the right of the second word and the stimuli to the left of the third word were not shown, while the "X"s to the right of it were shown with the word, and so forth. The strength of this type of presentation is that it ensures the presence of the peripheral information without encouraging subjects to "pre-read" the second word while reading the first word. In other words, it is matched to the one in Study 2a in the sense that both of them present only one word at a time. An example of the presentation is shown below:

Trial 1a:

dogXXXXXXXXXXXXXXXXXXX

Trial 1b:

catXXXXXXXXXXXXXXXX

etc...

Subjects who participated in Study 2a also participated in this study. The sensory measures and IQ data used in Study 2a were reanalysed in this study along with the new reading performance data. It should be noted that subjects had to reread the irregular words and nonsense words from Study 2a, both presented singly and continuously. Thus, subjects "double-read" the words in the single mode presentation. Therefore, the reading performance data in this condition is compared with that in Study 2a to see if there is a practice effect.

A repeated measures ANOVA showed that there is no practice effect in terms of accuracy ($F(1,78) = 0.72$, $p > 0.05$) but subjects read significantly faster in the second session ($F(1,78) = 49.6$, $p = 0.0001$). However, since reaction time is not a crucial and reliable reading measure in this study, it is unlikely to have an impact on the results.

8.6 Results

The means and standard deviations of the original and the log-transformed reading data are shown in Table 8-10. Analyses conducted were the same as for Study 2a. Moreover, only results differ from those in Study 2a will be commented.

Table 8-10: Means and (s.d.) of the Reading Measures (second session) and their Log-transformed Data (N=79)

Task	Original		Log-transformed	
IWSA2	78.1	(9.24)	4.35	(0.13)
IWLA2	78.78	(8.46)	4.36	(0.11)
NWSA2	82.87	(10.36)	4.41	(0.15)
NWLA2	81.65	(8.13)	4.4	(0.11)
IWST2	674.41	(199.57)	6.48	(0.28)
IWLT2	746.41	(218.02)	6.58	(0.28)
NWST2	754.18	(234.8)	6.58	(0.3)
NWLT2	829.03	(218.75)	6.69	(0.26)

N.B.: IWSA2, IWLA2 (%): Irregular Words Accuracy, Single / Continuous (Line) condition (second session)
NWSA2, NWLA2 (%): Nonsense Words Accuracy, Single / Continuous (Line) condition (second session)
IWST2, IWLT2 (ms): Irregular Words Reaction time, Single / Continuous (Line) condition (second session)
NWST2, NWLT2 (ms): Nonsense Words Reaction time, Single / Continuous (Line) condition (second session)

8.6.1 Reading

The results are in line with Study 2a such that there is a word-type effect ($F(1,78) = 10.43$, $p = 0.0018$), no presentation mode effect ($F(1,78) = 0$, $p > 0.05$) and no Word Type x Presentation Mode interaction ($F(1,78) = 1.73$, $p > 0.05$) in reading accuracy; a word-type effect ($F(1,78) = 23.15$, $p = 0.0001$) and no Word Type x Presentation Mode interaction ($F(1,78) = 0.02$, $p > 0.05$) in reading latency. However, continuous mode presentation takes longer than single mode presentation ($F(1,78) = 22.39$, $p = 0.0001$).

8.6.2 Intercorrelations among the Visual, Auditory and Reading Measures

Pearson correlation coefficients among the visual, auditory and reading measures (second session) and among the reading measures between the first and second session are listed in Tables 8-11 and 8-12. Only some special aspects of the correlation are stressed below.

Table 8-11: Correlation Matrix of the Log-transformed Data of the Visual, Auditory and Reading (second session) Tasks (N=79)

	FSEN2	FSEN12	VTOJ1	VTOJ7	BLAN2	BLAN12	FLICK2	FLICK12	CHAS2	CHAS12	AFUS15	AFUS100	ATOJ15	ATOJ75	ATOJ200
FSEN2	1.0000														
FSEN12	0.4882**	1.0000													
VTOJ1	0.0298	0.1397	1.0000												
VTOJ7	0.1627	0.1921	0.5376**	1.0000											
BLAN2	0.1774	0.2005	0.0794	0.1415	1.0000										
BLAN12	0.2109	0.2687*	0.2047	0.2585*	0.6767**	1.0000									
FLICK2	0.1589	0.2078	0.0144	0.2066	0.3752**	0.4713**	1.0000								
FLICK12	0.1087	0.2346*	-0.0126	0.1922	0.3416**	0.4643**	0.8134**	1.0000							
CHAS2	0.1474	0.0499	-0.0358	0.1076	0.1731	0.3308**	0.6109**	0.5612**	1.0000						
CHAS12	0.1199	0.0491	-0.1102	0.0892	0.0375	0.2186	0.5053**	0.5297**	0.6837**	1.0000					
AFUS15	0.3843**	0.221	0.2261*	0.2463*	0.2098	0.2871*	0.2488*	0.143	0.1877	0.1613	1.0000				
AFUS100	0.2965**	0.1705	0.312**	0.2051	0.2007	0.254*	0.1702	0.0658	0.0881	0.0839	0.5715**	1.0000			
ATOJ15	0.1849	-0.001	0.287*	0.2842*	0.045	-0.0007	0.1542	0.0297	0.1687	0.0049	0.2972**	0.1771	1.0000		
ATOJ75	0.1683	-0.0619	0.41**	0.2731*	0.1185	0.1158	0.1145	0.0541	0.2451*	0.1646	0.3917**	0.3074**	0.6756**	1.0000	
ATOJ200	0.236*	0.07	0.345**	0.3762**	0.0148	0.0409	0.1541	0.07	0.2536*	0.1477	0.3193**	0.1728	0.7256**	0.6488**	1.0000
IWSA2	-0.3739**	-0.1696	-0.2417*	-0.192	-0.1346	-0.169	-0.2119	-0.2133	-0.1218	-0.0562	-0.1936	-0.0188	-0.1904	-0.2252*	-0.2301*
IWLA2	-0.1555	-0.1807	-0.0547	-0.1602	-0.0064	-0.0457	-0.157	-0.1162	-0.1375	-0.0926	-0.1415	-0.0157	-0.2223*	-0.2076	-0.1825
NWSA2	-0.2612*	-0.0458	-0.2369*	-0.2525*	-0.0106	-0.1421	-0.087	-0.0483	-0.0663	-0.0293	-0.2502*	-0.2388*	-0.1151	-0.2732*	-0.2782*
NWLA2	-0.1728	-0.043	-0.089	-0.063	0.0538	0.0549	0.0256	0.0554	-0.0622	-0.0783	-0.0742	-0.0754	-0.1234	-0.2004	-0.1589
IWST2	0.2822*	0.0997	-0.1615	-0.007	0.0027	0.0654	0.0415	0.0633	0.0329	0.1488	0.0682	0.0219	0.1538	0.2221*	0.1196
IWLT2	0.1718	0.0054	-0.0727	-0.1085	-0.1528	-0.0604	-0.105	-0.0591	0.1076	0.0965	0.1431	-0.0208	0.1781	0.1651	0.1407
NWST2	0.0633	-0.0719	-0.0903	0.0572	-0.0718	0.0628	0.126	0.0529	0.1842	0.2404*	0.0293	-0.0056	0.088	0.1003	0.0189
NWLT2	0.0526	0.0111	-0.1153	-0.1005	-0.1625	0.0049	0.0072	0.0171	0.1191	0.0874	-0.0183	0.0015	0.0519	0.0943	0.0287
IQ	-0.1753	-0.1165	-0.2266*	-0.2845**	0.0158	-0.1693	-0.2795*	-0.2213*	-0.1815	-0.0897	-0.3427*	-0.1058	-0.2566*	-0.2978**	-0.3036**

* p<.05

** p<.01

Table 8-11 (cont.): Correlation Matrix of the Log-transformed Data of the Visual, Auditory and Reading (second session) Tasks (N=79)

	IWSA2	IWLA2	NWSA2	NWLA2	IWST2	IWLT2	NWST2	NWLT2	IQ
IWSA2	1.0000								
IWLA2	0.4958**	1.0000							
NWSA2	0.3581**	0.2169	1.0000						
NWLA2	0.211	0.2369*	0.6957**	1.0000					
IWST2	-0.317**	-0.2868*	-0.1026	-0.0255	1.0000				
IWLT2	-0.0843	-0.2034	0.0271	-0.056	0.4817**	1.0000			
NWST2	0.0416	-0.0787	0.0046	0.0105	0.3893**	0.537**	1.0000		
NWLT2	-0.0023	-0.1406	0.1593	0.1825	0.4702**	0.5477**	0.4679**	1.0000	
IQ	0.341**	0.5603**	0.2544*	0.1077	-0.1259	-0.2831*	-0.1725	-0.1604	1.0000

* p<.05
** p<.01

N.B.: FSEN2, FSEN12: Flicker Sensitivity at 2 and 12 Hz respectively
VTOJ1, VTOJ7: Visual Temporal Order Judgment at 1 and 7 c/d respectively
BLAN2, BLAN12: Visible Persistence (based on the judgment of a blank) at 2 and 12 c/d respectively
FLICK2, FLICK12: Visible Persistence (based on the judgment of a flicker) at 2 and 12 c/d respectively
CHAS2, CHAS12: Flicker Fusion at 2 and 12 c/d respectively
AFUS15, AFUS100: Auditory Fusion at 15 and 100 ms respectively
ATOJ15, ATOJ75, ATOJ200: Auditory Temporal Order Judgment at 15, 75 and 200 ms respectively
IWSA2, IWLA2: Irregular Words Accuracy, Single / Continuous (Line) condition (second session)
NWSA2, NWLA2: Nonsense Words Accuracy, Single / Continuous (Line) condition (second session)
IWST2, IWLT2: Irregular Words Reaction time, Single / Continuous (Line) condition (second session)
NWST2, NWLT2: Nonsense Words Reaction time, Single / Continuous (Line) condition (second session)
IQ: Nonverbal Reasoning Skills measured by Advanced Raven's Progressive Matrices

Table 8-12: Correlation Matrix of the Log-transformed Data of the Reading (first and second session) Tasks (N=79)

	IWSA1	IWLA1	NWSA1	NWLA1	IWST1	IWLT1	NWST1	NWLT1	IWSA2	IWLA2	NWSA2	NWLA2	IWST2	IWLT2	NWST2	NWLT2
IWSA1	1.0000															
IWLA1	0.471**	1.0000														
NWSA1	0.2083	0.153	1.0000													
NWLA1	0.4472**	0.1981	0.7146**	1.0000												
IWST1	0.0572	0.1537	0.0827	0.2238*	1.0000											
IWLT1	-0.0088	0.0541	0.0888	0.0963	0.7288**	1.0000										
NWST1	0.0901	0.2196	0.0087	0.1315	0.7139**	0.5822**	1.0000									
NWLT1	0.0318	0.124	-0.127	-0.0812	0.6378**	0.6188**	0.7837**	1.0000								
IWSA2	0.8509**	0.4723**	0.2233*	0.4672**	-0.0378	-0.0975	-0.0269	-0.0387	1.0000							
IWLA2	0.3798**	0.7373**	0.1979	0.2637*	-0.0271	-0.125	0.0389	-0.0505	0.4958**	1.0000						
NWSA2	0.3007**	0.0976	0.6699**	0.6971**	-0.0707	-0.0589	-0.1762	-0.3186**	0.3581**	0.2169	1.0000					
NWLA2	0.187	0.1686	0.5594**	0.6113**	0.0079	-0.0953	-0.059	-0.1731	0.211	0.2369*	0.6957**	1.0000				
IWST2	-0.331**	-0.1801	-0.1499	-0.2469*	0.1258	0.104	0.0862	0.0742	-0.317**	-0.2868*	-0.1026	-0.0255	1.0000			
IWLT2	-0.0882	-0.1367	-0.1948	-0.1048	0.2971**	0.325**	0.2096	0.3123**	-0.0843	-0.2034	0.0271	-0.056	0.4817**	1.0000		
NWST2	-0.0557	-0.1754	-0.1777	-0.0639	0.0575	0.1008	0.1873	0.2077	0.0416	-0.0787	0.0046	0.0105	0.3893**	0.537**	1.0000	
NWLT2	-0.0158	-0.0856	0.0542	0.1708	0.279*	0.1767	0.2158	0.1868	-0.0023	-0.1406	0.1593	0.1825	0.4702**	0.5477**	0.4679**	1.0000

* $p<.05$
** $p<.01$

N.B.: IWSA1, IWLA1: Irregular Words Accuracy, Single / Continuous (Line) condition (first session)
NWSA1, NWLA1: Nonsense Words Accuracy, Single / Continuous (Line) condition (first session)
IWST1, IWLT1: Irregular Words Reaction time, Single / Continuous (Line) condition (first session)
NWST1, NWLT1: Nonsense Words Reaction time, Single / Continuous (Line) condition (first session)
IWSA2, IWLA2: Irregular Words Accuracy, Single / Continuous (Line) condition (second session)
NWSA2, NWLA2: Nonsense Words Accuracy, Single / Continuous (Line) condition (second session)
IWST2, IWLT2: Irregular Words Reaction time, Single / Continuous (Line) condition (second session)
NWST2, NWLT2: Nonsense Words Reaction time, Single / Continuous (Line) condition (second session)

From Table 8-11, FSEN2 correlates significantly with IWSA2 (r = -0.3739), NWSA2 (r = -0.2612) and IWST2 (r = 0.2822). This implies that the better the sustained visual system, the higher the accuracy of both types of words. On the other hand, the less sensitive the sustained system, the longer the time to read words presented singly.

VTOJ1 correlates significantly with IWSA2 (r = -0.2417) and NWSA2 (r = -0.2369) and VTOJ7 correlates significantly with NWSA2 (r = -0.2525). This implies that the better the visual TOJ, the higher the accuracy when reading words presented singly.

CHAS12 significantly correlates with NWST2 (r = 0.2404), indicating that a less sensitive sustained visual system is related to longer latency in reading nonsense words presented singly.

AFUS15 correlates significantly with NWSA2 (r = -0.2502) and AFUS100 correlates significantly with NWSA2 (r = -0.2388), indicating lower gap detection threshold is associated with higher nonsense word reading accuracy.

ATOJ15 correlates significantly with IWLA2 (r = -0.2223). ATOJ75 significantly correlates with IWSA2 (r = -0.2252), NWSA2 (r = -0.2732) and IWST2 (r = 0.2221). ATOJ200 significantly correlates with IWSA2 (r = -0.2301) and NWSA2 (r = -0.2782). This implies higher SOAs are associated with lower accuracy and longer reading latencies.

IQ significantly correlates with IWSA2 (r = 0.341), IWLA2 (r = 0.5603), NWSA2 (r = 0.2544) and IWLT2 (r = -0.2831). Therefore, better nonverbal reasoning skill is associated with higher reading accuracy and shorter reading latency.

In line with Study 2a, higher reading accuracy is associated with better temporal resolution. Contrary to the lack of relationship between reading latency and temporal processing in Study 2a, this study shows that poor temporal resolution is related to longer reading latency. Moreover, while the visual measures correlate more with the irregular words and the auditory measures correlate more with the nonsense words in Study 2a, the visual and auditory measures correlate with both types of words in this study. This is contrary to what is expected and can not be attributed to the statistical power of the test because the sample size is the same in both sessions.

8.6.3 Factor Analyses of Study 2b

Results on: 1) irregular words in single mode presentation (IWS2); 2) irregular words in continuous mode presentation (IWL2); 3) nonsense words in single mode presentation (NWS2); and 4) nonsense words in continuous mode presentation (NWL2) are summarised below.

Factor Analysis on Irregular Words Single Mode Presentation (IWS2)

Six factors accounting for 71.9% of the variance were extracted. They are summarised in Table 8-13.

Table 8-13: Factor Analysis on Irregular Words Single Mode Presentation (IWS2)

	F1	F2	F3	F4	F5	F6
FSEN2	-	-	-	0.54157	0.64892	-
FSEN12	-	-0.32894	-	0.42452	0.47221	-
VTOJ1	-	-	0.76702	-	-	-
VTOJ7	-	-	0.73795	-	-	-

Table 8-13 (cont.)

	F1	F2	F3	F4	F5	F6	
BLAN2	-	-	-	-	-	0.91745	
BLAN12	0.30669	-	-	-	-	0.78558	
FLICK2	0.79796	-	-	-	-	0.32557	
FLICK12	0.80024	-	-	-	-	0.31843	
CHAS2	0.84343	-	-	-	-	-	
CHAS12	0.83542	-	-	-	-	-	
AFUS15	-	-	-	0.73876	-	-	
AFUS100	-	-	-	0.81725	-	-	
ATOJ15	-	0.83354	-	-	-	-	
ATOJ75	-	0.85645	-	-	-	-	
ATOJ200	-	0.76902	-	-	-	-	
IWSA2	-	-	-	-	-0.705	-	
IWST2	-	-	-0.34327	-	0.68704	-	
IQ	-0.46847	-	-0.48682	-	-0.34549	-	
Eigenvalue	4.717	2.651	1.78	1.528	1.215	1.051	Total = 12.941
Variance Explained	26.21%	14.73%	9.89%	8.49%	6.75%	5.84%	Total = 71.9%

N.B.: Loadings below |0.3| not shown

FSEN2, FSEN12: Flicker Sensitivity at 2 and 12 Hz respectively

VTOJ1, VTOJ7: Visual Temporal Order Judgment at 1 and 7 c/d respectively

BLAN2, BLAN12: Visible Persistence (based on the judgment of a blank) at 2 and 12 c/d respectively

FLICK2, FLICK12: Visible Persistence (based on the judgment of a flicker) at 2 and 12 c/d respectively

CHAS2, CHAS12: Flicker Fusion at 2 and 12 c/d respectively

AFUS15, AFUS100: Auditory Fusion at 15 and 100 ms respectively

ATOJ15, ATOJ75, ATOJ200: Auditory Temporal Order Judgment at 15, 75 and 200 ms respectively

IWSA2, IWST2: Irregular Words Accuracy / Reaction time, Single condition (second session)

IQ: Nonverbal Reasoning Skills measured by Advanced Raven's Progressive Matrices

The first factor is weighted on by the visible persistence and flicker fusion measures. It accounts for 26.21% of the variance explained. This is equivalent to factor 2 of IWS1.

The second factor is weighted on by flicker sensitivity at 12 Hz and the auditory temporal order judgment measures. It accounts for 14.73% of the variance explained. The factor is supportive of a transmodal timing factor and also the role of the transient visual system in auditory TOJ. Interestingly, higher contrast threshold is related to lower SOAs. Nevertheless, this loading is relatively small.

The third factor is weighted on by visual temporal order judgment, irregular words single mode reaction time and IQ. It accounts for 9.89% of the variance explained. Irregular word reading is related to both visual systems and that lower IQ is associated with longer SOAs. Furthermore, contrary to what is normally expected, longer naming time is related to higher IQ and lower SOAs. Moreover, the factor does not implicate the relation between the visual systems and text presentation mode.

The fourth factor is weighted on by the flicker sensitivity and auditory fusion measures. It accounts for 8.49% of the variance explained. This is supportive of a transmodal timing factor and that higher contrast thresholds are related to longer auditory gap detection thresholds.

The fifth factor is weighted on by the flicker sensitivity measures, irregular words single mode accuracy and reaction time and IQ. It accounts for 6.75% of the variance explained. Higher irregular word reading accuracy is related to higher IQ and lower contrast thresholds and reading latency. Furthermore, the involvement of the high temporal frequency (transient visual system) measure in single word presentation is hard to interpret.

The sixth factor is weighted on by the visible persistence measures. It accounts for 5.84% of the variance explained. The factor is presumably visible persistence.

Factor Analysis on Irregular Words Continuous Mode Presentation (IWL2)

Five factors accounting for 66.59% of the variance were extracted and are summarised in Table 8-14.

Table 8-14: Factor Analysis on Irregular Words Continuous Mode Presentation (IWL2)

	F1	F2	F3	F4	F5	
FSEN2	-	-	0.76078	-	-	
FSEN12	-	-	0.60861	-	-0.33061	
VTOJ1	-	0.48895	-	0.60042	-	
VTOJ7	-	0.37864	-	0.60232	-0.30084	
BLAN2	0.3259	-	0.39087	0.50778	-	
BLAN12	0.46167	-	0.41353	0.51971	-	
FLICK2	0.8283	-	-	-	-	
FLICK12	0.83081	-	-	-	-	
CHAS2	0.83677	-	-	-	-	
CHAS12	0.79274	-	-	-	-	
AFUS15	-	0.39768	0.66898	-	-	
AFUS100	-	0.32388	0.64141	-	-	
ATOJ15	-	0.81831	-	-	-	
ATOJ75	-	0.85012	-	-	-	
ATOJ200	-	0.81981	-	-	-	
IWLA2	-	-	-	-	0.80988	
IWLT2	-	-	-	-0.58598	-0.33696	
IQ	-	-	-	-	0.77723	
Eigenvalue	4.634	2.692	1.873	1.52	1.267	Total = 11.985
Variance Explained	25.74%	14.95%	10.41%	8.45%	7.04%	Total = 66.59%

N.B.: Loadings below |0.3| not shown

FSEN2, FSEN12: Flicker Sensitivity at 2 and 12 Hz respectively

VTOJ1, VTOJ7: Visual Temporal Order Judgment at 1 and 7 c/d respectively

BLAN2, BLAN12: Visible Persistence (based on the judgment of a blank) at 2 and 12 c/d respectively

FLICK2, FLICK12: Visible Persistence (based on the judgment of a flicker) at 2 and 12 c/d respectively

CHAS2, CHAS12: Flicker Fusion at 2 and 12 c/d respectively

AFUS15, AFUS100: Auditory Fusion at 15 and 100 ms respectively

ATOJ15, ATOJ75, ATOJ200: Auditory Temporal Order Judgment at 15, 75 and 200 ms respectively

IWLA2, IWLT2: Irregular Words Accuracy / Reaction time, Continuous (Line) condition (second session)

IQ: Nonverbal Reasoning Skills measured by Advanced Raven's Progressive Matrices

The first factor is weighted on by the visible persistence and flicker fusion measures. It accounts for 25.74% of the variance explained. Sensitive flicker detection is associated with sensitive gap detection.

The second factor is weighted on by the visual temporal order judgment, auditory fusion and auditory temporal order judgment measures. It accounts for 14.95% of the variance explained. The factor indicates a common mechanism across vision and audition and also a common mechanism among auditory fusion and TOJ.

The third factor is weighted on by the flicker sensitivity, visible persistence and auditory fusion measures. It accounts for 10.41% of the variance explained. The factor indicates that poorer gap detection thresholds are related to higher contrast thresholds and also a common mechanism across vision and audition.

The fourth factor is weighted on by the visual temporal order judgment measures, the visible persistence measures and irregular words continuous mode reaction time. It accounts for 8.45% of the variance explained. The factor supports the role of visual gap detection as a prerequisite for visual TOJ and also the role of the transient visual system in processing irregular words presented continuously. However, poorer visual temporal resolution is related to shorter reading latency. It may be that reading latency is not a reliable measure for reading processes.

The fifth factor is weighted on by flicker sensitivity at 12 Hz, visual temporal order judgment at 7 c/d, irregular words continuous mode measures and IQ. It accounts for 7.04% of the variance explained. The negative loadings indicate that higher irregular word reading accuracy is related to higher IQ and lower SOA, contrast threshold and reading time. In other words, better visual temporal resolution and higher IQ are associated with higher reading accuracy. Moreover, the factor is indicative of the role of the transient (high temporal frequency measure) system in processing irregular words presented continuously.

Factor Analysis on Nonsense Words Single Mode Presentation (NWS2)

Six factors accounting for 70.17% of the variance were extracted and are summarised in Table 8-15.

Table 8-15: Factor Analysis on Nonsense Words Single Mode Presentation (NWS2)

	F1	F2	F3	F4	F5	F6	
FSEN2	-	-	-	0.38718	-	0.76696	
FSEN12	-	-	-	-	-	0.84999	
VTOJ1	-	-	0.71245	-	-	-	
VTOJ7	-	-	0.76573	-	-	-	
BLAN2	-	-	-	-	0.80571	-	
BLAN12	0.41662	-	-	-	0.63369	-	
FLICK2	0.81444	-	-	-	-	-	
FLICK12	0.80709	-	-	-	-	-	
CHAS2	0.82725	-	-	-	-	-	
CHAS12	0.80506	-	-	-	-	-	
AFUS15	-	-	-	0.72437	-	-	
AFUS100	-	-	-	0.7979	-	-	
ATOJ15	-	0.89174	-	-	-	-	
ATOJ75	-	0.78399	-	0.3239	-	-	
ATOJ200	-	0.84558	-	-	-	-	
NWSA2	-	-	-0.4727	-0.40821	-	-	
NWST2	0.3609	-	-	-	-0.45526	-	
IQ	-	-	-0.56835	-	-	-	
Eigenvalue	4.652	2.705	1.849	1.286	1.107	1.029	Total = 12.629
Variance Explained	25.85%	15.03%	10.27%	7.15%	6.15%	5.72%	Total = 70.17%

N.B.: Loadings below |0.3| not shown

FSEN2, FSEN12: Flicker Sensitivity at 2 and 12 Hz respectively

VTOJ1, VTOJ7: Visual Temporal Order Judgment at 1 and 7 c/d respectively

BLAN2, BLAN12: Visible Persistence (based on the judgment of a blank) at 2 and 12 c/d respectively

FLICK2, FLICK12: Visible Persistence (based on the judgment of a flicker) at 2 and 12 c/d respectively

CHAS2, CHAS12: Flicker Fusion at 2 and 12 c/d respectively

AFUS15, AFUS100: Auditory Fusion at 15 and 100 ms respectively

ATOJ15, ATOJ75, ATOJ200: Auditory Temporal Order Judgment at 15, 75 and 200 ms respectively

NWSA2, NWST2: Nonsense Words Accuracy / Reaction time, Single condition (second session)

IQ: Nonverbal Reasoning Skills measured by Advanced Raven's Progressive Matrices

The first factor is weighted on by the visible persistence measures, the flicker fusion measures and nonsense words single mode reaction time. It accounts for 25.85% of the variance explained. The factor is indicative of the association between longer naming latency and poorer gap and flicker detection ability. However, the factor does not implicate the role of the sustained and transient systems in single word reading.

The second factor is weighted on by the auditory temporal order judgment measures. It accounts for 15.03% of the variance explained. Presumably, this represents auditory TOJ.

The third factor is weighted on by the visual temporal order judgment measures, nonsense words single mode accuracy and IQ. It accounts for 10.27% of the variance explained. The negative loadings indicate that better reading accuracy is associated with higher IQ and better visual temporal resolution. Furthermore, the factor does not implicate the relationship between the visual systems and text presentation mode.

The fourth factor is weighted on by flicker sensitivity at 2 Hz, the auditory fusion measures, auditory temporal order judgment at 75 ms and nonsense words single mode accuracy. It accounts for 7.15% of the variance explained. The factor is supportive of the role of audition in nonsense word reading and also the role of the sustained visual system in processing words presented singly. In addition, better accuracy is associated with better temporal resolution.

The fifth factor is weighted on by the visible persistence measures and nonsense words single mode reaction time. It accounts for 6.15% of the variance explained. Contrary to what is normally expected, poorer gap detection is related to shorter naming latency. Moreover, the factor does not implicate any relation between the visual systems and text presentation mode.

The sixth factor is weighted on by the flicker sensitivity measures. It accounts for 5.72% of the variance explained. Presumably, it represents contrast sensitivity.

Factor Analysis on Nonsense Words Continuous Mode Presentation (NWL2)

Six factors accounting for 70.3% of the variance were extracted and are summarised in Table 8-16.

Table 8-16: Factor Analysis on Nonsense Words Continuous Mode Presentation (NWL2)

	F1	F2	F3	F4	F5	F6	
FSEN2	-	-	-	0.8247	-	-	
FSEN12	-	-	-	0.73669	0.31769	-	
VTOJ1	-	0.35775	-	-	0.68269	-	
VTOJ7	-	-	-	-	0.76929	-	
BLAN2	-	-	0.81616	-	-	-	
BLAN12	0.3593	-	0.72017	-	-	-	
FLICK2	0.80659	-	0.30092	-	-	-	
FLICK12	0.82082	-	-	-	-	-	
CHAS2	0.83557	-	-	-	-	-	
CHAS12	0.80733	-	-	-	-	-	
AFUS15	-	0.49394	0.37614	0.4981	-	-	
AFUS100	-	0.4163	0.50013	0.41332	-	-	
ATOJ15	-	0.80371	-	-	-	-	
ATOJ75	-	0.86733	-	-	-	-	
ATOJ200	-	0.76994	-	-	-	-	
NWLA2	-	-	-	-	-	0.69229	
NWLT2	-	-	-	-	-	0.79247	
IQ	-	-	-	-	-0.46075	-	
Eigenvalue	4.538	2.678	1.82	1.349	1.181	1.089	Total = 12.654
Variance Explained	25.21%	14.88%	10.11%	7.5%	6.56%	6.05%	Total = 70.3%

N.B.: Loadings below |0.3| not shown

FSEN2, FSEN12: Flicker Sensitivity at 2 and 12 Hz respectively

VTOJ1, VTOJ7: Visual Temporal Order Judgment at 1 and 7 c/d respectively

BLAN2, BLAN12: Visible Persistence (based on the judgment of a blank) at 2 and 12 c/d respectively

FLICK2, FLICK12: Visible Persistence (based on the judgment of a flicker) at 2 and 12 c/d respectively

CHAS2, CHAS12: Flicker Fusion at 2 and 12 c/d respectively

AFUS15, AFUS100: Auditory Fusion at 15 and 100 ms respectively

ATOJ15, ATOJ75, ATOJ200: Auditory Temporal Order Judgment at 15, 75 and 200 ms respectively

Table 8-16 (cont.)

N.B.: NWLA2, NWLT2: Nonsense Words Accuracy / Reaction time, Continuous (Line) condition (second session)
IQ: Nonverbal Reasoning Skills measured by Advanced Raven's Progressive Matrices

The first factor is weighted on by the visible persistence and flicker fusion measures. It accounts for 25.21% of the variance explained. This is equivalent to factor 2 of IWS1.

The second factor is weighted on by visual temporal order judgment at 1 c/d, the auditory fusion and auditory temporal order judgment measures. It accounts for 14.88% of the variance explained. The factor is supportive of a transmodal mechanism across vision and audition, a common mechanism across auditory fusion and TOJ, and also the role of the transient visual system in auditory temporal resolution. Moreover, better visual temporal resolution is related to better auditory temporal resolution.

The third factor is weighted on by the visible persistence and auditory fusion measures. It accounts for 10.11% of the variance explained. Presumably, this is a gap detection factor.

The fourth factor is weighted on by the flicker sensitivity and auditory fusion measures. It accounts for 7.5% of the variance explained. Thus, higher contrast thresholds are related to higher auditory gap detection thresholds. Moreover, the factor is supportive of a transmodal mechanism across modality because the better the temporal resolution in one modality, the better the one in the other.

The fifth factor is weighted on by flicker sensitivity at 12 Hz, visual temporal order judgment and IQ. It accounts for 6.56% of the variance explained. Lower IQ is associated with poorer visual temporal resolution.

The sixth factor is weighted on by the reading measures. It accounts for 6.05% of the variance explained. Higher accuracy is related to longer naming latency.

Summary of Factor Analyses of Study 2b

In line with Study 2a: 1) there are some independent visual factors that may be influenced by IQ or vice versa (e.g., factors 1 and 6 of IWS2; factor 1 of IWL2; factor 6 of NWS2; factors 1 and 5 of NWL2); 2) evidence for a general sensory timing mechanism is suggested by the finding that some visual and auditory measures load on the same factors (e.g., factors 2 and 4 of IWS2; factors 2 and 3 of IWL2; factors 2, 3 and 4 of NWL2); and 3) irregular words are mostly related to the visual measures (e.g., factors 3 and 5 of IWS2; factors 4 and 5 of IWL2) whereas nonsense words (at least in single mode presentation) are related to both visual and auditory measures (e.g., factors 3 and 4 of NWS2).

In addition, this study also shows some independent auditory factors (e.g., factor 2 of NWS2). Words presented continuously are related to both high and low temporal frequency / spatial frequency (both transient and sustained systems) measures (e.g., factors 4 and 5 of IWL2), words presented singly also relate to both systems (e.g., factors 3 and 5 of IWS2; factors 1, 3, 4 and 5 of NWS2). This partially supports the role of the transient visual system in processing words continuously and the role of the sustained visual system in processing words presented singly. However, nonsense words continuous accuracy / latency is not related to any of the sensory measures (factor 6 of NWL2). Hence, it seems that the differential effect of the new text presentation mode is not as effective as the one used in Study 2a. Therefore, multiple regression analyses will be run in 8.6.4 to clarify the relationship between the two visual systems and text presentation mode. The aims of the multiple regression analyses are: 1) to sort out, relative to both visual subsystems, which subsystem dominates in each presentation mode; 2) to investigate the sensory modality effect between the two types of words found previously in the factor analyses.

8.6.4 Multiple Regression Analyses of Study 2b

Results of IWS2, IWL2, NWS2 and NWL2 (session 2) data are summarised below.

Multiple Regression on Irregular Words Single Mode Accuracy (IWSA2)

In this model, one outlier was identified and discarded. Results show that sensory measures and IQ together significantly account for 37.84% of the variance in irregular words single mode accuracy ($F(16,61) = 2.321$, $p = 0.0096$). According to the model, the significant predictors are FSEN2 and IQ. The results are shown in Table 8-17.

Table 8-17: Multiple Regression on Irregular Words Single Mode Accuracy (IWSA2)

D.V.	R^2	adjR^2	F	df	Sig. Predictors	Parameter	Beta	T	p
IWSA2	0.3784	0.2154	2.321	16,61					
					FSEN2	-0.15	-0.37	-2.89	0.0053
					IQ	0.21	0.3	2.44	0.0176

N.B.: FSEN2: Flicker Sensitivity at 2 Hz
IWSA2: Irregular Words Accuracy, Single condition (second session)
IQ: Nonverbal Reasoning Skills measured by Advanced Raven's Progressive Matrices

FSEN2, a low temporal frequency measure, significantly predicts irregular words single mode accuracy. This clarifies previous results and supports the hypothesis that the sustained system is dominant in processing words presented singly.

Multiple Regression on Irregular Words Single Mode Reaction Time (IWST2)

Results are consistent with Study 2a such that sensory measures and IQ nonsignificantly account for 24.74% of the variance in irregular words single mode reaction time ($F(16,62) = 1.274$, $p > 0.05$).

Multiple Regression on Irregular Words Continuous Mode Accuracy (IWLA2)

In this model, one outlier was identified and discarded. Results are consistent with Study 2a such that sensory measures and IQ together significantly account for 43.71% of the variance in irregular words continuous mode accuracy ($F(16,61) = 2.961$, $p = 0.0012$) and the significant predictors are IQ, FSEN12 and BLAN2. The results are shown in Table 8-18.

Table 8-18: Multiple Regression on Irregular Words Continuous Mode Accuracy (IWLA2)

D.V.	R^2	adjR^2	F	df	Sig. Predictors	Parameter	Beta	T	p
IWLA2	0.4371	0.2895	2.961	16,61					
					IQ	0.4	0.6	5.244	0.0001
					FSEN12	-0.15	-0.31	-2.55	0.0132
					BLAN2	-0.1	-0.34	-2.38	0.02

N.B.: FSEN12: Flicker Sensitivity at 12 Hz

BLAN2: Visible Persistence (based on the judgment of a blank) at 2 c/d

IWLA2: Irregular Words Accuracy, Continuous (Line) condition (second session)

IQ: Nonverbal Reasoning Skills measured by Advanced Raven's Progressive Matrices

FSEN12, a high temporal frequency measure, and BLAN2, a low spatial frequency measure, significantly predict irregular words continuous mode accuracy. This reinforces previous results that the transient system is involved in processing words presented continuously.

Multiple Regression on Irregular Words Continuous Mode Reaction Time (IWLT2)

Consistent with Study 2a, results show that sensory measures and IQ nonsignificantly account for 25.91% of the variance in irregular words continuous mode reaction time ($F(16,62) = 1.355$, $p > 0.05$).

Multiple Regression on Nonsense Words Single Mode Accuracy (NWSA2)

In this model, one outlier was identified and discarded. Consistent with Study 2a, results show that sensory measures and IQ nonsignificantly account for 24.06% of the variance in nonsense words single mode accuracy ($F(16,61) = 1.208$, $p > 0.05$).

Multiple Regression on Nonsense Words Single Mode Reaction Time (NWST2)

In line with Study 2a, results show that sensory measures and IQ nonsignificantly account for 16.65% of the variance in nonsense words single mode reaction time ($F(16,62) = 0.774$, $p > 0.05$).

Multiple Regression on Nonsense Words Continuous Mode Accuracy (NWLA2)

In this model, one outlier was identified and discarded. Contrary to Study 2a, results show that sensory measures and IQ nonsignificantly account for 12.42% of the variance in nonsense words continuous mode accuracy ($F(16,61) = 0.54$, $p > 0.05$).

Multiple Regression on Nonsense Words Continuous Mode Reaction Time (NWLT1)

In line with Study 2a, results show that sensory measures and IQ nonsignificantly account for 14.37% of the variance in nonsense words continuous mode reaction time ($F(16,62) = 0.65$, $p > 0.05$).

Summary of Multiple Regression Analyses of Study 2b

In sum, the multiple regression analyses clarify the role of the sustained visual system in single word reading and the role of the transient visual system in continuous word reading. However, the effect of the sensory measures is only found for the irregular words and not nonsense words. Nevertheless, these findings reinforce the relationship between irregular words and visual measures. Although these results are consistent with Study 2a, from the results of nonsense word reading, the differential effect of the new text presentation mode is not as effective as the one used in Study 2a. This will be further discussed in section 8.7.

8.7 Discussion for Study 2b

Similar to Study 2a, results in Study 2b show: 1) a relationship between the visual measures and irregular words; 2) a relationship between the visual and auditory measures and nonsense words; 3) the role of the sustained visual system in single word reading; and 4) the role of the transient visual system in continuous word reading.

Moreover, consistent with Study 2a, the effect of the sensory measures is more pronounced in reading accuracy than in reading latency. In addition, the effect of the visual measures is more pronounced in irregular words than in nonsense words. The effect of IQ on some reading and temporal processing measures also persists in Study 2b.

Although the addition of peripheral information in Study 2b had some effect on irregular word performance, it did not enhance the presentation mode effect in nonsense words. Rather, it attenuated the effect. In the continuous mode condition in Study 2a, the "+" guided the spatial separation between the words and no peripheral information was given during the task. This resulted in a clear-segmented presentation and it is assumed that any effect due to the transient system is attributed to the saccades and not to the peripheral information. On the other hand, the continuous mode presentation involving peripheral information in Study 2b should theoretically enhance the effect of the transient system and therefore should enhance the role of high temporal frequency / low spatial frequency predictors in nonsense word continuous mode accuracy. However, in this study, the addition of peripheral information reduced the presentation mode effect of the nonsense words originally found in Study 2a. A re-examination of the data did not reveal any difference in the variability in the continuous mode accuracy. Thus, the difference could not be attributed to response variability. One speculation is that the addition of "X"s probably requires subjects to "pick out" the word to read. The increasing cognitive demands in picking out the right words is shown by longer naming latency in the continuous mode. These demands may probably take up additional variance which can not be explained by the sensory measures. Therefore, the proportion of the variance accounted for by the sensory measures will become smaller, especially for nonsense words. In other words, rather than enhancing the presentation mode effect, the addition of "X"s may have introduced some extra processes which reduce the hypothesised effect. This also explains why some factors extracted in Study 2a differed from those extracted in Study 2b.

8.8 *Discriminant Function Analyses of Study 2a*

The next analysis is to determine how successfully the temporal processing measures differentiate various reading groups. Results from Study 2a were used in this analysis. Subjects were divided into "irregular word" readers and "nonsense word" readers. I defined subjects who had an accuracy of 15% higher in reading irregular words than nonsense words as "irregular word" readers, whereas those who had an accuracy of 15% higher in reading nonsense words than irregular words as "nonsense word" readers. The categorisation of subjects is based on reading accuracy averaging the presentation mode of the two types of words. Using this criteria, 3 "irregular word" readers (3 females, aged 18 to 41) and 13 "nonsense word" readers (13 females, aged 18 to 29) were identified. The proportion between the two groups is consistent with the prevalence of the dyseidetic and dysphonetic subtypes of Boder and Jarrico (1982). Note that the analysis is arbitrary and done as a preliminary analysis.

To maintain the statistical power of the test, only temporal processing measures that were related to the reading measures were used in the analysis. In addition, auditory temporal order judgment measures were added in order to maintain two types of visual and two types of auditory measures. Therefore, the temporal processing measures examined were flicker sensitivity, visible persistence (based on the judgment of a blank), auditory fusion and auditory temporal order judgment. There were nine temporal processing measures and a MANOVA was used to investigate whether the two groups differed on these measures. The α-level chosen was 0.05.

First, the two groups were compared with reference to the sensory measures. Then discriminant function analyses were run to determine: 1) how successfully the visual measures discriminate the two groups; 2) how successfully the auditory measures discriminate the two groups; and 3) how successfully both measures discriminate the groups.

8.9 Results and Discussion

The original means and standard deviations for the two groups of readers are listed in Table 8-19. Note that a log-transformation had been performed on the data and the statistical analyses were based on the log-transformed data.

Table 8-19: Means and (s.d.) of the Original and Log-transformed Data of the "Irregular Word" and "Nonsense Word" Readers on the Sensory and Reading Measures

	"Irregular Word" Readers (n=3)				"Nonsense Word" Readers (n=13)			
	Original		Log-transformed		Original		Log-transformed	
FSEN2	0.057	(0.004)	-2.87	(0.07)	0.045	(0.012)	-3.14	(0.26)
FSEN12	0.014	(0.005)	-4.28	(0.33)	0.016	(0.004)	-4.19	(0.25)
BLAN2	176.99	(17.63)	5.17	(0.1)	205.49	(60.81)	5.29	(0.27)
BLAN12	247.81	(63.42)	5.49	(0.25)	282.87	(65.37)	5.62	(0.25)
AFUS15	5.32	(1.72)	1.64	(0.3)	3.51	(0.76)	1.24	(0.2)
AFUS100	3.47	(0.84)	1.23	(0.23)	3.03	(0.38)	1.1	(0.12)
ATOJ15	96.29	(72.99)	4.39	(0.7)	62.64	(62.36)	3.7	(1.02)
ATOJ75	163.78	(73.76)	5.03	(0.46)	74.54	(36.89)	4.16	(0.61)
ATOJ200	248.54	(113.43)	5.43	(0.52)	126.6	(113.33)	4.56	(0.77)
IRRA	80.55	(4.81)	4.39	(0.06)	70.77	(6.76)	4.25	(0.1)
NWDA	59.45	(2.55)	4.08	(0.04)	88.97	(6.22)	4.49	(0.07)
IQ	100.67	(18.18)	4.6	(0.18)	108	(17.37)	4.67	(0.18)

N.B.: FSEN2, FSEN12: Flicker Sensitivity at 2 and 12 Hz respectively
BLAN2, BLAN12 (ms): Visible Persistence (based on the judgment of a blank) at 2 and 12 c/d respectively
AFUS15, AFUS100 (ms): Auditory Fusion at 15 and 100 ms respectively
ATOJ15, ATOJ75, ATOJ200 (ms): Auditory Temporal Order Judgment at 15, 75 and 200 ms respectively
IRRA, NWDA (%): Accuracy of Irregular / Nonsense Words respectively
IQ: Nonverbal Reasoning Skills measured by Advanced Raven's Progressive Matrices

Consistent with previous findings, there is a main temporal frequency effect in flicker sensitivity ($t(15) = 17.91$, $p < 0.0001$) and a main spatial frequency effect in visible persistence ($t(15) = 6.09$, $p < 0.0001$). Moreover, the auditory temporal order judgment thresholds are longer than the auditory fusion thresholds ($t(15) = 15.79$, $p < 0.0001$).

The "irregular word" readers read irregular words significantly better than nonsense words ($t(2) = 6.47$, $p < 0.05$). On the other hand, the "nonsense word" readers read nonsense words significantly better than irregular words ($t(12) = -16.45$, $p < 0.05$). Moreover the "irregular word" readers, compared to the "nonsense word" readers, have higher accuracy in reading irregular words ($t(14) = 2.17$, $p < 0.05$). On the other hand, the "nonsense word" readers, compared to the "irregular word" readers, have higher accuracy in reading nonsense words ($t(14) = -8.81$, $p < 0.05$). There is no difference between the two groups on nonverbal IQ ($t(14) = -0.59$, $p > 0.05$).

Comparing the reading groups on the sensory measures, the two groups did not differ on FSEN2 ($F(1,14) = 2.88$, $p > 0.05$), FSEN12 ($F(1,14) = 0.31$, $p > 0.05$), BLAN2 ($F(1,14) = 0.55$, $p > 0.05$), BLAN12 ($F(1,14) = 0.62$, $p > 0.05$), AFUS100 ($F(1,14) = 1.93$, $p > 0.05$), ATOJ15 ($F(1,14) = 1.21$, $p > 0.05$) and ATOJ200 ($F(1,14) = 3.36$, $p > 0.05$). However, the groups did differ on AFUS15 ($F(1,14) = 8.34$, $p = 0.012$) and ATOJ75 ($F(1,14) = 5.26$, $p = 0.038$), with the "nonsense word" readers having lower auditory thresholds. However, this may be due to the small sample size and the large number of measures used, MANOVA showed a nonsignificant combined temporal processing effect on the reading groups (Wilks' $\lambda = 0.19$, $F(9,6) = 2.75$, $p > 0.05$). The results indicate a trend for the "nonsense word" readers to have lower AFUS15 and ATOJ75 thresholds than the "irregular word" readers. This implies that better auditory temporal resolution is associated with better phonological skills. The result supports the proposal (Farmer & Klein, 1995; Watson & Miller, 1993; Watson & Watson, 1993a,b; Tallal et al, 1985a,b) of a relationship between auditory temporal processing and nonsense word reading. On the contrary, "irregular word" readers did not show better visual temporal resolution than the "nonsense word" readers. This implies that better whole-word skills are not associated with better visual temporal resolution and the results are consistent with Borsting et al (1996) and Ridder et al (in press) [The issue will be further elaborated in Chapter 10]. It may be that the differential effect of the visual measures is not as strong as that of the auditory ones.

Three discriminant function analyses were performed on the data, using: 1) visual; 2) auditory; and 3) visual and auditory measures as discriminants for the reading groups.

Using the visual measures, 2 out of 3 (66.67%) of the "irregular word" readers are categorised into the irregular word reading group while 12 out of 13 (92.31%) of the "nonsense word" readers are categorised into the nonsense word reading group. The percentage of correctly classified "grouped" cases is 87.5% and the model is insignificant (Wilks' $\lambda = 0.62$, $\chi^2(4) = 5.69$, $p > 0.05$). Table 8-20 summarises the loadings showing the correlations between the visual measures and the discriminant function. Results indicate that the function is largely a measure of the sustained visual system and the function is not effective in discriminating "irregular word" and "nonsense word" readers.

Table 8-20: Loadings showing Correlations between the Visual Measures and the Discriminant Function

Measure	Loading
FSEN2	-0.58249
FSEN12	-
BLAN2	-
BLAN12	-

N.B.: Loadings below |0.3| not shown

FSEN2, FSEN12: Flicker Sensitivity at 2 and 12 Hz respectively

BLAN2, BLAN12: Visible Persistence (based on the judgment of a blank) at 2 and 12 c/d respectively

Using the auditory and both visual and auditory measures, 3 out of 3 (100%) of the "irregular word" readers are categorised into the irregular word reading group while 13 out of 13 (100%) of the "nonsense word" readers are categorised into the nonsense word reading group. The percentage of correctly classified "grouped" cases is 100%. The auditory model is significant (Wilks' $\lambda = 0.32$, $\chi^2(5) = 13.14$, $p = 0.02$). Table 8-21 summarises the loadings showing the correlations between the auditory measures and the discriminant function. Results indicate that the function is largely a measure of auditory fusion and TOJ and the function is effective in discriminating "irregular word" and "nonsense word" readers. On the contrary, the visual and auditory model is insignificant (Wilks' $\lambda = 0.19$, $\chi^2(9) = 15.53$, $p > 0.05$). Table 8-22 summarises the loadings showing the correlations between the temporal measures and the discriminant function. Results indicate that the function is largely a measure of auditory fusion and TOJ and is not effective in discriminating "irregular word" and "nonsense word" readers.

Table 8-21: Loadings showing Correlations between the Auditory Measures and the Discriminant Function

Measure	Loading
AFUS15	0.52814
AFUS100	-
ATOJ15	-
ATOJ75	0.41955
ATOJ200	0.33501

N.B.: Loadings below |0.3| not shown
AFUS15, AFUS100: Auditory Fusion at 15 and 100 ms respectively
ATOJ15, ATOJ75, ATOJ200: Auditory Temporal Order Judgment at 15, 75 and 200 ms respectively

Table 8-22: Loadings showing Correlations between the Visual and Auditory Measures and the Discriminant Function

Measure	Loading
FSEN2	-
FSEN12	-
BLAN2	-
BLAN12	-
AFUS15	0.37979
AFUS100	-
ATOJ15	-
ATOJ75	0.3017
ATOJ200	-

N.B.: Loadings below |0.3| not shown
FSEN2, FSEN12: Flicker Sensitivity at 2 and 12 Hz respectively
BLAN2, BLAN12: Visible Persistence (based on the judgment of a blank) at 2 and 12 c/d respectively
AFUS15, AFUS100: Auditory Fusion at 15 and 100 ms respectively
ATOJ15, ATOJ75, ATOJ200: Auditory Temporal Order Judgment at 15, 75 and 200 ms respectively

Hence, the auditory measures are stronger and better discriminants than the visual measures in differentiating the reading groups. The result is consistent with the differential effects obtained in MANOVA. In fact, auditory temporal processing measures are generally stronger than visual measures in differentating language-impaired children (Tallal & Piercy, 1973b; Tallal et al, 1981) and these measures are usually stronger predictors for language performance (Watson, 1988; Watson & Miller, 1993; Watson & Watson, 1993a,b; Tallal et al, 1981, 1985a,b; Tallal & Stark, 1982). The results of this study, though based on the work with normals, are in line with dyslexic research. Furthermore, the sample size is small in each group and the statistical power of the test may be limited under this condition. Nevertheless, reanalysis using a less stringent criteria (by decreasing the accuracy discrepancy to 10% between irregular word and nonsense word reading) did not reveal any change in the statistical results. In sum, better phonological skills are associated with better auditory temporal resolution but better whole-word skills are not associated with better visual temporal resolution.

8.10 Discussion

This study aimed to investigate the relationship between various temporal processing measures and reading measures. The major findings are:

1) There are independent visual and auditory factors and these factors may be IQ dependent.

2) The loading of both visual and auditory measures on the same factor(s) implicates a common temporal processing mechanism across both modalities. This is supportive of a common generalised pansensory mechanism(s) in processing sensory information as hypothesised by Miller and Tallal (1995), Galaburda et al (1985, 1994), Farmer and Klein (1995) and Stein (1993). Moreover, the common mechanism(s) may be IQ dependent.

3) Nonverbal IQ is related to some temporal processing and reading measures. This is consistent with previous findings (e.g., Deary, 1980, 1993; Raz et al, 1983; Watson, 1991; Baddeley & Gathercole, 1992; Bowling & Mackenzie, 1996; Stough et al, 1996).

4) Factor analyses of Study 2a showed that irregular word reading is associated with visual temporal processing whereas nonsense word reading is associated with both visual and auditory temporal processing. The results support Farmer and Klein's (1995) suggestion about the modality effect on dyslexic subtypes.

5) However, factor analyses did not reveal any differential effect of the transient and sustained visual systems on the mode of text presentation. Although the results showed that both transient and sustained visual systems are involved in processing words presented continuously, both systems are also involved in processing words presented singly. This contradicts the argument that the sustained visual system is primarily involved in single word reading (Lovegrove, 1991; Breitmeyer, 1993a,b) but is compatible with Hughes et al (1996) that both high and low spatial frequency channels are involved in pattern recognition. Nevertheless, multiple regression analyses confirmed that the sustained visual system is dominant in single word reading whereas the transient system is dominant in continuous word reading. Furthermore, the visual effect was more observable in irregular words than in nonsense words. This reinforces Farmer and Klein's (1995) suggestion.

6) The lack of a differential effect between the transient and sustained visual systems in nonsense word reading led to the speculation that presenting peripheral information in continuous word reading may enhance the role of the transient visual system in continuous word reading. However, this method attenuated the hypothesised effect. One suggestion is that the peripheral information increased the cognitive demands to "pick out" the right word to read and that these demands relatively overwrote the role of the sensory measures.

Furthermore, the results obtained were generally consistent with those obtained without peripheral information.

7) Comparision of the "irregular word" and "nonsense word" readers showed that "nonsense word" readers tended to have better auditory temporal resolution than "irregular word" readers. This reinforces the relationship between better auditory temporal processing ability and better phonological processing as suggested by Farmer and Klein (1995), Watson and Miller (1993), Watson and Watson (1993a,b) and Tallal et al (1985a). On the other hand, in line with Borsting et al (1996) and Ridder et al (in press), "irregular word" readers did not exhibit better visual temporal resolution. Thus, better phonological skills are associated with better auditory temporal resolution but better whole-word skills are not associated with better visual temporal resolution.

8) Discriminant function analyses were run on the data to determine how successfully the sensory measures discriminated "irregular word" and "nonsense word" readers. Auditory measures were better discriminants than visual measures.

One difficulty in conducting this research is the sample size. Tabachnick and Fidell (1989) recommended at least 5 cases for each observed variable in factor analysis and at least 5 times more cases than independent variables (IV) in multiple regression. With a sample size of 79 and 16 IVs used in the multiple regressions, the ratio of cases to IVs roughly fulfills the requirement. However, there are 18 observed variables in each factor analysis and thus my sample size is comparatively marginal. Nevertheless, as the results of the factor analyses are consistent with those in Pearson correlation and multiple regressions, it is reasonable to conclude that even with a marginal sample size, the results of the factor analyses are generally quite robust.

As stressed before, the sample sizes are small in the irregular-word reading group and nonsense-word reading group, especially the former. The statistical power of the test may be limited under this condition. Furthermore, reanalysis using a less stringent criteria (by decreasing the discrepancy to 10% between irregular word accuracy and nonsense word accuracy) did not reveal any change in the statistical results. In general, it is harder to find "irregular word" readers than "nonsense word" readers. My sample size is consistent with the prevalence of the dysphonetic and dyseidetic subtypes, with a ratio of 4 to 1 (Boder & Jarrico, 1982).

Thus, the next study will focus on the relationship between the sensory temporal processing measures and various reading ability by using a larger sample size and fewer measures. Good and normal readers will be recruited to see whether good readers will exhibit better temporal processing ability than normal readers. Methods of comparison will be similar to those used on "irregular word" and "nonsense word" readers.

Chapter 9: Study 3

The Implication of Temporal Processing on Reading Ability

9.1 Rationale

The major findings from Study 2 partially support Farmer and Klein's (1995) suggestion that temporal processing differences in different modalities are associated with different reading subtypes; and also the differential involvement of the sustained and transient visual subsystems in single and continuous word reading, as argued by Hill and Lovegrove (1992) and Breitmeyer (1993a,b).

In addition, Study 2 showed that "nonsense word" readers tended to exhibit better auditory temporal resolution and better phonological processing skills than the "irregular word" readers. On the other hand, "irregular word" readers who had better sight-word skills did not exhibit better visual temporal resolution than the "nonsense word" readers. Moreover, auditory measures discriminated better than visual measures between different "types" of readers. Apart from arguing that auditory measures are generally stronger and more effective than the visual measures in differentiating various reading groups, the results also reinforce the relationship between auditory temporal processing and phonological ability, as argued by Watson and Miller (1993), Watson and Watson (1993a,b) and Tallal et al (1985a).

In the previous study, number of subjects compared to number of measures was not high and the subgroups analyses were post-hoc. Therefore, firstly, this study aimed to verify the results of Study 2: namely, 1) the relationship between recognition of irregular words and nonsense words and visual and auditory temporal processing; 2) the role of the sustained and transient visual systems in single and continuous word reading; and 3) the advantage of having better auditory temporal resolution in "nonsense word" readers. This will be done using a larger sample size and limiting the number of measures used. Measures to be used included flicker sensitivity, visible persistence based on the judgment of a blank, auditory fusion, auditory TOJ, reading accuracy and IQ. The reason for choosing these measures has been presented in the previous study. Results similar to those in Study 2 are expected.

Since dyslexics and dysphasics are impaired in some visual and auditory temporal processing tasks (see Chapter 4), the second aim of this study was to examine the relationship between various measures of rapid temporal processing and reading ability. Adult readers were divided into good and normal readers and the above temporal processing measures were administered. It was hypothesised that good readers should have better temporal processing ability than normal readers. Additionally, discriminant function analyses were run to determine how successfully the temporal processing measures discriminate different reading groups.

9.2 STUDY 3

Method

9.2.1 Subjects

105 undergraduates (17 males, 88 females, aged 17 to 55) who had never participated in Studies 1 and 2 participated in this study. The selection criteria were the same as in Study 2 except that subjects had to have a nonverbal reasoning IQ of 85 or above as measured by the Advanced Raven's Progressive Matrices. In addition, subjects were divided into different reading groups according to the following criteria:

i) "Irregular Word" Readers vs "Nonsense Word" Readers:

These groups identified readers who performed more accurately in recognising irregular words than nonsense words or the reverse. To obtain a larger sample, an accuracy discrepancy of 10% between irregular and nonsense word reading was used. Using this criteria, 10 "irregular word" readers (3 males, 7 females, aged 17 to 28) and 34 "nonsense word" readers (4 males, 30 females, aged 17 to 37) were identified.

ii) Good Readers vs Normal Readers:

Subjects who scored at or above 75th percentile in the Wide Range Achievement Test (WRAT) reading and spelling were considered good readers, whereas those who scored below 75th percentile in WRAT reading and spelling were considered normal readers. Using this criteria, 31 good readers (6 males, 25 females, aged 17 to 55) and 46 normal readers (8 males, 38 females, aged 17 to 37) were identified.

9.2.2 Tests and Procedures

The study consisted of four experimental sessions. The first session consisted of the Raven's nonverbal reasoning IQ test. The second session consisted of WRAT and irregular words and nonsense words reading tests. The third session consisted of visible persistence based on the judgment of a blank, auditory fusion and auditory TOJ tasks. The last session consisted of the flicker sensitivity task. Testing procedures were the same as those used in Study 2. Due to equipment constraints, counterbalancing between experiments was difficult. However, since data were taken within a short period of time and the temporal processing measures are relatively "independent" of each other, the carry over of "practice effect" from one task to subsequent ones was negligible. Hence, failure in counterbalancing the tasks was unlikely to have any significant impact on the results.

9.3 Results

A log-transformation was performed on the data to achieve normal distribution and homogeneous variance for better comparison. All statistical analyses were based on the log-transformed data.

9.3.1 Verification of Study 2

The means and standard deviations of the original and the log-transformed data are shown in Table 9-1.

Table 9-1: Means and (s.d.) of the Visual, Auditory and Reading Measures and their Log-transformed Data (N=105)

Task	Original		Log-transformed	
FSEN2	0.027	(0.009)	-3.65	(0.31)
FSEN12	0.014	(0.005)	-4.29	(0.31)
BLAN2	172.16	(60.42)	5.08	(0.38)
BLAN12	265.38	(96.77)	5.52	(0.34)
AFUS15	3.54	(1.43)	1.21	(0.33)
AFUS100	2.71	(0.49)	0.98	(0.19)
ATOJ15	65.44	(56.23)	3.89	(0.78)
ATOJ75	84.14	(62.93)	4.24	(0.62)
ATOJ200	114.73	(59.14)	4.61	(0.52)
IWSA	75.68	(10.4)	4.32	(0.15)
IWLA	75.33	(9.96)	4.31	(0.14)
NWSA	80.22	(11.56)	4.37	(0.17)
NWLA	80.51	(10.68)	4.38	(0.14)
IQ	111.55	(13.12)	4.71	(0.12)

N.B.: FSEN2, FSEN12: Flicker Sensitivity at 2 and 12 Hz respectively

BLAN2, BLAN12 (ms): Visible Persistence (based on the judgment of a blank) at 2 and 12 c/d respectively

AFUS15, AFUS100 (ms): Auditory Fusion at 15 and 100 ms respectively

ATOJ15, ATOJ75, ATOJ200 (ms): Auditory Temporal Order Judgment at 15, 75 and 200 ms respectively

IWSA, IWLA (%): Irregular Words Accuracy, Single / Continuous (Line) condition

NWSA, NWLA (%): Nonsense Words Accuracy, Single / Continuous (Line) condition

IQ: Nonverbal Reasoning Skills measured by Advanced Raven's Progressive Matrices

i) Reliability of Visual and Auditory Measures

Consistent with previous findings: 1) contrast threshold at low temporal frequency was higher than that at high temporal frequency ($t(104) = 25.95$, $p < 0.0001$); 2) visible persistence duration at low spatial frequency was shorter than that at high spatial frequency ($t(104) = 14.03$, $p < 0.0001$); and 3) the auditory fusion thresholds were shorter than those of auditory TOJ ($t(104) = 55.65$, $p < 0.0001$).

ii) Pearson Correlations

The Pearson correlation coefficients among the measures are shown in Table 9-2.

Table 9-2: Correlation Matrix of the Log-transformed Data of the Visual, Auditory and Reading Tasks (N=105)

	FSEN2	FSEN12	BLAN2	BLAN12	AFUS15	AFUS100	ATOJ15	ATOJ75	ATOJ200	IWSA	IWLA	NWSA	NWLA	IQ
FSEN2	1.0000													
FSEN12	0.6804**	1.0000												
BLAN2	0.3401**	0.4013**	1.0000											
BLAN12	0.3895**	0.3319**	0.6076**	1.0000										
AFUS15	0.0648	0.0722	0.0985	0.0133	1.0000									
AFUS100	0.1253	0.1932*	0.182	0.1573	0.2649**	1.0000								
ATOJ15	0.162	0.0664	0.1908	0.2084*	0.1866	0.0517	1.0000							
ATOJ75	0.1478	0.1355	0.207*	0.171	0.2062*	0.102	0.7816**	1.0000						
ATOJ200	0.1067	0.0688	0.1562	0.1529	0.095	0.162	0.7259**	0.717**	1.0000					
IWSA	-0.136	-0.1761	-0.1046	-0.0827	-0.1443	-0.0926	-0.218*	-0.1658	-0.1692	1.0000				
IWLA	-0.1437	-0.0781	-0.171	-0.0869	-0.1705	-0.145	-0.2702**	-0.1572	-0.2005*	0.584**	1.0000			
NWSA	-0.1085	-0.0943	-0.0203	-0.0471	-0.3273**	-0.1415	-0.2268*	-0.2076*	-0.2487*	0.3484**	0.3471**	1.0000		
NWLA	-0.0786	-0.1106	-0.0413	-0.002	-0.3808**	-0.2168*	-0.2478*	-0.2081*	-0.2171*	0.4188**	0.3786**	0.6968**	1.0000	
IQ	-0.1237	-0.1476	-0.1266	-0.192*	-0.2309*	-0.0045	-0.1152	-0.1972*	-0.1734	0.2421*	0.2957**	0.1918*	0.129	1.0000

* p<.05
** p<.01

N.B.: FSEN2, FSEN12: Flicker Sensitivity at 2 and 12 Hz respectively
BLAN2, BLAN12: Visible Persistence (based on the judgment of a blank) at 2 and 12 c/d respectively
AFUS15, AFUS100: Auditory Fusion at 15 and 100 ms respectively
ATOJ15, ATOJ75, ATOJ200: Auditory Temporal Order Judgment at 15, 75 and 200 ms respectively
IWSA, IWLA: Irregular Words Accuracy, Single / Continuous (Line) condition
NWSA, NWLA: Nonsense Words Accuracy, Single / Continuous (Line) condition
IQ: Nonverbal Reasoning Skills measured by Advanced Raven's Progressive Matrices

In general,

1) FSEN2 correlates significantly with FSEN12 (r = 0.6804), BLAN2 (r = 0.3401) and BLAN12 (r = 0.3895). FSEN12 significantly correlates with BLAN2 (r = 0.4013) and BLAN12 (r = 0.3319). BLAN2 significantly correlates with BLAN12 (r = 0.6076). The significant positive correlations among the visual measures indicate that higher persistence thresholds are related to higher contrast thresholds.

2) The positive correlations between the visual and auditory measures indicate that the poorer the temporal resolution in one modality, the poorer is the temporal resolution in the other: e.g., FSEN12 correlates with AFUS100 (r = 0.1932), BLAN2 correlates with ATOJ75 (r = 0.207), and BLAN12 correlates with ATOJ15 (r = 0.2084).

3) The positive correlations between the auditory measures indicate that higher auditory fusion thresholds are related to higher auditory TOJ thresholds: AFUS15 significantly correlates with AFUS100 (r = 0.2649) and ATOJ75 (r = 0.2062). ATOJ15 correlates with ATOJ75 (r = 0.7816) and ATOJ200 (r = 0.7259). ATOJ75 correlates with ATOJ200 (r = 0.717).

4) The reading accuracies positively correlate with each other: IWSA significantly correlates with IWLA (r = 0.584), NWSA (r = 0.3484) and NWLA (r = 0.4188). IWLA significantly correlates with NWSA (r = 0.3471) and NWLA (r = 0.3786). NWSA significantly correlates with NWLA (r = 0.6968).

5) The visual measures do not correlate significantly with the irregular word accuracies but the auditory measures correlate with the irregular word accuracies: IWSA significantly correlates with ATOJ15 (r = -0.218). IWLA

correlates with ATOJ15 (r = -0.2702) and ATOJ200 (r = -0.2005). The negative correlations indicate that higher accuracies are related to better auditory temporal resolution.

6) There are also significant correlations between nonsense word reading accuracies and auditory measures: NWSA correlates with AFUS15 (r = -0.3273), ATOJ15 (r = -0.2268), ATOJ75 (r = -0.2076) and ATOJ200 (r = -0.2487). NWLA significantly correlates with AFUS15 (r = -0.3808), AFUS100 (r = -0.2168), ATOJ15 (r = -0.2478), ATOJ75 (r = -0.2081) and ATOJ200 (r = -0.2171). Similarly, the negative correlations indicate that higher accuracies are related to better auditory temporal resolution.

7) IQ significantly correlates with both visual and auditory measures and reading accuracies. The negative correlations between IQ and visual and auditory measures indicate that higher IQ is related to better temporal resolution: e.g., IQ significantly correlates with BLAN12 (r = -0.192), AFUS15 (r = -0.2309) and ATOJ75 (r = -0.1972). The positive correlations between IQ and reading accuracies indicate higher IQ is related to higher accuracies: e.g., IQ significantly correlates with IWSA (r = 0.2421), IWLA (r = 0.2957) and NWSA (r = 0.1918).

Similar to Study 2, factor analyses and multiple regression analyses were used to investigate the relationship between the types of words, modes of presentation and different temporal processing measures. To minimise the number of variables, only reading accuracies were examined.

iii) Factor Analyses

Principal components factor analyses with varimax rotation were performed on the temporal processing measures with: 1) irregular words single mode accuracy (IWSA); 2) irregular words continuous mode accuracy (IWLA); 3) nonsense words single mode accuracy (NWSA); and 4) nonsense words continuous mode accuracy (NWLA) separately. Results are summarised below.

Factor Analysis on Irregular Words Single Mode Presentation (IWSA)

Four factors accounting for 67.98% of the variance were extracted in the analysis. They are summarised in Table 9-3.

Table 9-3: Factor Analysis on Irregular Words Single Mode Presentation (IWSA)

	F1	F2	F3	F4	
FSEN2	-	0.77538	-	-	
FSEN12	-	0.77837	-	-	
BLAN2	-	0.73737	-	-	
BLAN12	-	0.74433	-	-	
AFUS15	-	-	-0.3712	0.71995	
AFUS100	-	-	-	0.83383	
ATOJ15	0.90962	-	-	-	
ATOJ75	0.8905	-	-	-	
ATOJ200	0.8836	-	-	-	
IWSA	-	-	0.68854	-	
IQ	-	-	0.77623	-	
Eigenvalue	3.251	1.947	1.225	1.054	Total = 7.477
Variance Explained	29.56%	17.7%	11.14%	9.58%	Total = 67.98%

N.B.: Loadings below |0.3| not shown

FSEN2, FSEN12: Flicker Sensitivity at 2 and 12 Hz respectively

BLAN2, BLAN12: Visible Persistence (based on the judgment of a blank) at 2 and 12 c/d respectively

AFUS15, AFUS100: Auditory Fusion at 15 and 100 ms respectively

ATOJ15, ATOJ75, ATOJ200: Auditory Temporal Order Judgment at 15, 75 and 200 ms respectively

IWSA: Irregular Words Accuracy, Single condition

IQ: Nonverbal Reasoning Skills measured by Advanced Raven's Progressive Matrices

The first factor is weighted on by the auditory temporal order judgment measures. It accounts for 29.56% of the variance explained. The factor refers to auditory TOJ.

The second factor is weighted on by the flicker sensitivity and visible persistence measures. It accounts for 17.7% of the variance explained. The factor indicates a common visual mechanism such that higher contrast thresholds are related to longer visible persistence.

The third factor is weighted on by auditory fusion at 15 ms, irregular words single mode reading accuracy and IQ. It accounts for 11.14% of the variance explained. The loadings imply higher reading accuracy is related to lower auditory fusion thresholds (better auditory temporal resolution) and higher IQ.

The fourth factor is weighted on by the auditory fusion measures. It accounts for 9.58% of the variance explained. The factor represents auditory fusion.

In sum, the factor analysis of performance on irregular words presented singly indicates that:

1) There is a common visual factor on flicker sensitivity and visible persistence, as shown by factor 2.
2) There are independent auditory fusion and TOJ factors, as shown by factors 1 and 4. The large sample size may have successfully categorised the two tasks in a more precise way than the previous study.
3) Factor 3 shows that irregular word reading accuracy does not load with the visual measures. It loads with IQ and auditory fusion. The strong auditory effect may have overrode the weak visual effect especially when a large sample size is

used. This will be further clarified in the multiple regression analyses reported in section iv).

Factor Analysis on Irregular Words Continuous Mode Presentation (IWLA)

Four factors accounting for 68.35% of the variance were extracted in this analysis. They are summarised in Table 9-4.

Table 9-4: Factor Analysis on Irregular Words Continuous Mode Presentation (IWLA)

	F1	F2	F3	F4	
FSEN2	-	0.78497	-	-	
FSEN12	-	0.79447	-	-	
BLAN2	-	0.7249	-	-	
BLAN12	-	0.73634	-	-	
AFUS15	-	-	-0.37466	0.69033	
AFUS100	-	-	-	0.84485	
ATOJ15	0.90943	-	-	-	
ATOJ75	0.89351	-	-	-	
ATOJ200	0.88389	-	-	-	
IWLA	-	-	0.67869	-	
IQ	-	-	0.8384	-	
Eigenvalue	3.274	1.95	1.256	1.04	Total = 7.52
Variance Explained	29.76%	17.73%	11.41%	9.45%	Total = 68.35%

N.B.: Loadings below |0.3| not shown
FSEN2, FSEN12: Flicker Sensitivity at 2 and 12 Hz respectively
BLAN2, BLAN12: Visible Persistence (based on the judgment of a blank) at 2 and 12 c/d respectively
AFUS15, AFUS100: Auditory Fusion at 15 and 100 ms respectively
ATOJ15, ATOJ75, ATOJ200: Auditory Temporal Order Judgment at 15, 75 and 200 ms respectively
IWLA: Irregular Words Accuracy, Continuous (Line) condition
IQ: Nonverbal Reasoning Skills measured by Advanced Raven's Progressive Matrices

The first factor is weighted on by the auditory TOJ measures. It accounts for 29.76% of the variance explained. This factor is equivalent to factor 1 of IWSA.

The second factor is weighted on by the visual measures. It accounts for 17.73% of the variance explained. This factor is equivalent to factor 2 of IWSA.

The third factor is weighted on by auditory fusion at 15 ms, irregular words continuous mode reading accuracy and IQ. It accounts for 11.41% of the variance explained. This factor is equivalent to factor 3 of IWSA.

The fourth factor is weighted on by the auditory fusion measures. It accounts for 9.45% of the variance explained. The factor is equivalent to factor 4 of IWSA.

In sum, the factor analysis shows that the results of IWLA are equivalent to those of IWSA, namely:

1) There are individual visual (factor 2) and auditory factors (factors 1 and 4).
2) The visual measures do not load with irregular word reading accuracy but the auditory measure does. Consequently, there is no differential visual effect between IWLA and IWSA. This will be further clarified in the multiple regression analyses reported in section iv).

Factor Analysis on Nonsense Words Single Mode Presentation (NWSA)

Four factors accounting for 68.7% of the variance were extracted in this analysis. They are summarised in Table 9-5.

Table 9-5: Factor Analysis on Nonsense Words Single Mode Presentation (NWSA)

	F1	F2	F3	F4	
FSEN2	-	0.77914	-	-	
FSEN12	-	0.79113	-	-	
BLAN2	-	0.73675	-	-	
BLAN12	-	0.74133	-	-	
AFUS15	-	-	0.77611	-	
AFUS100	-	-	0.32644	0.79349	
ATOJ15	0.90964	-	-	-	
ATOJ75	0.88765	-	-	-	
ATOJ200	0.88297	-	-	-	
NWSA	-	-	-0.69516	-	
IQ	-	-	-0.55905	0.57875	
Eigenvalue	3.257	1.973	1.326	1.001	Total = 7.557
Variance Explained	29.61%	17.93%	12.06%	9.1%	Total = 68.7%

N.B.: Loadings below |0.3| not shown

FSEN2, FSEN12: Flicker Sensitivity at 2 and 12 Hz respectively

BLAN2, BLAN12: Visible Persistence (based on the judgment of a blank) at 2 and 12 c/d respectively

AFUS15, AFUS100: Auditory Fusion at 15 and 100 ms respectively

ATOJ15, ATOJ75, ATOJ200: Auditory Temporal Order Judgment at 15, 75 and 200 ms respectively

NWSA: Nonsense Words Accuracy, Single condition

IQ: Nonverbal Reasoning Skills measured by Advanced Raven's Progressive Matrices

The first factor is weighted on by the auditory TOJ measures. It accounts for 29.61% of the variance explained. This factor is equivalent to factor 1 of IWSA.

The second factor is weighted on by the visual measures. It accounts for 17.93% of the variance explained. This factor is equivalent to factor 2 of IWSA.

The third factor is weighted on by the auditory fusion measures, nonsense words single mode reading accuracy and IQ. It accounts for 12.06% of the variance explained. The factor implies that higher fusion threshold (poorer auditory temporal resolution) is related to lower IQ and reading accuracy and the factor is similar to factor 3 of NWS1 in Study 2a.

The fourth factor is weighted on by the auditory fusion at 100 ms and IQ. It accounts for 9.1% of the variance explained. Although the factor shows the dependence of auditory temporal processing on IQ, the loading shows that, contrary to what is expected, higher fusion thresholds are related to higher IQ.

In sum, the factor analysis of performance on nonsense words presented singly shows that:

1) There are individual visual (factor 2) and auditory factors (factors 1 and 4) and that these factors may depend upon IQ.

2) The auditory measures load with nonsense word reading accuracy. This is supportive of previous findings. However, no visual effect is observed in this analysis. The results will be further clarified in the multiple regression analyses reported in section iv).

Factor Analysis on Nonsense Words Continuous Mode Presentation (NWLA)

Three factors accounting for 60.14% of the variance were extracted in this analysis. They are summarised in Table 9-6.

Table 9-6: Factor Analysis on Nonsense Words Continuous Mode Presentation (NWLA)

	F1	F2	F3
FSEN2	-	0.77278	-
FSEN12	-	0.77938	-
BLAN2	-	0.73729	-
BLAN12	-	0.74776	-
AFUS15	-	-	0.80138
AFUS100	-	-	0.5703

Table 9-6 (cont.)

	F1	F2	F3	
ATOJ15	0.90714	-	-	
ATOJ75	0.89	-	-	
ATOJ200	0.8786	-	-	
NWLA	-	-	-0.72808	
IQ	-	-	-0.3068	
Eigenvalue	3.256	1.975	1.38	Total = 6.615
Variance Explained	29.6%	17.96%	12.58%	Total = 60.14%

N.B.: Loadings below |0.3| not shown
FSEN2, FSEN12: Flicker Sensitivity at 2 and 12 Hz respectively
BLAN2, BLAN12: Visible Persistence (based on the judgment of a blank) at 2 and 12 c/d respectively
AFUS15, AFUS100: Auditory Fusion at 15 and 100 ms respectively
ATOJ15, ATOJ75, ATOJ200: Auditory Temporal Order Judgment at 15, 75 and 200 ms respectively
NWLA: Nonsense Words Accuracy, Continuous (Line) condition
IQ: Nonverbal Reasoning Skills measured by Advanced Raven's Progressive Matrices

The first factor is weighted on by the auditory TOJ measures. It accounts for 29.6% of the variance explained. This factor is equivalent to factor 1 of IWSA.

The second factor is weighted on by the visual measures. It accounts for 17.96% of the variance explained. This factor is equivalent to factor 2 of IWSA.

The third factor is weighted on by the auditory fusion measures, nonsense words continuous mode reading accuracy and IQ. It accounts for 12.58% of the variance explained. The factor is equivalent to factor 3 of NWSA and is similar to factor 3 of NWL1 in Study 2a.

Similar to the results of NWSA, the factor analysis of performance on nonsense words presented continuously shows that:

1) There are individual visual (factor 2) and auditory factors (factor 1).

2) The auditory measures load with nonsense word reading accuracy. This is supportive of previous findings. Similar to the results of NWSA, no visual effect is obtained. The results will be further clarified in the multiple regression analyses reported in section iv).

iv) Multiple Regression Analyses

Standard multiple regressions were run on the IWSA, IWLA, NWSA and NWLA data respectively. The method is the same as that in Study 2. Results are summarised below.

Multiple Regression on Irregular Words Single Mode Accuracy (IWSA)

In this model, two outliers were identified and discarded. Results show that sensory measures and IQ insignificantly account for 12.9% of the variance in irregular words single mode accuracy ($F(10,92) = 1.363$, $p > 0.05$). This is inconsistent with the finding in Study 2 that FSEN2 significantly predicted IWSA. This will be discussed more fully later.

Multiple Regression on Irregular Words Continuous Mode Accuracy (IWLA)

In this model, one outlier was identified and discarded. Results show that sensory measures and IQ together significantly account for 25.33% of the variance in irregular words continuous mode accuracy ($F(10,93) = 3.155$, $p = 0.0016$). According to the model, the significant predictors are IQ and ATOJ15. The results are shown in Table 9-7.

Table 9-7: Multiple Regression on Irregular Words Continuous Mode Accuracy (IWLA)

D.V.	R^2	adjR^2	F	df	Sig. Predictors	Parameter	Beta	T	p
IWLA	0.2533	0.1731	3.155	10,93					
					IQ	0.38	0.34	3.56	0.0006
					ATOJ15	-0.08	-0.48	-2.96	0.0036

N.B.: ATOJ15: Auditory Temporal Order Judgment at 15 ms
IWLA: Irregular Words Accuracy, Continuous (Line) condition
IQ: Nonverbal Reasoning Skills measured by Advanced Raven's Progressive Matrices

Contrary to the results of Study 2 where FSEN12 and BLAN2 significantly predicted IWLA, no visual measures significantly predicting irregular word reading accuracy in this study. By contrast, the auditory measure does. The significant correlations between irregular words and some auditory measures may explain this finding. This will be discussed later.

Multiple Regression on Nonsense Words Single Mode Accuracy (NWSA)

In this model, three outliers were identified and discarded. Results show that sensory measures and IQ nonsignificantly account for 16.5% of the variance in nonsense words single mode accuracy ($F(10,91) = 1.798$, $p > 0.05$).

Multiple Regression on Nonsense Words Continuous Mode Accuracy (NWLA)

In this model, one outlier was identified and discarded. Results show that sensory measures and IQ together significantly account for 19.96% of the variance in nonsense words continuous mode accuracy ($F(10,93) = 2.32$, $p = 0.017$). According to the model, the significant predictor is AFUS15. The results are shown in Table 9-8.

Table 9-8: Multiple Regression on Nonsense Words Continuous Mode Accuracy (NWLA)

D.V.	R^2	adjR^2	F	df	Sig. Predictors	Parameter	Beta	T	p
NWLA	0.1996	0.1136	2.32	10,93					
					AFUS15	-0.13	-0.31	-3.05	0.003

N.B.: AFUS15: Auditory Fusion at 15 ms
NWLA: Nonsense Words Accuracy, Continuous (Line) condition

The prediction of nonsense words continuous mode accuracy by AFUS15 is consistent with the involvement of auditory processing in nonsense word reading as suggested by Study 2.

v) Summary and Discussion of Factor Analyses and Multiple Regression Analyses

While the factor analyses and multiple regression analyses replicate the relationship between auditory temporal processing and nonsense word reading, they fail to replicate the effect of visual measures on irregular word reading. Moreover, this study provides no evidence of the differential effect of the transient and sustained visual systems in single and continuous text presentation.

One possible reason for this discrepancy is that: only subjects with IQ at or above 85 were selected for this study whereas in Study 2, in order to see the effect on a general English-speaking University sample, the author did not control for this factor. As stressed in Chapter 5 and from previous findings, IQ may contribute to individual's temporal processing ability such that better IQ results in better temporal resolution or vice versa (Raz et al, 1987; Bowling & Mackenzie, 1996; Deary, 1995; Stough et al, 1996). Moreover, visual temporal processing indexed by visual inspection time is more related to performance IQ than to verbal IQ (Deary, 1993; Stough et al, 1996). Since nonverbal IQ is used in this study, it is reasonable to suggest the control of IQ may have eliminated the visual effect.

Secondly, Watson and Watson (1993b) found that nonverbal temporal processing was unrelated to phonological processing once intelligence was controlled. From previous findings, auditory measures are stronger than the visual ones. Thus, it is also possible that the control of IQ weakened the visual effect but not the auditory effect. In other words, visual measures may be more vulnerable to the effect of IQ whereas auditory measures remain relatively robust to this change.

Thirdly, the statistical analyses have been improved by using a larger sample and fewer parameters. This improvement is observed when very clear-cut individual visual and auditory factors are extracted. Moreover, the reading data show no floor or ceiling effects which could hinder the function of the analyses. Therefore, the auditory effect may have masked the visual effect in this study.

9.3.2 "Irregular Word" Readers vs "Nonsense Word" Readers

The method of comparison of different groups of readers here is the same as that in Study 2 except the "irregular word" readers and "nonsense word" readers were selected using a 10% discrepancy (rather than 15%) between irregular word and nonsense word reading accuracies for each subject. Similarly, the categorisation is based on reading accuracy averaging the presentation modes of the two types of words. The means and standard deviations of the original and the log-transformed data of the reading groups are shown in Table 9-9.

Table 9-9: Means and (s.d.) of the Original and Log-transformed Data of the "Irregular Word" and "Nonsense Word" Readers on the Sensory and Reading Measures

	"Irregular Word" Readers (n=10)				"Nonsense Word" Readers (n=34)			
	Original		Log-transformed		Original		Log-transformed	
FSEN2	0.025	(0.009)	-3.72	(0.3)	0.027	(0.008)	-3.65	(0.27)
FSEN12	0.013	(0.005)	-4.4	(0.34)	0.014	(0.005)	-4.3	(0.33)
BLAN2	148.76	(58.67)	4.93	(0.42)	180.84	(67.12)	5.13	(0.39)
BLAN12	271.56	(93.13)	5.55	(0.36)	277.02	(104.33)	5.57	(0.34)
AFUS15	4.58	(2.57)	1.42	(0.45)	3.36	(1.15)	1.17	(0.28)
AFUS100	2.63	(0.57)	0.94	(0.23)	2.7	(0.48)	0.97	(0.19)
ATOJ15	91.23	(88.87)	4.1	(0.97)	69.09	(60.85)	3.93	(0.81)
ATOJ75	99.56	(85.14)	4.31	(0.82)	85.99	(64.81)	4.24	(0.66)
ATOJ200	133.04	(61.23)	4.8	(0.43)	118.39	(64.9)	4.62	(0.59)
IRRA	76	(7.67)	4.33	(0.1)	68.58	(8.38)	4.22	(0.13)
NWDA	62.83	(8.57)	4.13	(0.14)	84.85	(7.19)	4.44	(0.09)
IQ	109.4	(12.62)	4.69	(0.12)	107.44	(10.95)	4.67	(0.1)

N.B.: FSEN2, FSEN12: Flicker Sensitivity at 2 and 12 Hz respectively
BLAN2, BLAN12 (ms): Visible Persistence (based on the judgment of a blank) at 2 and 12 c/d respectively
AFUS15, AFUS100 (ms): Auditory Fusion at 15 and 100 ms respectively
ATOJ15, ATOJ75, ATOJ200 (ms): Auditory Temporal Order Judgment at 15, 75 and 200 ms respectively
IRRA, NWDA (%): Accuracy of Irregular / Nonsense Words respectively
IQ: Nonverbal Reasoning Skills measured by Advanced Raven's Progressive Matrices

The "irregular word" readers read irregular words significantly better than nonsense words ($t(9) = -11.53$, $p < 0.05$) while the "nonsense word" readers read nonsense words significantly better than irregular words ($t(33) = 16.62$, $p < 0.05$). Moreover the "irregular word" readers, compared to the "nonsense word" readers, read irregular words more accurately ($t(42) = 2.39$, $p < 0.05$). On the other hand, the "nonsense word" readers, compared to the "irregular word" readers, have higher accuracy in reading nonsense words ($t(42) = -8.35$, $p < 0.05$). There is no difference between the two groups on nonverbal IQ ($t(42) = 0.44$, $p > 0.05$).

Comparing the reading groups on the sensory measures, the two groups did not differ on FSEN2 ($F(1,42) = 0.43$, $p > 0.05$), FSEN12 ($F(1,42) = 0.67$, $p > 0.05$), BLAN2 ($F(1,42) = 1.99$, $p > 0.05$), BLAN12 ($F(1,42) = 0.02$, $p > 0.05$), AFUS100 ($F(1,42) =

0.18, $p > 0.05$), ATOJ15 ($F(1,42) = 0.31$, $p > 0.05$), ATOJ75 ($F(1,42) = 0.08$, $p > 0.05$) and ATOJ200 ($F(1,42) = 0.82$, $p > 0.05$). Although the groups differed on AFUS15 ($F(1,42) = 4.58$, $p = 0.038$), with the "nonsense word" readers having lower auditory thresholds, MANOVA showed a nonsignificant combined temporal processing effect on the reading groups (Wilks' $\lambda = 0.77$, $F(9,34) = 1.13$, $p > 0.05$). The results support those of Study 2 such that there is a trend for the "nonsense word" readers to have lower auditory fusion thresholds than the "irregular word" readers and that better auditory temporal resolution is associated with better phonological skills.

Three discriminant function analyses were performed on the data, using: 1) visual; 2) auditory; and 3) visual and auditory measures as discriminants for the reading groups.

Using the visual measures, 5 out of 10 (50%) of the "irregular word" readers are categorised into the irregular word reading group while 24 out of 34 (70.59%) of the "nonsense word" readers are categorised into the nonsense word reading group. The percentage of correctly classified "grouped" cases is 65.91% and the model is nonsignificant (Wilks' $\lambda = 0.93$, $\chi^2(4) = 2.73$, $p > 0.05$). Table 9-10 summarises the loadings showing the correlations between the visual measures and the discriminant function. Results indicate that the function is largely a measure of the transient visual system because FSEN and BLAN2 have higher correlations. Therefore, consistent with Study 2, the visual measures are not effective in discriminating "irregular word" and "nonsense word" readers.

Table 9-10: Loadings showing Correlations between the Visual Measures and the Discriminant Function

Measure	Loading
FSEN2	0.37979
FSEN12	0.47507
BLAN2	0.81972
BLAN12	-

N.B.: Loadings below |0.3| not shown

FSEN2, FSEN12: Flicker Sensitivity at 2 and 12 Hz respectively

BLAN2, BLAN12: Visible Persistence (based on the judgment of a blank) at 2 and 12 c/d respectively

Using the auditory measures, 5 out of 10 (50%) of the "irregular word" readers are categorised into the irregular word reading group while 27 out of 34 (79.41%) of the "nonsense word" readers are categorised into the nonsense word reading group. The percentage of correctly classified "grouped" cases is 72.73% and the model is nonsignificant (Wilks' $\lambda = 0.82$, $\chi^2(5) = 7.93$, $p > 0.05$). Table 9-11 summarises the loadings showing the correlations between the auditory measures and the discriminant function. Results indicate that the function is largely a measure of auditory fusion and the function is not effective in discriminating "irregular word" and "nonsense word" readers. Although the result is consistent with that found in MANOVA, it is contrary to that of Study 2 in which the auditory measures significantly discriminated the two types of readers.

Table 9-11: Loadings showing Correlations between the Auditory Measures and the Discriminant Function

Measure	Loading
AFUS15	0.70001
AFUS100	-
ATOJ15	-
ATOJ75	-
ATOJ200	-

Table 9-11 (cont.)

N.B.: Loadings below |0.3| not shown

AFUS15, AFUS100: Auditory Fusion at 15 and 100 ms respectively

ATOJ15, ATOJ75, ATOJ200: Auditory Temporal Order Judgment at 15, 75 and 200 ms respectively

Using the visual and auditory measures, 7 out of 10 (70%) of the "irregular word" readers are categorised into the irregular word reading group while 29 out of 34 (85.29%) of the "nonsense word" readers are categorised into the nonsense word reading group. The percentage of correctly classified "grouped" cases is 81.82% and the model is nonsignificant (Wilks' $\lambda = 0.77$, $\chi^2(9) = 9.84$, $p > 0.05$). Table 9-12 summarises the loadings showing the correlations between the temporal measures and the discriminant function. Results indicate that the function is largely a measure of the transient visual system and auditory fusion. Consistent with Study 2, the function is not effective in discriminating "irregular word" and "nonsense word" readers.

Table 9-12: Loadings showing Correlations between the Visual and Auditory Measures and the Discriminant Function

Measure	Loading
FSEN2	-
FSEN12	-
BLAN2	-0.39745
BLAN12	-
AFUS15	0.60249
AFUS100	-
ATOJ15	-
ATOJ75	-
ATOJ200	-

N.B.: Loadings below |0.3| not shown

FSEN2, FSEN12: Flicker Sensitivity at 2 and 12 Hz respectively

BLAN2, BLAN12: Visible Persistence (based on the judgment of a blank) at 2 and 12 c/d respectively

AFUS15, AFUS100: Auditory Fusion at 15 and 100 ms respectively

ATOJ15, ATOJ75, ATOJ200: Auditory Temporal Order Judgment at 15, 75 and 200 ms respectively

Study 2 showed that the auditory measures are significantly better discriminants than the visual measures in differentiating the reading groups. Although the auditory discriminant function model is not significantly better than the visual model in Study 3, the results are still in the direction consistent with that of Study 2. For instance, the probability level of significance of the visual model is 0.6 while that of the auditory model is 0.16. Furthermore, it seems that temporal processing may not be an important discriminant for whole-word and phonological skills.

9.3.3 Good Readers vs Normal Readers

The method of comparison is similar to that used for comparing "irregular word" and "nonsense word" readers. Table 9-13 summarises the results of the good and normal readers.

Table 9-13: Means and (s.d.) of the Original and Log-transformed Data of the Good and Normal Readers on the Sensory and Reading Measures

	Good Readers (n=31)				Normal Readers (n=46)			
	Original		Log-transformed		Original		Log-transformed	
FSEN2	0.027	(0.009)	-3.67	(0.31)	0.027	(0.008)	-3.64	(0.3)
FSEN12	0.014	(0.004)	-4.33	(0.28)	0.015	(0.005)	-4.27	(0.32)
BLAN2	153.15	(56.7)	4.96	(0.4)	183.31	(68.61)	5.14	(0.39)
BLAN12	252.21	(85.65)	5.48	(0.33)	265.53	(101.09)	5.52	(0.35)
AFUS15	3.26	(1.14)	1.14	(0.28)	3.61	(1.29)	1.23	(0.31)
AFUS100	2.49	(0.46)	0.89	(0.19)	2.84	(0.51)	1.03	(0.19)
ATOJ15	44.07	(28.21)	3.57	(0.71)	86.03	(68.62)	4.19	(0.74)
ATOJ75	65.22	(30.02)	4.06	(0.51)	106.87	(83.35)	4.43	(0.7)
ATOJ200	90.67	(44.14)	4.39	(0.49)	141.13	(65.58)	4.84	(0.47)
IWSA	81.72	(6.26)	4.4	(0.08)	70.65	(11.23)	4.24	(0.17)
IWLA	81.61	(6.99)	4.4	(0.09)	69.71	(9.86)	4.23	(0.15)
NWSA	85.48	(7.48)	4.44	(0.09)	75.87	(13.76)	4.31	(0.21)
NWLA	85.27	(6.82)	4.44	(0.08)	76.88	(12.48)	4.33	(0.17)
IQ	114.84	(13.7)	4.74	(0.12)	108.09	(12.41)	4.68	(0.12)

Table 9-13 (cont.)

	Good Readers (n=31)				Normal Readers (n=46)			
	Original		Log-transformed		Original		Log-transformed	
WRAT-R	114.29	(3.43)	4.74	(0.03)	100.91	(6.05)	4.61	(0.06)
WRAT-S	116.16	(3.73)	4.75	(0.03)	101.76	(5.06)	4.62	(0.05)

N.B.: FSEN2, FSEN12: Flicker Sensitivity at 2 and 12 Hz respectively

BLAN2, BLAN12 (ms): Visible Persistence (based on the judgment of a blank) at 2 and 12 c/d respectively

AFUS15, AFUS100 (ms): Auditory Fusion at 15 and 100 ms respectively

ATOJ15, ATOJ75, ATOJ200 (ms): Auditory Temporal Order Judgment at 15, 75 and 200 ms respectively

IWSA, IWLA (%): Irregular Words Accuracy, Single / Continuous (Line) condition

NWSA, NWLA (%): Nonsense Words Accuracy, Single / Continuous (Line) condition

IQ: Nonverbal Reasoning Skills measured by Advanced Raven's Progressive Matrices

WRAT-R: WRAT Reading Standard Scores

WRAT-S: WRAT Spelling Standard Scores

Good readers, compared to the normal readers, did significantly better in WRAT reading ($t(75) = 10.64$, $p < 0.05$) and spelling scores ($t(75) = 12.99$, $p < 0.05$). They also have higher nonverbal reasoning IQ ($t(75) = 2.19$, $p < 0.05$).

A repeated-measures ANOVA was performed, taking the group factor (GROUP) as a between subject factor and the type of words (WORD) and mode of presentation (LINE) as within subject factors. Results showed that there is a main GROUP effect, indicating good readers are significantly better in reading both irregular words and nonsense words ($F(1,75) = 32.37$, $p = 0.0001$). There is also a main WORD effect, indicating nonsense words yield higher accuracies than irregular words ($F(1,75) = 12.9$, $p = 0.0006$). There is no main LINE effect, indicating no difference when reading singly and continuously presented text ($F(1,75) = 0.01$, $p > 0.05$). There is no WORD x GROUP ($F(1,75) = 1.08$, $p > 0.05$), LINE x GROUP ($F(1,75) = 0.08$, $p > 0.05$), WORD x LINE ($F(1,75) = 0.38$, $p > 0.05$) and WORD x LINE x GROUP ($F(1,75) = 0.35$, $p > 0.05$) interactions.

Since good readers have higher IQ than normal readers, the two groups were compared using two statistical methods. The first method compared the two groups on their nine temporal processing measures without taking IQ into account. Therefore, a MANOVA was performed and the α-level chosen was 0.05. The second method was to use MANCOVA which takes IQ as the covariate.

MANOVA showed an overall GROUP effect on the combined temporal processing measures (Wilks' $\lambda = 0.67$, $F(9,67) = 3.71$, $p = 0.0008$). Good readers performed significantly better in AFUS100 ($F(1,75) = 9.4$, $p = 0.003$), ATOJ15 ($F(1,75) = 13.31$, $p = 0.0005$), ATOJ75 ($F(1,75) = 6.34$, $p = 0.014$), ATOJ200 ($F(1,75) = 16.07$, $p = 0.0001$), and performed marginally better in the low spatial frequency measure BLAN2 ($F(1,75) = 3.85$, $p = 0.054$). The two groups did not differ in FSEN2 ($F(1,75) = 0.12$, $p > 0.05$), FSEN12 ($F(1,75) = 0.74$, $p > 0.05$), BLAN12 ($F(1,75) = 0.3$, $p > 0.05$) and AFUS15 ($F(1,75) = 1.79$, $p > 0.05$).

However, once IQ is controlled, MANCOVA showed the difference on BLAN2 diminished ($F(1,74) = 3.04$, $p > 0.05$) even though the overall GROUP effect on the combined temporal processing measures remained significant (Wilks' $\lambda = 0.64$, $F(9,66) = 4.04$, $p = 0.0004$). Good readers performed significantly better in AFUS100 ($F(1,74) = 10.45$, $p = 0.0018$), ATOJ15 ($F(1,74) = 13.08$, $p = 0.0005$), ATOJ75 ($F(1,74) = 5.02$, $p = 0.0281$), ATOJ200 ($F(1,74) = 15.56$, $p = 0.0002$) and not FSEN2 ($F(1,74) = 0.02$, $p > 0.05$), FSEN12 ($F(1,74) = 0.24$, $p > 0.05$), BLAN2 ($F(1,74) = 3.04$, $p > 0.05$), BLAN12 ($F(1,74) = 0.13$, $p > 0.05$) and AFUS15 ($F(1,74) = 1.07$, $p > 0.05$).

Three discriminant function analyses were performed on the data, using: 1) visual; 2) auditory; and 3) visual and auditory measures as discriminants for the reading groups.

Using the visual measures, 17 out of 31 (54.84%) of the good readers are categorised into the good reading group while 30 out of 46 (65.22%) of the normal readers are categorised into the normal reading group. The percentage of correctly classified "grouped" cases is 61.04% and the model is nonsignificant (Wilks' $\lambda = 0.94$, $\chi^2(4) = 4.47$, $p > 0.05$). Table 9-14 summarises the loadings showing the correlations between the visual measures and the discriminant function. Results indicate that the function is largely a measure of the transient visual system because FSEN12 and BLAN2 have higher correlations. Therefore, the transient visual function is not too effective in discriminating good and normal readers.

Table 9-14: Loadings showing Correlations between the Visual Measures and the Discriminant Function

Measure	Loading
FSEN2	-
FSEN12	0.39597
BLAN2	0.90110
BLAN12	-

N.B.: Loadings below |0.3| not shown
FSEN2, FSEN12: Flicker Sensitivity at 2 and 12 Hz respectively
BLAN2, BLAN12: Visible Persistence (based on the judgment of a blank) at 2 and 12 c/d respectively

Using the auditory measures, 23 out of 31 (74.19%) of the good readers are categorised into the good reading group while 33 out of 46 (71.74%) of the normal readers are categorised into the normal reading group. The percentage of correctly classified "grouped" cases is 72.73% and the model is significant (Wilks' $\lambda = 0.71$, $\chi^2(5) = 25$, $p = 0.0001$). Table 9-15 summarises the loadings showing the correlations between the auditory measures and the discriminant function. Results indicate that the function is largely a measure of auditory fusion and TOJ and the function is effective in discriminating good and normal readers.

Table 9-15: Loadings showing Correlations between the Auditory Measures and the Discriminant Function

Measure	Loading
AFUS15	-
AFUS100	0.55172
ATOJ15	0.65667
ATOJ75	0.45301
ATOJ200	0.72149

N.B.: Loadings below |0.3| not shown
AFUS15, AFUS100: Auditory Fusion at 15 and 100 ms respectively
ATOJ15, ATOJ75, ATOJ200: Auditory Temporal Order Judgment at 15, 75 and 200 ms respectively

Using the visual and auditory measures, 23 out of 31 (74.19%) of the good readers are categorised into the good reading group while 35 out of 46 (76.09%) of the normal readers are categorised into the normal reading group. The percentage of correctly classified "grouped" cases is 75.32% and the model is significant (Wilks' λ = 0.67, $\chi^2(9)$ = 28.48, p = 0.0008). Table 9-16 summarises the loadings showing the correlations between the temporal measures and the discriminant function. Results indicate that the function is largely a measure of the transient visual system and auditory temporal processing and is effective in discriminating good and normal readers.

Table 9-16: Loadings showing Correlations between the Visual and Auditory Measures and the Discriminant Function

Measure	Loading
FSEN2	-
FSEN12	-
BLAN2	0.32111
BLAN12	-

Table 9-16 (cont.)

Measure	Loading
AFUS15	-
AFUS100	0.50180
ATOJ15	0.59726
ATOJ75	0.41202
ATOJ200	0.65621

N.B.: Loadings below |0.3| not shown
FSEN2, FSEN12: Flicker Sensitivity at 2 and 12 Hz respectively
BLAN2, BLAN12: Visible Persistence (based on the judgment of a blank) at 2 and 12 c/d respectively
AFUS15, AFUS100: Auditory Fusion at 15 and 100 ms respectively
ATOJ15, ATOJ75, ATOJ200: Auditory Temporal Order Judgment at 15, 75 and 200 ms respectively

Thus, the auditory measures are better discriminants than the visual measures in differentiating good from normal readers. Moreover, the transient visual measures are more effective than the sustained visual measures in differentiating the reading groups. In general, the auditory temporal processing measures and the transient visual measures are important discriminants / factors in classifying good and normal readers even though the transient visual measures are not as effective as the auditory measures. Further, the results are consistent with May et al (1992) in which their low spatial frequency factor best discriminated between good and poor readers.

9.3.4 Further Analysis

The results in 9.3.2 and 9.3.3 show that "nonsense word" readers tend to have better auditory temporal precision while good readers excel in their auditory temporal processing ability. The question is whether the choice of reading strategy (using visual or GPC route) is related to how well one reads. Therefore, a χ^2 test was performed, using reading strategy (WORD: irregular vs nonsense) as one variable and reading ability (GROUP: good vs normal) as the other. The analysis showed that 2 "irregular word" readers are good readers while 6 "irregular word" readers are normal readers. On the other hand, 8 "nonsense word" readers are good readers while 19 "nonsense word" readers are normal readers. The level of reading ability is independent of the choice of reading strategy ($\chi^2(1, N = 35) = 0.065$, $p > 0.05$). However, note that as there are only 2 subjects in the "irregular word" / good reader category, the results may not be valid (Jaccard & Becker, 1990). Nevertheless, inspection of the data also yields a similar conclusion: in each type of word reader, the proportion of good to normal readers is approximately 1 to 3. The independence between reading proficiency and choice of reading strategy is consistent with the discriminant function analyses which show that temporal processing is an important discriminant for good and normal readers but not for "choice" of reading routes.

9.4 Discussion

9.4.1 Verification of Study 2

The results confirm those of Study 2 that better auditory temporal resolution is related to better phonological skills (Farmer & Klein, 1995; Watson & Miller, 1993; Watson & Watson, 1993a,b; Tallal et al, 1985a). This has been shown by the consistent findings that nonsense word performance is related to the auditory measures and that "nonsense word" readers tend to have lower auditory thresholds.

This study, however, failed to find the relationship between the visual measures and irregular words as suggested by Farmer and Klein (1995). It also failed to demonstrate the differential involvement of the sustained and transient visual systems in single and continuous text presentation as suggested by Hill and Lovegrove (1992). As suggested in Chapter 5, IQ may contribute to individual's temporal processing ability or vice versa (Raz et al, 1987; Bowling & Mackenzie, 1996; Deary, 1995; Stough et al, 1996). Moreover, visual temporal processing indexed by visual inspection time is more related to performance IQ than to verbal IQ (Deary, 1993; Stough et al, 1996). Since nonverbal IQ is used in this study, it is reasonable to suggest the control of IQ may conceal the influence of the visual measures. In fact, when IQ is taken as the covariate in comparing good and normal readers, MANCOVA fails to reveal the visual but not the auditory effect. This supports the speculation that visual measures are more vulnerable to the influence of IQ whereas auditory measures are more robust. This issue will be discussed more fully in Chapter 10. Another possibility for the poor relationship between the visual and the irregular word reading measures may be that visual ability is no longer a limiting factor in practised adult normal readers, even though it is important for poor readers.

Although discriminant function analyses failed to show that the auditory discriminant function is significantly better than the visual one in differentiating the "irregular word" and "nonsense word" readers, the results still suggest that the auditory measures are better discriminants. In addition, the persistence of the auditory effect found by the MANCOVA after taking IQ into account also supports the argument that the auditory measures are stronger and hence have better discriminative power than the visual measures. Furthermore, temporal processing measures, in general, are not effective in discriminating whole-word and phonological skills. This will be discussed more fully in Chapter 10.

9.4.2 Good Readers vs Normal Readers

The most significant finding of this study is that good readers have better temporal resolution than normal readers. This suggests that temporal processing ability does relates to individual's reading level and that this relationship is not confined to the comparison between normal and reading-disabled subjects.

One interesting point is that good readers performed better on a low spatial frequency visual measure. This has been interpreted as good readers having a better / faster transient visual system than normal / average readers. Although the advantage diminishes when IQ is controlled, there is still a trend for the good readers to have a stronger transient visual system. In fact, discriminant function analyses also show that the transient visual measures are better than the sustained visual measures in classifying good and normal readers. These results are compatible with the interpretation that poor performance by reading-disabled subjects is related to deficits in the transient visual system (Lovegrove et al, 1986a; Brannan & Williams, 1988a,b; Chase & Jenner, 1993) and are suggestive that at all points on the reading ability continuum, readers with a faster transient system will read better. Evidence for this suggestion is provided by Cornelissen, Hansen, Hutton, Evangelinou and Stein (in press) who found that in normal population, reading skills are positively related to the sensitivity of the transient visual system.

Further, the visual differences obtained in this study are not pronounced, especially when IQ was controlled. Apart from the influence of IQ on visual temporal processing as discussed above, possible explanations may include: 1) the comparison within normal and not between normal and reading-disabled subjects. There is little doubt in terms of previous evidence that many reading-disabled subjects should perform worse on these measures and that comparison between them and normal subjects would enhance the visual system differences. A comparison within a normal sample may make the differences too subtle; and 2) the use of both visual and auditory measures for comparison. It is clear that the auditory measures are stronger discriminants than the visual ones and it is possible that the auditory effect masks the visual one. Freides (1974) argued that language is an auditory-temporal code and that the modality is a significant variable. For instance, some researchers found that dyslexics / dysphasics were impaired in the auditory and not visual tasks, whether it is a fusion (Farmer & Klein, 1993), TOJ (Farmer & Klein, 1993; Reed, 1989) or sequence matching task (Tallal & Piercy, 1973b; Bryden, 1972; Gould & Glencross, 1990). Moreover, Eden et al (1995a,b) found that visual temporal dot and dot localisation tasks accounted for an extra 5-9% of the variance explained in reading whereas Tallal et al's (1985a) auditory temporal variables accounted for 7-60% of the variance explained. Hence, it is not surprising to find primarily auditory and not visual differences between good and normal readers.

Consequently, the differences between good and normal readers are mainly in the auditory measures, with discriminant function analyses showing that the auditory measures are better discriminants between the reading groups. A point of interest is that the two groups differ more in auditory TOJ than in auditory fusion. The results are consistent with some findings (e.g., Lowe & Campbell, 1965; Ludlow et al, 1983) that language-impaired children experienced more difficulty in TOJ than in fusion tasks.

In addition, the fact that good and normal readers performed equally well in both single and continuous word reading tasks is consistent with Hill and Lovegrove's (1992) findings that dyslexics performed as well as reading aged matched controls when reading singly words presented in the same location or when the words were presented within a "moving window" across a computer monitor. This issue will be further discussed in Chapter 10.

9.4.3 Are Good Readers Necessarily "Nonsense Word" Readers?

The assumption is if auditory temporal processing is related to one's phonological ability (e.g., Tallal et al, 1985a), there should be a relationship between nonsense word reading and auditory temporal processing. In fact, this has been confirmed in both Studies 2 and 3. On the other hand, this study also shows that good readers have better auditory temporal resolution. Therefore, it is of interest to ask if good readers, based on their better auditory temporal processing ability (Tallal et al, 1985a) and phonological skills (Stone & Brady, 1995), are more likely to be "nonsense word" readers or users of the GPC route. Results show that even though both good and "nonsense word" readers have better auditory temporal processing ability, the choice of reading strategy (i.e., whether to use the visual or the GPC route) is unrelated to how well they read. In other words, good readers are not necessarily "nonsense word" readers (or readers who favour the use of the GPC route) even though the acquisition of phonological ability (or nonsense word reading ability) which relates to auditory temporal perception (Tallal, 1980) is important for subsequent reading development (e.g., Stanovich, 1986; Bradley & Bryant, 1983) and that good phonic skills are important for good reading ability (Stone & Brady, 1995).

Indirect evidence of the independence between reading proficiency and reading strategy has been implicated by Freebody and Byrne (1988) and Byrne, Freebody and Gates (1992). These researchers termed their "irregular word" and "nonsense word" readers "Chinese" and "Phoenician" readers. They demonstrated the importance of acquisition of phonic skills for subsequent reading development by finding that the "Chinese" readers showed deterioration in reading from second to third grade while the "Phoenicians" improved in reading. Nevertheless, their data failed to provide evidence that children can be skilled readers while showing reliance on whole-word or phonological skills. Thus, the choice of skills does not provide "short-cuts" for proficient reading and their studies imply good readers are not necessarily phonic-skills-users. Though their studies concentrate on children learning to read whereas mine concentrate on reading proficiency in adults, my results are consistent with their implications. In addition, discriminant function analyses which show that temporal processing is important in classifying good and normal readers and not whole-word and phonological skills also reinforce the independence between reading proficiency and strategy. This issue will be further discussed in Chapter 10.

9.5 Summary

This study aimed to: 1) verify the results of Study 2; and 2) compare good and normal readers on the temporal processing measures.

Although the results confirm the relationship between nonsense words and auditory temporal processing as argued by Tallal et al (1985a), they fail to confirm the relationship between irregular words and visual temporal processing as suggested by Farmer and Klein (1995) and the differentiation of the sustained and transient visual systems in single and continuous text reading as argued by Hill and Lovegrove (1992). The control of IQ may contribute to the absence of significant visual processing effects. Furthermore, a trend that the auditory measures are better discriminants than the visual measures in classifying "irregular word" and "nonsense word" readers is consistent with those found in Study 2. Nevertheless, it seems that temporal processing is not efficient in discriminating whole-word and phonological skills.

Good readers have better auditory temporal processing ability than normal readers. They also tend to have a better transient visual system. However, once IQ is controlled, the visual difference diminishes but the auditory effect remains. Similarly, the auditory measures are better discriminants than the visual measures and the transient visual measures are better discriminants than the sustained visual measures in classifying good and normal readers. Moreover, consistent with previous findings, the two groups differ more in auditory than in visual temporal tasks and in TOJ than in fusion tasks. The relationship between individual's temporal processing ability and his / her reading ability remains prominent even in normal readers.

In addition, good readers are not necessarily "nonsense word" readers even though both groups gain the advantage of having better auditory temporal resolution. Results confirm the importance of phonic skills in reading proficiency and that the choice of reading strategy needs not necessarily provide alternative routes for proficient reading. The argument is further supported by the fact that temporal processing is important in discriminating good and normal readers but not reading strategies.

Chapter 10: Discussion

10.1 Overview

This thesis consists of three studies which investigated the relationship between rapid sensory temporal processing and reading ability in University students.

The studies were motivated by the evidence that many dyslexics and dysphasics are impaired in both visual and auditory temporal tasks (e.g., Kinsbourne et al, 1991). In addition, the finding of abnormality in both visual and auditory magnocellular pathways in dyslexics by Livingstone et al (1991) and Galaburda and Livingstone (1993) has led to the hypothesis of a generalised pansenory deficit in which dyslexics and dysphasics have difficulty resolving rapidly presented stimuli in more than one modality (Miller & Tallal, 1995; Farmer & Klein, 1995; Stein, 1993). Therefore, the major aim of my thesis was to investigate the more general case of this relationship in normal readers.

Study 1 aimed to investigate the relationship between the visual and auditory temporal processing measures. Even though there are independent visual and auditory factors, some results are suggestive of a common temporal processing mechanism because some visual and auditory measures load on the same factor(s). Moreover, different components / levels responsible for different stimulus dimensions on tasks may exist within this mechanism and the mechanism may operate differently at different levels of temporal processing. This will be illustrated in 10.2.1 and 10.2.2.

Since extensive evidence supports the relationship between temporal processing and reading, Study 2 aimed to relate the visual and auditory temporal processing measures to various reading measures. Further, most of the literature concentrates on the relationship between temporal processing deficits and poor phonological processing ability exhibited by dyslexics / dysphasics (e.g., Tallal et al, 1985a, Lovegrove et al, 1989). Yet little research has been done on the relationship between these measures and whole-word recognition skills. Therefore, Study 2 attempted to relate both irregular word reading (which manifests individual's whole-word recognition skills) and nonsense word reading (which reflects phonological skills) with these temporal processing measures. More specifically, the study attempted to relate Coltheart's (1978) dual-route model of reading to the temporal processing framework. It also attempted to examine Farmer and Klein's (1995) suggestion about the relationship between visual temporal processing deficits and dyseidetic dyslexia and between auditory temporal processing deficits and dysphonetic dyslexia. Additionally, the study attempted to examine the involvement of the sustained and transient visual systems in single and continuous word reading tasks as suggested by Hill and Lovegrove (1992) and Breitmeyer (1993a,b). Further, since most evidence supporting the rationale comes from research on dyslexics and dysphasics, this thesis attempted to examine the above notions using normal University students. This partially addresses the issue of whether dyslexics, in terms of rapid sensory processing, fall on a continuum with normal readers.

Results from Study 2a support: 1) the relationship between visual temporal processing and irregular word reading and between auditory temporal processing and nonsense word reading; and 2) the primary involvement of the sustained visual system in single word reading and the primary involvement of the transient visual system in continuous word reading. Furthermore, the effect of these temporal processing measures is relatively small, especially in the visual domain but is consistent with some previous findings (e.g., Eden et al, 1995a,b).

Therefore, Study 2b attempted to increase the involvement of the transient visual system by adding peripheral information in the continuous text presentation. This manipulation produced no noticeable change. It is speculated that adding peripheral information may have increased some other cognitive demands which diminished the relative contribution of the temporal processing measures. In other words, the temporal processing influence may be subtle and may only be manifested in tasks where additional cognitive demands are minimal.

If the relationship between irregular words and visual temporal processing and between nonsense words and auditory temporal processing is supported, the next step was to see whether "irregular word" readers excel in visual temporal tasks and "nonsense word" readers excel in auditory temporal tasks. Results show that "nonsense word" readers who have better phonological skills tend to be better in the auditory tasks but the "irregular word" readers who have better whole-word skills are not better in the visual tasks. Moreover, auditory measures are better discriminants than visual measures in differentiating reading groups.

In sum, Study 2 demonstrated: 1) a relationship between visual temporal processing and irregular words and between auditory temporal processing and nonsense words; 2) the possible involvement of the sustained visual system in single word reading and the possible involvement of the transient visual system in continuous word reading, at least shown by Study 2a and partially by Study 2b; 3) a trend for an advantage of better auditory temporal resolution in phonological skills but not that of better visual temporal resolution in whole-word skills; and 4) stronger discriminative power of the auditory measures in differentiating "irregular word" and "nonsense word" readers.

Study 3 investigated the impact of different reading ability on various temporal processing measures. Since Study 2 aimed to produce a general picture about reading and temporal processing without taking IQ into account, and noting that IQ may be a covariate for both reading and temporal processing measures (e.g., Baddeley & Gathercole, 1992; Rudel & Denckla, 1976), Study 3 extended the results of Study 2 by controlling the effect of IQ and reducing the number of measures and increasing the number of subjects.

Results show that the relationship between auditory temporal processing and nonsense words remains but the link between visual temporal processing and irregular words is not found. Nor is there any relationship between the two visual systems and single and continuous text reading. The control of IQ, as discussed in Chapter 9, may have masked the visual effect. Nevertheless, "nonsense word" readers tend to have better auditory temporal resolution. Partially inconsistent with Study 2, temporal processing measures are not effective discriminants for "irregular word" and "nonsense word" readers.

On the other hand, good readers have better temporal processing ability than normal readers, especially in the auditory domain. There is also an advantage for the good readers having a better transient visual system but the advantage diminishes after controlling the effect of IQ. One interesting point is that both good and "nonsense word" readers have better auditory temporal resolution and it is known that good readers also have better phonological skills (e.g., Bradley & Bryant, 1983; Stanovich, 1986; Stone &

Brady, 1995). Therefore, the author was interested to see whether good readers are more likely to be "nonsense word" readers. Results show that the "choice" of reading route is unrelated to how well one reads. Moreover, even though discriminant function analyses show that the auditory measures and the transient visual measures are effective discriminants for good and normal readers, they are unlikely effective discriminants for whole-word and phonological skills. The results imply that temporal processing is not an important factor for choice of reading strategy but is an important factor for reading proficiency. This reinforces the relationship between temporal processing and reading (e.g., Lovegrove et al, 1989; Tallal et al, 1985a) and the independence between reading proficiency and choice of strategy as suggested by Freebody and Byrne (1988) and Byrne et al (1992).

10.2 Global Issues

In order to be more coherent within each study, some of the specific issues have already been discussed in those studies. Therefore, this section mainly concentrates on the issues which are relevant to all studies reported.

10.2.1 Differentiation of the Transient and Sustained Visual System within a Temporal Framework?

It is well documented that there are transient and sustained subsystems within the visual system (e.g., Bassi & Lehmkuhle, 1990). It is generally assumed that the two systems may be selectively activated by careful selection of the spatial and / or temporal frequency content of the stimuli used (e.g., Badcock & Lovegrove, 1981; Chase & Jenner, 1993; Lovegrove et al, 1982; May et al, 1988b). In Study 1, visual stimuli were chosen to reflect the transient or sustained system's properties. However, whether these measures reflect the function of temporal processing is questionable in terms of the data reported. In fact, the loading of both high and low temporal frequency / spatial frequency measures on the same factor suggests a common mechanism / system is responsible for performing tasks requiring rapid temporal resolution (e.g., Schiller et al, 1990) regardless of the stimulus properties chosen. For instance, it is difficult to separate out "pure sustained measures" given the temporal nature of the task. Moreover, the two systems do not function independently of each other. For example, contrast sensitivity of gratings of particular spatial frequency is affected by the movement of those gratings (Derrington & Lennie, 1984; Kulikowski & Tolhurst, 1973). Therefore, the author suggests tasks which use "flicker-free" equipment (see Slaghuis & Lovegrove, 1986) and have slow presentation rates, compared to those with rapid presentation rates, may be able to separate the sustained measures. Conversely, tasks which make use of colour can also be employed as the sustained system is colour-sensitive (Livingstone & Hubel, 1984a, 1987, 1988). For instance, these tasks are proven adequate enough to separate the function of the sustained system (e.g., Chase & Jenner, 1993).

In addition, there are limitations with these temporal processing tasks. Presumably, the speed of presentation dominates such that the specific stimulus parameters become less important than the nature of the task even when the parameters chosen are believed to tap into the function of the sustained visual system. In other words, the task requirements may over-ride stimulus dimensions in determining what visual subsystem is used. Therefore, these temporal processing tasks may not be as clean as the colour / luminance tasks which well differentiate the sustained (using the colour component) and the transient (using the luminance component) systems. Besides, dyslexics are less sensitive in detecting coherent motion in random dot kinematograms and have lower critical flicker fusion (CFF) frequencies (Talcott et al, 1997). Moreover, the former task is effective in discriminating between dyslexics and controls even at photopic levels (Cornelissen et al, 1995). Accordingly, these tasks are sensitive measures of the transient system and should well-differentiate between the two visual subsystems.

If temporal processing is supported by one mechanism (presumably the transient system), then what is the role of the sustained system in temporal processing? We can not ignore the fact that some visual measures are "sustained" in nature, nor that the data reported in this study is sufficient to conclude this "sustainedness" originates either from the transient or sustained system. It is likely that the temporal framework of the tests creates limitations in differentiating pure "sustained" measures and the results give an impression of the sustainedness originated from the transient system. However, as noted in Chapter 2, it is possible, both anatomically and psychophysically, to have an interaction between the two systems in monitoring a task (see Blanckensee 1980; Sherman et al, 1984; Crook et al, 1988; Shapley, 1990; Grosser & Spafford, 1992; Kaplan et al, 1990; Schiller et al, 1990). Moreover, as stated in Chapter 5, an inefficient "central executive" resulting in automatisation deficits in both cognitive and motor skills in dyslexics (Fawcett & Nicolson, 1992; Nicolson & Fawcett, 1993c) may imply that the temporal processing mechanism is likely to be the higher-level "central executive" which coordinates the two visual subsystems rather than the lower-level transient system (as discussed in Chapter 7).

Consequently, the close relationship between temporal processing and reading as discussed in Chapters 4 and 5 should qualify the temporal processing tests in these studies to be adequate and sensitive for various reading measures. With the assumption that a "higher-order" "central executive" coordinates the two visual subsystems, the temporal tests should be adequate tests of the "low-level" sustained and transient involvement in single and continuous word reading.

10.2.2 Common Temporal Processing Mechanism across Vision, Audition and Reading?

Although some results of Studies 1 and 2 are suggestive of a common temporal processing mechanism across vision and audition, the result of Study 3 is less suggestive of this. Though the sample size of Study 2 may not be statistically adequate for analyses consisting of so many variables, the sample sizes of Studies 1 and 3 are adequate as suggested by Tabachnick and Fidell (1989). More importantly, Study 3 makes use of a larger sample size and fewer temporal processing measures. The smaller number of variables used may result in fewer factors. In Study 3, clean factors like auditory TOJ and fusion are separated out. The finding of these distinctive auditory factors is consistent with that in Study 1. Nevertheless, the lack of combined visual and auditory factors in Study 3 proposes a difficulty in interpreting the results of Study 1. What is generally observed is: with relatively "small" sample size and more variables (e.g., Study 1), it is easier to obtain common visual and auditory factors; whereas with larger sample size and fewer variables (e.g., Study 3), the categorisation between the tasks becomes more distinct such that it is harder to obtain such factors. What remains puzzling is: if larger sample size and fewer variables leads to more distinct and detailed categorisation in Study 3, why is a combined visual factor of visible persistence and flicker sensitivity observed in Study 3 whereas separate visible persistence and flicker sensitivity factors are observed in Study 1? On the other hand, should the lack of common visual and auditory factors in Study 3 be interpreted as a result of the control of IQ? In addition, should the combined visible persistence and flicker sensitivity factor in Study 3 be interpreted as a "higher-order" factor compared to individual "lower-order" factors in vision? At times, it appears that some factors stem from a common timing mechanism; at other times they appear to have different sources. Thus, the author has to acknowledge that though some results are suggestive of a common timing mechanism across vision and audition, there are also independent visual and auditory factors. Furthermore, it is likely that these "independent" factors reflect different components / levels of processing within the higher-level common mechanism rather than individual mechanisms (as argued in Chapter 7). Accepting too many variables may include noise in the analysis and consequently results in the failure in replicating some original factors. Inclusion of fewer variables or the use of canonical correlation may improve the results.

One interesting finding in Study 2 is that there are individual visual and transmodal factors but there are also individual transmodal and reading factors. As stressed before, these factors likely reflect different levels of processing within a common mechanism. Take Study 2a as an example, the consistent factors across analyses are listed in Tables 10-1 to 10-3.

i) Loading of both Visible Persistence and Flicker Fusion Measures across all Analyses (Independent Visual Factor)

Consistent results across the studies are found with BLAN12, FLICK2, FLICK12, CHAS2 and CHAS12 loading on the same factor across all analyses. Table 10-1 summarises the results.

Table 10-1: Independent Visual Factor: Loading of the Visible Persistence and Flicker Fusion Measures across Analyses (Study 2a)

	Factor	Measures	Eigen-Value	%age of Variance Explained
IWS1	2	BLAN12, FLICK2, FLICK12, CHAS2, CHAS12	2.658	14.77
IWL1	1	BLAN12, FLICK2, FLICK12, CHAS2, CHAS12	4.616	25.65
NWS1	1	BLAN12, FLICK2, FLICK12, CHAS2, CHAS12	4.604	25.58
NWL1	1	BLAN12, FLICK2, FLICK12, CHAS2, CHAS12	4.664	25.91

N.B.: BLAN12: Visible Persistence (based on the judgment of a blank) at 12 c/d
FLICK2, FLICK12: Visible Persistence (based on the judgment of a flicker) at 2 and 12 c/d respectively
CHAS2, CHAS12: Flicker Fusion at 2 and 12 c/d respectively
IWS1, IWL1: Irregular Words, Single / Continuous (Line) condition (first session)
NWS1, NWL1: Nonsense Words Single / Continuous (Line) condition (first session)

ii) Loading of both Visual and Auditory Measures on the Same Factor (Transmodal Factor)

The transmodal factors are shown by both visual and auditory measures loading on the same factor. Across analyses, similar factors were extracted, namely: factor 1 of IWS1, factor 2 of IWL1, NWS1 and NWL1; and factor 5 of IWS1, factor 3 of IWL1 and factor 4 of NWS1. Moreover, some factors may depend upon IQ such that lower IQ is associated with poorer temporal resolution. The results are summarised in Table 10-2.

Table 10-2: Transmodal Factor: Loading of both Visual and Auditory Measures on the Same Factor (Study 2a)

	Factor	Measures	Eigen-Value	%age of Variance Explained
IWS1	1	VTOJ1, VTOJ7, AFUS15, ATOJ15, ATOJ75, ATOJ200, IQ	4.658	25.88
	5	FSEN2, AFUS15, AFUS100, ATOJ75	1.198	6.66
IWL1	2	VTOJ1, AFUS15, ATOJ15, ATOJ75, ATOJ200	2.683	14.91
	3	FSEN2, FSEN12, AFUS15, AFUS100	1.81	10.05
NWS1	2	VTOJ1, AFUS15, AFUS100, ATOJ15, ATOJ75, ATOJ200	2.747	15.26
	4	BLAN2, BLAN12, AFUS15, AFUS100	1.298	7.21
NWL1	2	VTOJ1, AFUS15, ATOJ15, ATOJ75, ATOJ200, IQ	2.693	14.96

N.B.: FSEN2, FSEN12: Flicker Sensitivity at 2 and 12 Hz respectively
VTOJ1, VTOJ7: Visual Temporal Order Judgment at 1 and 7 c/d respectively
BLAN2, BLAN12: Visible Persistence (based on the judgment of a blank) at 2 and 12 c/d respectively
AFUS15, AFUS100: Auditory Fusion at 15 and 100 ms respectively
ATOJ15, ATOJ75, ATOJ200: Auditory Temporal Order Judgment at 15, 75 and 200 ms respectively
IWS1, IWL1: Irregular Words, Single / Continuous (Line) condition (first session)
NWS1, NWL1: Nonsense Words, Single / Continuous (Line) condition (first session)
IQ: Nonverbal Reasoning Skills measured by Advanced Raven's Progressive Matrices

iii) Loading of both Temporal Processing and Reading Measures on the Same Factor (Transmodal and Reading Factor)

Some temporal processing and reading measures load on the same factor across analyses. The results are summarised in Table 10-3.

Table 10-3: Transmodal and Reading Factor: Loading of both Temporal Processing and Reading Measures on the Same Factor (Study 2a)

	Factor	Measures	Eigen-Value	%age of Variance Explained
IWS1	4	FSEN2, FSEN12, IWSA1, IQ	1.338	7.43
IWL1	5	BLAN2, BLAN12, IWLT1	1.281	7.12
	6	AFUS100, IWLA1, IQ	1.054	5.85
NWS1	3	FSEN2, FSEN12, AFUS15, AFUS100, NWSA1	1.845	10.25
NWL1	3	FSEN2, FSEN12, AFUS15, AFUS100, NWLA1	1.813	10.07
	5	BLAN2, BLAN12, AFUS100, NWLT1	1.18	6.55

N.B.: FSEN2, FSEN12: Flicker Sensitivity at 2 and 12 Hz respectively
BLAN2, BLAN12: Visible Persistence (based on the judgment of a blank) at 2 and 12 c/d respectively

Table 10-3 (cont.)

N.B.: AFUS15, AFUS100: Auditory Fusion at 15 and 100 ms respectively

IWSA1, IWLA1: Irregular Words Accuracy, Single / Continuous (Line) condition (first session)

NWSA1, NWLA1: Nonsense Words Accuracy, Single / Continuous (Line) condition (first session)

IWLT1: Irregular Words Reaction time, Continuous (Line) condition (first session)

NWLT1: Nonsense Words Reaction time, Continuous (Line) condition (first session)

IWS1, IWL1: Irregular Words, Single / Continuous (Line) condition (first session)

NWS1, NWL1: Nonsense Words, Single / Continuous (Line) condition (first session)

IQ: Nonverbal Reasoning Skills measured by Advanced Raven's Progressive Matrices

Based on these results and Chapter 7, the author would like to further speculate and elaborate on the functioning of this common timing mechanism.

As stated in Chapter 5, Spring and Davis (1988) argued that temporal processing efficiency is essential for both direct-access and speech-recoding routes of word recognition. Fawcett and Nicolson (1992), Nicolson and Fawcett (1993c) and Frith (1992) proposed a deficient "central executive" which explains various deficits experienced by dyslexics. Incorporating the results from the studies reported here with Fawcett and Nicolson's (1992) DAD hypothesis, the author would like to suggest the possibility of the existence of such a "central executive" (CE). In the proposed model, the CE controls various sensory, temporal and cognitive tasks like reading via different levels of processing. For levels of processing, the author means factors which manifest themselves through different dimensions. The multi-dimensional factors can vary from lower (e.g., sensory) to higher (e.g., cognitive) levels and from modal-specific to transmodal. Some factors may deal with the lower-level aspects of the temporal tasks (e.g., temporal processing per se) while others may deal with the cognitive aspects of the temporal tasks (e.g., perceptual integration of temporal information). Moreover, factors which deal with the cognitive aspects of the temporal tasks may or may not deal with the cognitive aspects of some other tasks like reading. Alternatively, factors dealing with the cognitive aspects of reading may or may not "overlap" with factors dealing with temporal processing within similar levels of processing. Hence, regarding the results of Study 2, the transmodal factors may reflect lower-levels of temporal processing whereas the transmodal and reading factors may reflect higher / cognitive levels of temporal processing. A deficient "central executive" hypothesised by the DAD hypothesis may result in poor temporal processing per se in one aspect and / or poor temporal integration plus poor reading in the other. For instance, Stein and McAnally (1995) argued that dyslexics had impaired "neuronal systems responsible for processing the timing of auditory frequency changes" (p. 220). Efron (1963) and Swisher and Hirsh (1972) argued that TOJ required an intact temporal lobe. More specifically, Robin, Tranel and Damasio (1990) found that left temporoparietal structures were important for temporal information perception. Several researchers also argued that frontal lobe lesions resulted in impaired memory or judgment for temporal order (Shimamura, Janowsky & Squire, 1990; McAndrews & Milner, 1991). Similarly, Grabowska, Luczywek, Fersten, Herman et al (1994) showed that even small damage in anterior hippocampus and medial part of amygdala resulted in memory deficits of temporal order of sequential items. Furthermore, different types of temporal processing depend upon different parts of these brain areas. For instance, right parietal damage affects the perception of temporal order without disrupting motion perception (Rorden, Mattingley, Karnath & Driver, 1997) and that the dorsolateral prefrontal cortex is important for the semantic / strategic but not automatic processing of temporal information (Mangels, 1997). In addition, hippocampus plays a more important part in memory for the temporal order of spatial locations, compared to medial prefrontal cortex (Chiba, Kesner & Reynolds, 1994). The selectivity of different brain areas for different types of temporal processing shown by the above research further supports the notion of different "operational" levels in the proposed model. Nonetheless, these levels probably lie in different brain areas and it is suggested that CE may lie in the hippocampal area.

The "overlapping" among factors provides flexibility in explaining why temporal processing deficits may or may not accompany reading deficits. Additionally, deficits in particular levels of processing may result in deficits in aspects of tasks operated within that level of processing. Conversely, deficits in particular tasks may also affect the performance of other tasks, provided that the "operational field" of that task overlaps with the one of the other. What most researchers find about the relationship between reading and temporal processing may possibly lie within the transmodal and reading factor or the cognitive levels of temporal processing. Evidence is cited from Raymond and Sorensen (1997) who found that dyslexics were impaired in poor perceptual integration and not low level motion detection in a random dot motion coherent test. Apart from being consistent with the results observed in Studies 1 and 2 and the argument presented in Chapter 7, Nicolson and Fawcett (1993c) and Frith (1992), the suggested model is in concord with the above physiological findings.

Nevertheless, the model is still inadequate in explaining some of the results. For example, if the results found by most researchers lie within the transmodal and reading factor, then temporal processing measures which are more cognitive should have a more significant relationship with the reading measures. Though evidence supporting the above argument is provided by Study 3 which shows that good readers differ from normal readers in terms of auditory TOJ rather than auditory fusion, Study 2 gives a different picture. In Study 2, auditory fusion is more likely to have significant relationship with various reading measures whereas auditory TOJ which is assumed to be more cognitive, seldomly shows a significant relationship with the reading measures.

The discrepancies may result from the methodological difference between the two studies: e.g., statistical tests which treat the sample as a single "continuous" category vs tests that compare different groups. In fact, studies which show differences regarding the cognitive aspects of temporal processing and reading are more likely to be those which compare good / normal and poor readers (e.g., Di Lollo et al , 1983) using ANOVA and correlations (e.g., Rudel & Denckla, 1976). For instance, Sterritt and Rudnick (1966) failed to find any significant relationship between the ability to match sequence of lights with dot patterns and reading. Their results have been attributed to the use of normal subjects, multiple regression techniques and the control of IQ. Study 2 adopted multiple regression techniques and the methodolody is similar to Sterritt and Rudnick (1966) whereas Study 3 (good readers vs normal readers section) adopted MANOVA and MANCOVA for group comparison. So, it is reasonable to find the desired cognitive effect of temporal processing in Study 3 but not Study 2.

10.2.3 Effect of the Transient Visual System in Dyslexics in the "Moving Window" Condition: Commentaries for Chapter 9

The continuous (LINE) text presentation used in this thesis is based on the moving window technique of Hill and Lovegrove (1992). The author chose this presentation in order to maximise the role of the transient visual system attributed to the saccades and not to the peripheral information presented in normal text condition. As found in Study 2, some transient system involvement was found in the moving window condition though the effect was small. Study 3 showed that good and normal readers do not differ in reading words presented singly or in a moving window and the results are compatible with Hill and Lovegrove (1992). Furthermore, if the transient effect due to the saccades is present in the moving window condition, then the dyslexics in Hill and Lovegrove's (1992) study should also have been impaired in this condition. However, the dyslexics were only impaired in the normal text condition, i.e., a condition in which peripheral information was provided. The likely explanation is that the transient system is highly involved in reading normal text but not in the moving window condition. With only minor transient system involvement in the moving window condition, there is very little likelihood of this condition revealing a transient weakness. On the contrary, normal text condition requires significant greater involvement of the transient system. Thus, the deficit becomes apparent as the system can not cope with the large demand.

Though it is difficult to generalise my results (based on the work with normal subjects) to Hill and Lovegrove's (1992) dyslexics, Hill and Lovegrove's (1992) controls and my normal adults performed similarly in the single word and "moving window" conditions. This minimises the difficulty in generalising my argument to dyslexic research.

10.2.4 Relationship between Visual Temporal Processing and Reading in the Context of IQ

Study 3 failed to demonstrate a relationship between the visual measures and irregular words as suggested by Farmer and Klein (1995) and also the differential involvement of the sustained and transient visual systems in single and continuous text presentation as suggested by Hill and Lovegrove (1992). The lack of relationship has been attributed to the control of IQ because visual temporal processing is more related to nonverbal IQ (Deary, 1993; Stough et al, 1996). Accordingly, it seems that the relationship between reading and visual temporal processing is mediated by IQ. As discussed in 10.2.1, random dot coherent motion and critical flicker fusion tasks may provide more sensitive measures in differentiating the sustained and transient visual systems. Moreover, Talcott et al (1997) showed that these temporal detection tasks could discriminate 75% of the dyslexics from controls. Thus, even if the relationship between visual temporal perception and reading is "hindered" by the influence of IQ, the use of stronger and more sensitive measures may reveal a more pronounced visual effect.

10.2.5 What Facilitates Whole-word Skills?

It is well documented that poor readers are usually deficient in phonological skills (e.g., Gathercole & Baddeley, 1990; Katz, 1986; Snowling, 1981; Pennington et al, 1990) and there is evidence concerning the relationship between auditory temporal perception and phonological processing (Watson & Miller, 1993; Tallal et al, 1985a). Interestingly, Study 3 shows that good readers perform better in auditory temporal tasks and "nonsense word" readers also tend to excel in these tasks. With the assumption of better phonological skills present in good readers and a common auditory temporal processing advantage existed in both good and "nonsense word" readers, the author was interested in whether good readers are more likely to be "nonsense word" readers, i.e. whether they favour the use of GPC route. Nevertheless, the "choice" of reading route is unrelated to reading ability and the results are consistent with Freebody and Byrne (1988) and Byrne et al (1992). In that case, good readers can be facilitated by either good phonological skills or good whole-word skills even though they have better auditory temporal perception. In fact, Study 3 also shows that good readers have better whole-word skills than normal readers. However, Studies 2 and 3 show that good whole-word skills need not be facilitated by good visual temporal resolution, even though a minimum amount of visual effect is necessary for processing irregular words. If good auditory temporal perception facilitates good phonological skills, what facilitates good whole-word skills? The answer may be found from people who are good readers but poor spellers.

Good phonological abilities are necessary for the development of good spelling skills and that phonological processing deficits are associated with spelling difficulties (Snowling, Stackhouse & Rack, 1986). Bruck and Waters (1988, 1990) viewed poor spelling as a result of a phonological processing deficit which affects both reading and spelling and that good readers who are also poor spellers are suffering from a mild form of dyslexia (Joshi & Aaron, 1991). If good readers / poor spellers are deficient in their phonological skills, then good reading must be compensated via the whole-word strategy. Evidence is cited by Bryant and Bradley (1980) who found that adult good readers / poor spellers managed to read well by using a whole word visual recognition strategy. These readers recognised words on the basis of partial visual cues (Frith, 1979, 1980) and they also have good visual memories (Burden, 1992).

Thus, good visual memories may be the key to good sight-word skills. In fact, Tallal and Stark (1982) found that reading-disabled children who were unimpaired in reading nonsense words, were impaired in serial memory and visual scanning. The deficits implicate "difficulty at higher levels of the reading processes, perhaps in integrating the printed word with meaning" (p.170). Presumably, these deficits should relate to whole-word skills.

10.2.6 Visual Temporal Perception: Secondary to Auditory Temporal Perception

If phonological processing is facilitated by auditory temporal perception and whole-word strategy is facilitated by visual memories, what is the role of visual temporal perception? One point is that the visual effect is generally weaker than the auditory effect regarding reading performance. For instance, dyslexics who are impaired in auditory temporal tasks need not necessarily be impaired in the visual ones (e.g., Farmer & Klein, 1993; Reed, 1989; Tallal & Piercy, 1973b; Bryden, 1972; Gould & Glencross, 1990). My thesis, though based on the work with normal adults, also found that the auditory temporal processing measures are stronger discriminants than the visual ones for various reading measures and the results are compatible with the above dyslexic research. Hence, it seems that visual temporal processing may not influence reading performance directly in normal readers. It may coexist with or even be secondary to auditory temporal perception. The evidence does not totally refute the suggestion of Farmer and Klein (1995) as Study 2 found a relationship between visual temporal processing and irregular words. However, it should be stressed that visual temporal processing may not make a major contribution to whole-word skills and dyseidetic dyslexia because Studies 2 and 3 show that "irregular word" readers who have better whole-word skills do not exhibit better visual temporal perception, even though the visual measures are minimally involved in irregular word reading. In fact, my results, based on the work with normal adults, are also consistent with Borsting et al (1996) and Ridder et al (in press) in that only dyslexics who have phonological deficits and severe reading problems exhibit visual temporal processing deficits. Additionally, Lovegrove et al's (1989) dyslexics fulfilled Borsting et al (1996) and Ridder et al (in press) criteria and therefore showed a relationship between visual temporal processing deficits and phonic deficits. In general, problems with reading (especially irregular words) caused by the visual mechanisms are quite rare (Rayner, Pollatsek & Bilsky, 1995), whereas problems with reading nonsense words caused by the same mechanisms are more common (e.g., Lovegrove et al, 1989). Accordingly, the relationship between reading and visual temporal perception may be due to visual temporal perception being secondary to or coexisting with auditory temporal perception (and on the basis of phonological processing: this will be discussed in the next section). As most research attends to mechanisms related to phonological processing, future direction can focus on mechanisms related to whole-word skills in dyslexia.

With reference to the proposed model in 10.2.2, one possibility of the coexistence of the two types of temporal processing deficits lies in the sharing of similar levels of processing with reading. Furthermore, most research concentrates on temporal processing in individual visual or auditory modalities and transmodal research examining the relative contribution of the two modalities is rare. Even with research examining the temporal perception of the two modalities, cross-modal sequence matching tasks are always used. As stressed in Chapter 4, these tasks are usually confounded by IQ and memory and hence may not be sensitive enough to test for pure temporal processing.

10.2.7 Implications for Dyslexic Subtypes

This research is mainly based on the work of correlational studies. Correlation does not necessarily imply causation (Bynner, 1988) and their difference is still relevant even when variables are separated in time (Cliff, 1983). For instance, causality involves the active control of variables but with correlational data, it is impossible "to isolate the empirical system sufficiently so that the nature of the relations among the variables can be unambiguously ascertained" (Cliff, 1983, p.119). Thus, A and B can be correlated because A causes B, or B causes A, or an unknown variable produces changes in both A and B (Schustack, 1988). The relationship between correlation and causation has been studied via: 1) necessary and sufficient conditions (Schustack, 1988; Bynner, 1988); and 2) "cues-to-causality" such as covariation, temporal order, contiguity in time and space, and similarity of cause and effect (Einhorn & Hogarth, 1986). Some researchers (e.g., Cliff, 1983; Schustack, 1988) argued that causation can only be tested by actively manipulating all relevant variables and by examining the statistical variation of all these variables. However, other researchers (e.g., Keith, Page & Robertson, 1984; Page 1981; Page & Keith, 1981, 1982) defended the use of correlational data to infer causality. Games (1990) concluded that correlations only suggest causations which must be tested by proper experiments. Nevertheless, Duncan (1975) argued that given sufficient correlations or constraints, identification can be achieved.

As a result, "this is not to say that correlational data cannot be suggestive of causal relations ...... It is just that they do not establish these relations, and until various lines of converging evidence support the ideas of a causal relation ......" (Cliff, 1983, p.119).

Most of the results of this research are based on correlational analyses and consequently, do not necessarily imply causation. Furthermore, the author found that the results obtained in this research converged with most dyslexic research (as discussed below) and therefore would like to suggest the possibility of such causality. The author wants to stress that the following implications are not a "must". They are just "if-then" suggestions.

The discrepancy between intelligence and reading achievement has been crucial for the definition of dyslexia and is of critical importance in distinguishing dyslexics from other poor readers such as "slow learners", "backward readers" (Rutter & Yule, 1975) or "garden-variety poor readers" (Gough & Tunmer, 1986). One argument for this distinction is that Rutter and Yule's (1975) dyslexics formed a "hump" in the lower end of the distribution. However, whether dyslexia remains as a separate entity according to the IQ-discrepancy concept has been controversial in terms of the methodology used (e.g., see Stanovich, 1991a,b; Cone & Wilson, 1981; Finlan, 1992; Siegel, 1989) and increasingly, the validity of dyslexia as a separate entity has been challenged on statistical grounds. For instance, several researchers (Shaywitz, Escobar, Shaywitz, Fletcher & Makuch, 1992; Rodgers, 1983; Share, McGee, McKenzie, Williams & Silva, 1987) failed to find this "hump" and concluded that reading disabilities may represent the lower end of a continuum that includes normal reading ability, and that dyslexia is not a discrete entity. Rutter and Yule's (1975) "hump" may be a result of the ceiling effects on the reading test.

This thesis is based on the work with normal readers and consequently, in Rutter and Yule's (1975) point of view, should not be generalised to dyslexia. However, as stressed before, there has been growing evidence claiming dyslexia may represent the lower tail of a normal distribution of reading ability. A point of interest is the proportion of males to females in the good and normal reading groups. The percentages of males in the two groups are (6 out of 31) 19.35% and (8 out of 46) 17.39% respectively. This indicates that the proportion of males to females does not change with reading ability. Though one may argue that the result is confined to normal readers and is not consistent with studies which found a higher prevalence rate in males (e.g., Rutter & Yule, 1975), my samples are taken from arts and health science faculties at which most of their students are females. Also, several researchers (e.g., Shaywitz, Shaywitz, Fletcher & Escobar, 1990) argue that the high prevalence of reading disability reported in males are attributable to social / environmental bias and that dyslexia may be just one "cause" of reading difficulty (Snowling, 1989). Thus, the discrepancy in prevalence rates between my study and Rutter and Yule's (1975) neither provides evidence that reading disability is a separate entity, nor does it ruin the possibility that dyslexia representing the lower end of a normal distribution of reading ability. Moreover, my results, based on the work with normal readers, are partially compatible with the findings in dyslexic research. Therefore, it provides evidence of dyslexia representing the lower end of the reading ability continuum and accordingly, justifies the use of normal readers and minimises the difficulty in generalising my results on dyslexic research.

In addition, though the use of normal readers in examining dyslexia may sound "irrelevant" from the point of view that dyslexia is a discrete entity, it is necessary to uncover the reading process in both normal and poor readers. Besides, as explained in Chapter 6, the use of normal readers favours the recruitment of subjects especially when large-scale studies are carried out.

Borsting et al (1996) and Ridder et al (in press) found that only the dysphoneidetics and those dysphonetics graded as severe exhibited decreased contrast sensitivity to high temporal frequency visual information. Similarly, Bauserman and Obrzut (1981) found that dyseidetic and normal readers performed better than alexic and dysphonetic readers on a visual sequence matching task. In Tallal and Stark (1982), reading-disabled children without concomitant receptive or expressive language deficits did not "have difficulty learning the phoneme to grapheme correspondences necessary for learning phonics rules" (p.170). The interesting finding is that those children who were unimpaired in reading nonsense words, were also unimpaired in a majority of temporal perceptual tasks (e.g., temporal integration) whereas children with expressive language deficits were impaired in those tasks. Thus, it seems that, firstly, for visual temporal processing deficits to be apparent, dyslexics normally need to have: 1) phonological processing deficits; and 2) severe reading problems. This may explain why dyseidetics who are deficient in whole-word and not phonological skills do not have a transient visual subsystem problem. Research which can not replicate the visual deficits may have employed mild dyslexics (e.g., Arnett & Di Lollo, 1979). For instance, Lovegrove et al (1989) used dysphonetic and severe dyslexics and they found the coexistence of visual and phonological problems. Secondly, it seems that phonological deficits and temporal processing deficits coexist with / undermine each other, as found in Tallal and Stark (1982).

The results of this thesis are consistent with the above findings. Firstly, good readers have better auditory temporal perception and phonological skills. Since normal subjects are used in this thesis, it may be reasonable not to have found the significant visual processing differences. Secondly, the author's speculation of visual temporal processing being secondary to auditory temporal processing (section 10.2.6) is also plausible. For example, Studies 2 and 3 show that though visual temporal processing is involved in irregular word reading, "irregular word" readers who have better whole-word skills do not exhibit better visual temporal resolution. It follows that visual temporal perception does not make a major contribution to whole-word skills, an issue argued in 10.2.5. Consequently, dyseidetics who are deficient in whole-word skills should be unlikely to exhibit visual temporal processing deficits because these deficits do not directly relate to whole-word skills. In fact, this argument is consistent with Borsting et al (1996), Ridder et al (in press) and Bauserman and Obrzut (1981).

If visual temporal processing does not facilitate whole-word skills, two questions arise: 1) what facilitates whole-word skills; and 2) what is the role of visual temporal processing? As stressed in 10.2.5, visual memory may facilitate whole-word skills. The author does not attempt to go further as this is beyond the scope of the thesis. Further, the author's suggestion that visual temporal processing being secondary to auditory temporal processing becomes more relevant. Recall Borsting et al (1996), Ridder et al (in press) and Bauserman and Obrzut (1981), phonological and severe reading problems undermine visual temporal processing deficits. In addition, poor auditory temporal perception results in phonological deficits (e.g., Tallal, 1980). If this is the case, dyslexics who exhibit visual temporal processing deficits, because of the coexistence of phonological deficits, should also exhibit auditory temporal processing deficits. On the other hand, dyslexics who have auditory temporal processing deficits may or may not have the visual one, depending on the severity of the reading problem. This is in fact supported by Farmer and Klein (1993), Reed (1989), Tallal and Piercy (1973b), Bryden (1972) and Gould and Glencross (1990) that dyslexics / dysphasics who were impaired in auditory tasks need not necessarily be impaired in visual tasks. Hence, visual temporal processing deficits seem to be secondary to the auditory one. Moreover, poor readers need to be deficient in their phonological skills for the temporal deficits to be apparent, as found in Tallal and Stark (1982).

Nevertheless, one can argue that the irregular word reading task used in this research has a large phonic component which may obscure the relationship between visual temporal processing and visual capture of orthography. Some results of the factor analyses and multiple regressions (e.g., inconsistency in factors extracted) may have supported this notion. However, good readers still excelled normal readers in the transient visual measures, though the results were not significant. Thus, the suggestion that visual temporal processing being secondary to the auditory one may not be totally impossible with reference to the consistency between my results and other research (e.g., Borsting et al, 1996; Tallal & Stark, 1982).

Regarding the proposed model in 10.2.2, the "operational field" of phonological deficits must overlap with that of auditory temporal processing, at least in the cognitive level. If the deficits are severe enough, these may generate deficits in visual temporal processing which shares the same "operational field" with the auditory one.

If good-reading-poor-spelling is a mild form of dyslexia, then by analogy, dyslexia with just auditory temporal processing deficits should be a mild form of that with visual ones.

One worthwhile implication is that the dyslexic subtypes may reflect different mechanisms. It seems that dyslexic subtypes with phonological deficits (dysphonetic and mixed dyslexia) will exhibit temporal processing deficits whereas the dyseidetic subtype is unlikely to exhibit such deficits (e.g., Ridder et al, in press; Tallal and Stark, 1982). Moreover, for subtypes which accompany phonological deficits, auditory temporal processing deficits seem inevitable whereas visual temporal processing deficits may be secondary. For the dyseidetic subtype which accompanies whole-word and not phonological deficits, visual memory or the ability to integrate coding visual gestalts with higher reading processes becomes far more important. Therefore, to reconcile the finding in this thesis with Farmer and Klein (1995), auditory temporal processing deficits are necessary for dysphonetic dyslexia. On the contrary, visual temporal processing deficits are unlikely to be found in dyseidetic dyslexia even though some amount of visual processing is required for reading irregular words.

Meanwhile, if dyslexic subtypes reflect different mechanisms, then dyslexia should not be viewed as homogeneous. Different research methodologies should target different subtypes and the subtypes should be investigated independently. For instance, to verify the author's suggestion, future research can compare various temporal processing ability on different subtypes. Additionally, research can also target the mechanisms behind both phonological and sight-word skills.

10.3 Conclusion

In conclusion, some of the results are suggestive of a common temporal processing mechanism across vision and audition and the factors extracted may imply different components / levels of processing within the "higher-order" mechanism. Auditory temporal perception facilitates nonsense word reading whereas visual temporal perception, though the effect is small, facilitates irregular word reading only in one study. Results also support the primary involvement of the sustained visual system in reading words presented singly and the primary involvement of the transient visual system in reading words presented continuously. Furthermore, the differentiation only occurs partially in Study 2 with the small visual effect vulnerable to the influence of IQ (e.g., Study 3). "Nonsense word" readers who have better phonological skills tend to exhibit better auditory temporal resolution whereas "irregular word" readers who have better sight-word skills do not exhibit better visual temporal resolution. Good readers have better auditory temporal perception and a trend for better transient visual system.

Although both "nonsense word" readers and good readers excel in auditory temporal tasks, the choice of reading strategy is unrelated to reading performance. In addition, the auditory temporal processing measures and the transient visual measures are effective discriminants for good and normal readers but not for whole-word and phonological skills. This reinforces previous findings on the relationship between visual and auditory temporal perception and reading (e.g., Lovegrove et al, 1989; Tallal et al, 1985a) and the independence between reading proficiency and choice of reading strategy (Freebody & Byrne, 1988; Byrne et al, 1992).

While auditory temporal perception is essential for developing phonological skills, whole-word skills may be facilitated by visual memory rather than visual temporal perception. This implies that visual temporal perception may be secondary to auditory temporal perception such that dyslexics need to have phonological deficits and severe reading problems for the visual deficits to be evident. Moreover, temporal processing deficit(s) may only appear in dyslexics who have phonological deficits, whereas dyslexics who have no phonological deficits would have a different source of problem. Thereafter, dyslexia should not be viewed as homogeneous. Dyslexics subtypes should be treated differently, both in research methodology and in remediation.

The findings of this study provide a strong basis for investigating the possibility of pansensory deficits in dyslexia. Subsequent research can focus on how this timing mechanism functions with reference to the proposed model (section 10.2.2) and Nicolson and Fawcett's (1993c) and Frith's (1992) argument. This thesis has also shown what are the most sensitive measures and how some common assumptions about how to measure the transient and sustained visual systems' activity appear to be invalid. Therefore, future research can examine the validity of tests in differentiating the two subsystems. Moreover, future direction can focus on transmodal research on dyslexic subtypes and also studies which investigate mechanisms relating to phonological and sight-word skills.

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Appendix A

Word Lists

Irregular Words			Nonsense Words		
Practice	**List 1**	**List 2**	**Practice**	**List 1**	**List2**
do	come	sure	ab	gop	ted
eye	shoe	lose	yox	nad	lif
are	pint	choir	rez	sut	thim
own	tomb	cough	pid	phot	chut
good	soul	iron	mell	sith	giph
said	wolf	bowl	feap	hoil	toud
have	blood	quay	knap	gead	daul
four	gauge	break	hend	prin	stet
give	island	answer	lundy	mulp	roin
world	ceiling	pretty	eldop	nint	gren
friend	debris	indict	wotfob	gurdet	torlep
great	regime	meringue	biftel	tadlen	latsar
	bouquet	beret		polmex	tashet
	colonel	routine		sothep	miphic
	brooch	yacht		lishon	dethix
	chord	ache		rayed	coge
	aisle	depot		squow	byrcal
	deny	psalm		mieb	phigh
	nausea	debt		hudned	quog
	rarefy	naive		lindify	pnir
	gaoled	thyme		cythe	throbe
	heir	hiatus		nolhod	sloy
	gist	subtle		cedge	depine
	simile	banal		whumb	lunap
	facade	cellist		knoink	dinlan
	drachm	zealot		expram	rhunk
	aeon	idyll		dreek	imbaf
	prelate	aver		brecked	glack
	demesne	radix		wroutch	zoath
	labile	syncope		rejune	pertome

Appendix B

Instructions to Subjects

Word Reading Test

In this experiment, I am investigating the ability to read nonsense and irregular words.

On each trial, you will see some words presented in two different ways. In one way, a single word will be presented. In the other way, a group of words will be presented in the form of a sentence. Your task is to read the words aloud through the microphone attached to the computer. However, if the words are presented in the form of a sentence, you need to follow the "+"s and read the one that is highlighted.

The experiment will proceed in the following way:

1) The experimenter will inform you that the practice trials are about to begin and that you are to look at the centre of the screen or to look at the "+".

2) You will be asked to press the space bar to begin the trials.

3) The words will be presented on the screen.

4) If the word is presented singly, just read it aloud through the microphone attached to the computer.

5) If the words are presented in the form of a sentence, follow the "+"s and read the highlighted words. Dont jump to the next "+" unless the word under that "+" appears.

6) Don't make any noise other than reading. Make sure you've figured out how to read the word before you read it. Try your best if you are not sure of the pronunciation.

7) As soon as you have made your response, the next trial begins.

8) After the practice trials, you will be told that the test trials are about to begin.

If you have any questions, don't be hesitated to ask. It is important that you clearly understand the instructions before you begin the test trials.

N.B.: In the second session continuous presentation, the word was presented with a line of "X"s followed on its right. Subjects were asked to ignore the "X"s and read the word on the left. Similar procedures were applied.

Appendix B (cont.)

Instructions to Subjects

Flicker Sensitivity Test

In this experiment, I am investigating the precision with which the visual system can detect flickering stimuli.

On each trial, you will hear two beeps and see a flickering pattern after one of the beeps. Sometimes, the flickering pattern will be presented following the first (high tone) beep. At other times the flickering pattern will be presented following the second (low tone) beep. Then a third beep will signal you to respond. Your task is to decide whether the flickering pattern is presented immediately following the first or the second beep. If you think that the flickering pattern appears with the first (high tone) beep, press "1" on the response box. If you think that it appears with the second (low tone) beep, press "2" on the response box.

The experiment will proceed in the following way:

1) The experimenter will inform you that the practice trials are about to begin and that you are to look at the circle in the centre of the screen.

2) You will be asked to press either "1" or "2" on the response box.

3) The first (high tone) beep will now be heard. You will see either a flickering pattern or nothing.

4) The second (low tone) beep will be heard. If you saw the flickering pattern following immediately after the first beep, you will now see nothing. If you saw nothing following the first beep, you will now see the flickering pattern.

5) After the two beeps and the pattern have disappeared from the screen, you will hear the third beep that signals you to respond. If you think the flickering pattern appears with the first (high tone) beep, press "1" on the response box. If you think the flickering pattern appears with the second (low tone) beep, press "2" on the response box.

6) As soon as you made your response, the next trial begins.

7) After the practice trials, you will be told that the test trials are about to begin.

On some trials, it will be harder to determine which beep the flickering pattern appears. On such occasions, just guess at the right answer.

If you have any questions, don't be hesitated to ask. It is important that you clearly understand the instructions before you begin the test trials.

Appendix B (cont.)

Instructions to Subjects

Visual Temporal Order Judgment Test

In this experiment, I am investigating the precision with which the visual system can resolve the order of presentation of two rapidly presented stimuli.

On each trial, two sets of stripes will appear in the circles on the screen. One set will appear in the circle on the left side of the screen while the other set will appear in the circle on the right. One set will always appear on the display just before the other set. Sometimes, the stripes on the right side will appear first while at other times the stripes on the left will appear first. Your task is to indicate whether you saw the stripes in the circle on the left or the stripes in the circle on the right first. If you think the stripes on the left side appear first, press "L" on the response box. If you think the stripes on the right side appear first, press "R" on the response box.

The experiment will proceed in the following way:

1) The experimenter will inform you that the practice trials are about to begin and that you are to look at the "+" in the centre of the screen.

2) You will be asked to press either "L" or "R" on the response box to begin the trials.

3) A beeping sound will be heard to indicate the stripes are about to be presented.

4) The stripes on the left side of the screen or the stripes on the right side of the screen will now appear.

5) Shortly after, the stripes on the other side of the screen will appear.

6) Both sets of stripes will now disappear at the same time.

7) You are required to respond. If you think the stripes appear on the left side first, press "L" on the response box. If you think the stripes appear on the right side first, press "R" on the response box.

8) As soon as you have made your response, the next trial begins.

9) After the practice trials, you will be informed that the test trials are about to begin.

On some trials, it will become harder to determine which set of stripes appears first. On such occassions, just guess at the right answer.

If you have any questions, don't be hesitated to ask. It is very important that you understand the instructions before you begin the test trials.

Appendix B (cont.)

Instructions to Subjects

Visible Persistence Test (based on the judgment of a blank)

In this experiment, I am investigating the precision with which the visual system can detect a blank field within the alternating gratings.

On each trial, you will see some gratings alternating with a blank field. Sometimes, it is easier to see the blank field alternating among the gratings and sometimes it is harder to see. Your task is to decide whether you can see the blank field clearly or not. If you clearly see the blank field alternating among the gratings, press "Y" on the response box. If you cannot see it clearly, press "N" on the response box. Just ignore the flicker on the display.

The experiment will proceed in the following way:

1) The experimenter will inform you that the practice trials are about to begin and that you are to look at the centre of the screen.

2) You will see a grating pattern alternating with a blank field for several times.

3) After the patterns have disappeared from the screen, you are required to respond. If you clearly see the blank field alternating among the gratings, press "Y" on the response box. If you can not see it clearly, press "N" on the response box. Ignore any flicker on the display.

4) As soon as you made your response, the next trial begins.

5) After the practice trials, you will be told that the test trials are about to begin.

If you have any questions, don't be hesitate to ask. It is important that you clearly understand the instructions before you begin the test trials.

Appendix B (cont.)

Instructions to Subjects

Visible Persistence Test (based on the judgment of a flicker)

In this experiment, I am investigating the precision with which the visual system can detect a flicker within the alternating gratings.

On each trial, you will see some gratings alternating with a flicker. Sometimes, it is easier to see the flicker alternating among the gratings and sometimes it is harder to see. Your task is to decide whether you can see the flicker clearly or not. If you clearly see the flicker alternating among the gratings, press "Y" on the response box. If you cannot see it clearly, press "N" on the response box.

The experiment will proceed in the following way:

1) The experimenter will inform you that the practice trials are about to begin and that you are to look at the centre of the screen.

2) You will see a grating pattern alternating with a flicker for several times.

3) After the patterns have disappeared from the screen, you are required to respond. If you clearly see the flicker alternating among the gratings, press "Y" on the response box. If you can not see it clearly, press "N" on the response box.

4) As soon as you made your response, the next trial begins.

5) After the practice trials, you will be told that the test trials are about to begin.

If you have any questions, don't be hesitate to ask. It is important that you clearly understand the instructions before you begin the test trials.

Appendix B (cont.)

Instructions to Subjects

Flicker Fusion Test

In this experiment, I am investigating the precision with which the visual system can detect a stimulus that flicks.

On each trial, you will see a vertical and a horizontal grating alternating with each other to form a "chequerboard" pattern. Sometimes, the display looks unstable and flickering. At other times, the display looks stable and does not flick. Your task is to decide the point which the display appears not to flick. If you think that the display appears unstable and flickering, press "Y" on the response box. If you think that it appears stable and does not flick, press "N" on the response box.

The experiment will proceed in the following way:

1) The experimenter will inform you that the practice trials are about to begin and that you are to look at the centre of the screen.

2) You will now see the display that flicks or not.

3) After the patterns have disappeared from the screen, you are required to respond. If you see the display being unstable and flickering, press "Y" on the response box. If you see the display being stable and appears not to flick, press "N" on the response box.

4) As soon as you made your response, the next trial begins.

5) After the practice trials, you will be told that the test trials are about to begin.

If you have any questions, don't be hesitate to ask. It is important that you clearly understand the instructions before you begin the test trials.

Appendix B (cont.)

Instructions to Subjects

Auditory Fusion Test

In this experiment, I am investigating the precision with which the auditory system can detect discrete time intervals between two rapidly presented stimuli.

On each trial, you will hear two sounds. One of the sounds consists of two bursts of noise separated by a short gap of silence. The other sound will be a single continuous burst of noise. On some trials, the two bursts of noise will be presented before the single burst of noise (i.e., presented on the first interval) and on other trials, the two bursts of noise will be presented after the single burst of noise (i.e., presented on the second interval). Your task is to indicate whether the two bursts of noise are presented on the first or the second interval. If you think the two bursts of noise are presented on the first interval, press "1" on the response box. If you think the two bursts of noise are presented on the second interval, press "2" on the response box.

The experiment will proceed in the following way:

1) The experimenter will inform you that the practice trials are about to begin.

2) The first sound will now be heard (presented on the first interval). This sound will either consists of two bursts of noise separated by a short gap of silence or a single continuous burst of noise.

3) Shortly after, the other sound will be presented on the second interval.

4) You are required to respond. If you think the two bursts of noise are presented on the first interval, press "1" on the response box. If you think the two bursts of noise are presented on the second interval, press "2" on the response box.

5) As soon as you respond, the next trial begins.

6) After the practice trials, you will be told that the test trials are about to begin.

On some trials, it will become harder to determine which set of sounds consists of two bursts of noise. On such occassions, just guess at the right answer.

If you have any questions, don't be hesitated to ask. It is very important that you understand the instructions before you begin the test trials.

Appendix B (cont.)

Instructions to Subjects

Auditory Temporal Order Judgment Test

In this experiment, I am investigating the precision with which the auditory system can resolve the order of presentation of two rapidly presented sounds.

On each trial, two tones will be presented over earphones. One is a high tone while the other is a low tone. One tone will always be presented before the other. Sometimes the high tone will be presented first while at other times the low tone will be presented first. Your task is to indicate whether you heard the high tone or the low tone first. If you think you heard the high tone first, press "H" on the response box. If you think you heard the low tone first, press "L" on the response box.

The experiment will proceed in the following way:

1) The experimenter will inform you that the practice trials are about to begin.

2) You will be asked to press either the "H" or "L" key to begin the trials.

3) You will now hear the first tone.

4) Shortly after, the second tone will be presented.

5) Both tones will stop at the same time.

6) You are required to respond. If you think the low tone was presented first, press "L" on the response box. If you think the high tone was presented first, press "H" on the response box.

7) As soon as you respond, the next trial begins.

8) After the practice trials, you will be informed that the test trials are about to begin.

On some trials it will become harder to determine which tone was presented first. On such occassions, just guess at the right answer.

If you have any questions, don't be hesitated to ask. It is very important that you understand the instructions before you begin the test trials.

Appendix C

Table C-1: Subjects' Data for Study 1

SUBJ	FSEN2	FSEN12	VTOJ1	VTOJ7		
	BLAN2	BLAN12	FLICK2	FLICK12	CHAS2	CHAS12
	AFUS15	AFUS100	ATOJ15	ATOJ75	ATOJ200	
001	0.04150	0.01325	036.97095	228.11450		
	209.90	366.74	03.42	18.56	15.98	19.52
	02.280	01.920	021.330	026.405	022.100	
002	0.06695	0.01830	033.52995	227.15660		
	227.79	333.29	22.22	43.57	33.87	38.97
	04.095	03.050	414.960	126.650	859.185	
003	0.05095	0.01880	048.30205	115.18335		
	223.71	376.26	04.76	21.29	19.50	26.65
	03.890	03.015	018.600	068.420	068.950	
004	0.03760	0.01180	026.07810	085.32800		
	166.93	271.19	04.12	17.26	21.07	33.07
	03.030	03.045	034.810	071.680	067.340	
005	0.03400	0.01250	039.66965	097.39435		
	183.43	271.59	01.65	02.00	11.08	17.97
	05.380	02.735	038.285	076.065	072.260	
007	0.03630	0.01380	044.35715	257.28600		
	234.48	242.21	12.89	27.59	22.76	33.14
	03.115	02.760	052.665	122.945	119.815	
008	0.02965	0.01680	066.72405	090.95040		
	203.94	256.56	02.99	04.02	15.06	19.68
	02.650	02.420	089.245	150.115	118.910	
009	0.03705	0.01230	080.53500	240.99850		
	222.43	345.65	06.69	22.62	16.68	27.80
	04.175	02.970	035.245	058.155	114.835	
010	0.03025	0.01045	032.68440	149.54690		
	142.00	274.28	02.01	06.57	15.31	23.39
	03.625	02.955	028.530	035.825	049.800	
011	0.03920	0.01750	038.05925	093.34495		
	133.40	209.08	02.25	11.36	13.48	22.87
	03.410	02.670	034.390	043.060	064.405	
012	0.04195	0.01085	106.59700	535.61095		
	303.60	350.98	07.56	18.56	16.54	23.81
	06.040	03.030	132.770	145.455	351.375	
013	0.04470	0.01640	034.36825	232.30100		
	208.79	386.32	15.58	48.31	19.32	29.04
	03.780	02.860	024.460	051.090	068.645	
014	0.04765	0.01860	067.63895	183.21825		
	231.80	280.63	10.03	23.01	16.68	24.02
	05.005	03.865	053.695	040.055	148.930	
015	0.05695	0.01745	080.17400	144.45840		
	310.82	377.24	10.20	25.52	18.19	26.63
	02.205	03.135	042.120	156.980	144.885	

Table C-1 (cont.)

SUBJ	FSEN2	FSEN12	VTOJ1	VTOJ7		
	BLAN2	BLAN12	FLICK2	FLICK12	CHAS2	CHAS12
	AFUS15	AFUS100	ATOJ15	ATOJ75	ATOJ200	
016	0.03960	0.00795	080.22480	161.30395		
	016.72	120.47	01.88	03.66	18.51	26.66
	02.700	02.950	140.210	131.420	201.845	
017	0.03570	0.00810	120.08185	162.53800		
	244.16	376.11	04.01	04.61	18.99	20.55
	03.500	02.990	066.450	251.345	168.385	
018	0.04760	0.01550	045.80360	231.02155		
	233.67	327.68	11.36	12.18	15.57	21.47
	02.525	02.705	017.025	030.090	056.815	
019	0.02585	0.01225	073.30705	152.18210		
	120.32	174.54	24.41	61.52	20.03	29.03
	02.905	02.985	042.365	084.745	103.435	
020	0.03405	0.01845	048.64675	127.54550		
	162.59	190.28	01.48	01.60	13.82	22.42
	02.875	02.955	080.415	110.665	071.270	
021	0.03270	0.01025	041.55460	135.90620		
	151.74	211.17	07.35	13.29	16.68	20.56
	03.170	02.815	048.940	112.745	131.850	
022	0.04870	0.01820	036.25295	127.01480		
	324.53	357.23	05.98	23.81	19.66	28.06
	05.325	02.625	078.745	105.460	115.560	
023	0.03420	0.01480	088.40475	152.27945		
	219.96	322.07	03.79	11.39	17.60	21.12
	07.710	03.495	085.840	192.250	261.400	
025	0.02895	0.01450	076.30050	199.68230		
	154.78	272.56	04.00	21.87	13.81	19.18
	02.845	03.065	117.880	110.105	105.960	
026	0.05265	0.02025	076.28900	309.31025		
	197.34	224.04	01.83	04.34	14.54	23.82
	04.455	03.030	052.565	097.530	129.100	
027	0.04655	0.01600	027.32760	099.20495		
	126.74	301.13	06.53	18.22	12.66	22.61
	03.570	03.045	039.325	095.240	116.810	
028	0.10460	0.01835	058.47645	238.52160		
	182.12	293.01	16.40	35.11	20.54	41.05
	03.480	03.670	106.015	186.920	134.100	
029	0.02785	0.00950	016.83050	099.87755		
	197.31	200.31	07.28	17.51	18.51	23.21
	03.755	02.845	030.160	038.230	069.140	
030	0.03870	0.01050	054.27395	145.20175		
	153.07	228.01	09.10	25.29	18.19	29.03
	02.540	02.455	088.670	121.580	111.760	
031	0.03365	0.01600	037.98755	046.24330		
	126.41	242.40	02.01	03.56	14.41	23.20
	03.860	03.015	020.805	050.890	094.210	
032	0.03940	0.01195	042.15890	138.13280		
	232.13	308.46	04.30	04.69	16.68	24.37
	03.115	02.080	027.690	022.480	044.185	

Table C-1 (cont.)

SUBJ	FSEN2 BLAN2 AFUS15	FSEN12 BLAN12 AFUS100	VTOJ1 FLICK2 ATOJ15	VTOJ7 FLICK12 ATOJ75	 CHAS2 ATOJ200	 CHAS12
033	0.05565	0.01410	042.16245	156.73755		
	171.21	386.32	02.87	07.00	14.65	17.91
	03.535	03.400	081.845	069.515	104.075	
034	0.02930	0.01345	071.38765	193.94885		
	210.98	285.46	04.86	21.69	16.25	28.30
	02.480	03.120	020.915	045.180	076.110	
035	0.03165	0.01190	037.89280	148.64690		
	116.26	266.47	03.71	19.18	14.41	19.18
	02.155	01.940	023.400	034.535	129.925	
036	0.05425	0.01975	104.17310	218.52780		
	237.84	293.01	03.24	07.61	13.46	18.53
	02.935	04.100	064.115	091.795	072.620	
037	0.03795	0.00960	045.39100	141.63470		
	162.59	157.76	01.99	03.47	08.91	20.74
	03.050	03.050	066.905	060.185	205.760	
038	0.06650	0.02120	028.10845	138.74080		
	158.43	210.93	06.92	12.64	18.20	24.86
	02.610	02.865	040.650	055.065	174.390	
039	0.04505	0.01565	039.34935	232.19385		
	155.66	238.07	02.01	04.99	14.65	22.06
	02.675	02.950	044.135	059.770	140.240	
040	0.05980	0.01195	085.42005	500.55970		
	166.81	319.68	02.94	05.23	16.11	21.47
	04.210	04.440	180.555	243.255	354.800	
041	0.03380	0.01445	047.05820	107.03950		
	252.89	290.60	16.78	30.35	14.16	32.21
	03.050	02.985	023.345	049.130	025.510	
042	0.06585	0.01645	069.49240	193.74345		
	226.24	275.71	03.39	14.93	15.84	28.06
	07.000	04.280	056.660	230.870	122.500	
043	0.03740	0.01035	091.32460	220.94165		
	141.67	237.98	02.87	12.08	14.65	19.36
	04.760	03.070	052.265	084.595	121.455	
044	0.05150	0.01150	052.67000	128.79725		
	359.97	421.78	03.05	07.61	16.26	22.82
	02.600	03.015	038.910	041.345	096.960	
045	0.03870	0.01465	068.89945	175.07310		
	174.43	345.13	07.10	27.14	16.99	26.18
	04.215	02.045	064.330	152.550	119.235	
046	0.03380	0.01510	074.68185	226.51320		
	174.36	316.92	10.00	33.63	18.99	36.99
	02.940	03.130	022.905	074.085	109.970	
047	0.05940	0.01305	054.84065	163.59010		
	153.13	240.73	02.01	09.99	15.58	29.03
	03.535	03.310	070.595	129.335	129.500	
048	0.03845	0.01395	047.04110	193.46760		
	100.23	157.29	02.96	10.68	13.34	18.22
	01.930	02.690	031.000	047.130	116.855	

Table C-1 (cont.)

SUBJ	FSEN2	FSEN12	VTOJ1	VTOJ7		
	BLAN2	BLAN12	FLICK2	FLICK12	CHAS2	CHAS12
	AFUS15	AFUS100	ATOJ15	ATOJ75	ATOJ200	
049	0.06085	0.01605	078.42110	139.40155		
	129.95	218.55	04.19	06.41	16.40	19.02
	05.845	02.970	216.690	118.140	133.240	
050	0.04280	0.01955	058.90615	180.80930		
	116.26	383.06	04.32	18.37	15.19	25.95
	03.730	02.770	021.545	038.060	107.470	
052	0.04195	0.01505	099.99845	118.25900		
	226.00	491.91	09.95	20.82	18.67	25.29
	02.495	03.015	041.895	062.715	115.030	
061	0.03005	0.01500	046.10485	171.75625		
	218.00	378.29	04.16	16.08	14.67	17.30
	03.410	02.800	068.335	121.905	171.100	
062	0.05745	0.01420	070.51985	186.55010		
	137.97	195.18	02.64	06.89	14.29	19.87
	03.640	02.930	053.380	014.250	097.645	
063	0.04380	0.01790	062.49660	186.48865		
	284.40	326.19	02.18	12.94	14.29	22.06
	02.315	03.000	065.440	088.125	084.360	
064	0.05560	0.01770	068.32665	219.26270		
	205.28	347.99	12.94	27.80	15.57	27.10
	03.395	03.000	007.785	037.605	033.640	
065	0.05345	0.01980	097.95610	270.50825		
	285.00	443.46	18.08	42.17	13.57	17.51
	04.395	02.830	086.790	054.025	175.850	
066	0.03680	0.01295	036.43690	058.83310		
	074.22	126.75	04.08	04.98	14.41	23.59
	02.845	02.725	025.730	039.795	027.600	
067	0.04185	0.01145	039.69440	055.51575		
	164.04	157.29	02.01	11.95	14.78	16.88
	03.005	02.920	044.445	059.665	075.410	
068	0.05270	0.01235	034.63030	105.40890		
	190.50	251.06	04.38	19.06	16.68	30.89
	02.700	01.920	046.985	042.830	111.180	
069	0.06510	0.01805	090.12295	202.22800		
	140.77	210.93	02.27	07.82	16.69	23.59
	02.765	02.750	012.280	050.065	040.010	
070	0.05310	0.01755	041.33930	135.46775		
	195.18	268.25	02.08	03.05	13.61	18.19
	03.770	03.115	015.105	054.615	078.840	
071	0.08435	0.01270	024.64420	052.37890		
	362.73	574.38	25.06	45.88	20.89	35.45
	02.950	03.000	022.685	065.135	086.790	
072	0.06380	0.01235	041.08500	116.06600		
	150.21	129.01	03.14	06.31	16.56	23.24
	03.115	03.290	057.445	075.940	110.565	
073	0.03480	0.01220	031.84450	086.68155		
	222.09	316.92	06.70	12.61	15.04	18.85
	04.935	03.690	017.750	022.045	024.285	

Table C-1 (cont.)

SUBJ	FSEN2 BLAN2 AFUS15	FSEN12 BLAN12 AFUS100	VTOJ1 FLICK2 ATOJ15	VTOJ7 FLICK12 ATOJ75	 CHAS2 ATOJ200	 CHAS12
074	0.02620	0.01400	054.36360	163.07680		
	099.44	146.37	02.76	03.36	14.67	24.90
	05.250	02.980	095.750	068.755	227.180	
075	0.04025	0.01230	038.21455	106.86990		
	250.56	244.60	02.01	01.61	15.05	18.21
	03.125	01.920	064.945	103.120	156.915	
076	0.03475	0.01535	041.46100	122.84335		
	216.78	351.11	21.82	25.74	20.00	29.61
	02.650	02.535	033.285	046.415	095.060	
077	0.05175	0.01385	075.02145	274.25720		
	195.18	285.35	11.95	16.14	18.51	31.67
	06.755	03.130	199.020	216.180	175.280	
078	0.06885	0.02375	045.97555	553.77080		
	140.46	305.72	11.54	19.18	17.13	23.39
	03.815	02.640	052.335	054.285	136.300	
079	0.04675	0.01410	049.97025	140.88820		
	120.18	190.14	02.01	07.56	15.84	21.47
	03.290	02.465	031.185	136.830	079.790	
080	0.03625	0.01005	051.43350	107.75625		
	200.12	251.06	01.93	06.99	13.57	17.21
	02.515	02.475	013.705	054.935	065.045	
081	0.04655	0.01185	035.72400	170.98550		
	268.41	339.14	03.78	10.57	14.53	28.78
	06.995	03.740	089.990	205.200	129.755	
082	0.04795	0.01685	046.21065	080.59120		
	140.35	255.40	01.94	01.90	13.57	21.10
	02.910	04.310	021.055	029.365	038.930	
083	0.04295	0.01120	044.77280	172.22080		
	112.33	222.18	02.01	04.90	17.45	20.74
	04.215	03.000	035.985	052.825	079.995	
084	0.06435	0.01630	032.48345	113.84470		
	261.62	300.46	29.03	33.96	16.26	22.06
	08.415	03.515	330.360	095.615	068.245	
085	0.12090	0.01765	045.53030	136.02110		
	125.46	275.80	12.04	23.68	18.71	29.54
	09.625	03.845	071.250	198.910	283.475	
086	0.04725	0.01240	027.13025	115.44380		
	205.44	248.85	03.08	13.94	16.68	21.46
	02.705	02.625	091.065	065.505	097.555	
088	0.03155	0.01580	029.74795	093.14215		
	268.21	342.13	03.95	09.31	06.85	12.80
	03.350	02.790	015.065	028.105	104.415	
089	0.05740	0.01935	114.23880	349.15965		
	287.54	804.23	21.07	35.84	23.39	28.57
	18.120	07.195	067.305	139.460	184.155	
090	0.05205	0.01475	055.98365	173.92735		
	229.67	274.21	05.31	20.77	16.12	27.74
	02.935	02.970	026.475	206.190	090.775	

Table C-1 (cont.)

SUBJ	FSEN2	FSEN12	VTOJ1	VTOJ7		
	BLAN2	BLAN12	FLICK2	FLICK12	CHAS2	CHAS12
	AFUS15	AFUS100	ATOJ15	ATOJ75	ATOJ200	
091	0.03450	0.01245	025.51030	118.31515		
	036.92	169.15	02.01	05.30	16.14	27.61
	02.600	01.855	023.985	026.140	074.060	
093	0.08375	0.02095	044.00385	152.99955		
	163.98	261.94	02.92	07.97	15.17	22.44
	09.265	03.070	016.530	032.745	078.820	
094	0.05015	0.01515	049.37235	167.22985		
	372.70	354.50	20.57	25.32	19.00	23.63
	02.945	03.030	083.395	106.785	159.920	
095	0.07150	0.02605	081.08145	121.63895		
	172.72	292.80	04.54	18.13	16.27	20.76
	03.400	02.470	235.455	118.420	471.055	
096	0.05910	0.01575	041.36040	160.57475		
	132.43	161.54	02.63	05.78	14.65	18.85
	02.810	03.030	100.500	077.140	153.540	
098	0.04200	0.01575	043.27685	107.36655		
	134.57	158.78	07.02	12.27	16.11	23.24
	03.065	03.110	041.365	052.700	098.380	
099	0.04935	0.01535	104.57560	232.60665		
	122.28	319.69	02.14	04.89	16.68	27.61
	08.840	03.690	145.965	092.090	217.260	
100	0.03530	0.00955	032.50375	081.58670		
	189.00	280.63	02.01	06.04	14.53	17.68
	02.630	02.895	010.780	039.180	037.720	
101	0.05285	0.01440	039.37780	187.27865		
	170.65	220.23	14.04	35.46	19.51	29.57
	05.145	03.245	018.925	044.085	095.420	
102	0.03485	0.01215	077.25645	170.67125		
	164.04	222.66	03.34	06.26	14.79	15.19
	03.455	02.920	088.625	098.600	173.965	
103	0.05775	0.01095	074.31370	205.07020		
	166.81	199.71	02.01	03.75	14.16	19.36
	07.300	02.950	055.760	150.560	261.710	
104	0.04020	0.01635	042.13420	105.02835		
	180.34	203.95	01.99	10.94	14.53	19.03
	02.965	02.575	007.630	022.855	045.635	
105	0.04445	0.01595	062.09155	299.88060		
	186.93	280.85	04.46	05.89	12.69	19.36
	03.060	02.985	095.920	080.725	092.940	

N.B.: SUBJ: Subject Number
FSEN2, FSEN12: Flicker Sensitivity at 2 and 12 Hz respectively
VTOJ1, VTOJ7 (ms): Visual Temporal Order Judgment at 1 and 7 c/d respectively
BLAN2, BLAN12 (ms): Visible Persistence (based on the judgment of a blank) at 2 and 12 c/d respectively
FLICK2, FLICK12 (ms): Visible Persistence (based on the judgment of a flicker) at 2 and 12 c/d respectively
CHAS2, CHAS12 (ms): Flicker Fusion at 2 and 12 c/d respectively
AFUS15, AFUS100 (ms): Auditory Fusion at 15 and 100 ms respectively
ATOJ15, ATOJ75, ATOJ200 (ms): Auditory Temporal Order Judgment at 15, 75 and 200 ms respectively

Appendix C (cont.)

Summary Tables of Study 1

Table C-2: Summary Tables of Repeated Measures ANOVA on Visible Persistence (BLAN and FLICK)

i) Main Effect of Task Type:

Source	df	Type III SS	Mean Square	F	Pr>F
Model	1	1040.3727	1040.3727	2160.95	0.0001
Error	90	43.3298	0.4814		
Total	91	1083.7025			

ii) Main Effect of Spatial Frequency:

Source	df	Type III SS	Mean Square	F	Pr>F
Model	1	38.7679	38.7679	434.94	0.0001
Error	90	8.0220	0.0891		
Total	91	46.7899			

iii) Task Type x Spatial Frequency:

Source	df	Type III SS	Mean Square	F	Pr>F
Model	1	4.8824	4.8824	62.42	0.0001
Error	90	7.0398	0.0782		
Total	91	11.9222			

Table C-3: Summary Tables of Repeated Measures ANOVA on the Auditory Measures

i) Within-Subject Effects among the Five Tasks:

Source	df	Type III SS	Mean Square	F	Pr>F
Model	4	1061.1201	265.2800	1385.93	0.0001
Error	360	68.9073	0.1914		
Total	364	1130.0274			

ii) Contrast: AFUS15 vs AFUS100:

Source	df	Type III SS	Mean Square	F	Pr>F
Mean	1	4.0632	4.0632	38.37	0.0001
Error	90	9.5310	0.1059		
Total	91	13.5942			

iii) Contrast: ATOJ15 vs ATOJ75:

Source	df	Type III SS	Mean Square	F	Pr>F
Mean	1	17.2320	17.2320	45.61	0.0001
Error	90	34.0017	0.3778		
Total	91	51.2337			

iv) Contrast: ATOJ15 vs ATOJ200:

Source	df	Type III SS	Mean Square	F	Pr>F
Mean	1	59.7447	59.7447	188.38	0.0001
Error	90	28.5439	0.3172		
Total	91	88.2886			

v) Contrast: ATOJ75 vs ATOJ200:

Source	df	Type III SS	Mean Square	F	Pr>F
Mean	1	12.8044	12.8044	41.73	0.0001
Error	90	27.6186	0.3069		
Total	91	40.423			

Table C-4: Summary Tables examining the Effect of Time Course between the First Half (Subject 1-52) and Second Half (Subject 61-105) of Subjects on the Sensory Measures ($\alpha' = 0.05 / 15 = 0.0033$):

i) FSEN2:

Source	df	Type III SS	Mean Square	F	Pr>F
Model	1	0.4742	0.4742	5.61	0.0201
Error	89	7.5299	0.0846		
Total	90	8.0041			

ii) FSEN12:

Source	df	Type III SS	Mean Square	F	Pr>F
Model	1	0.0494	0.0494	0.92	0.3398
Error	89	4.7694	0.0536		
Total	90	4.8188			

iii) VTOJ1:

Source	df	Type III SS	Mean Square	F	Pr>F
Model	1	0.233	0.233	1.41	0.238
Error	89	14.6934	0.1651		
Total	90	14.9264			

iv) VTOJ7:

Source	df	Type III SS	Mean Square	F	Pr>F
Model	1	0.3359	0.3359	1.63	0.2053
Error	89	18.361	0.2063		
Total	90	18.6969			

v) BLAN2:

Source	df	Type III SS	Mean Square	F	Pr>F
Model	1	0.0007	0.0007	0	0.9505
Error	89	16.8525	0.1894		
Total	90	16.8532			

Table C-4 (cont.)

vi) BLAN12:

Source	df	Type III SS	Mean Square	F	Pr>F
Model	1	0.0898	0.0898	0.84	0.3609
Error	89	9.4798	0.1065		
Total	90	9.5696			

vii) FLICK2:

Source	df	Type III SS	Mean Square	F	Pr>F
Model	1	0.0545	0.0545	0.09	0.7711
Error	89	56.9703	0.6401		
Total	90	57.0248			

viii) FLICK12:

Source	df	Type III SS	Mean Square	F	Pr>F
Model	1	0.7031	0.7031	1	0.3208
Error	89	62.7676	0.7053		
Total	90	63.4707			

ix) CHAS2:

Source	df	Type III SS	Mean Square	F	Pr>F
Model	1	0.0573	0.0573	1.55	0.2162
Error	89	3.2862	0.0369		
Total	90	3.3435			

x) CHAS12:

Source	df	Type III SS	Mean Square	F	Pr>F
Model	1	0.1806	0.1806	3.98	0.0491
Error	89	4.0404	0.0454		
Total	90	4.221			

Table C-4 (cont.)

xi) AFUS15:

Source	df	Type III SS	Mean Square	F	Pr>F
Model	1	0.3957	0.3957	2.64	0.1078
Error	89	13.3465	0.15		
Total	90	13.7422			

xii) AFUS100:

Source	df	Type III SS	Mean Square	F	Pr>F
Model	1	0.0013	0.0013	0.03	0.8555
Error	89	3.3616	0.0378		
Total	90	3.3629			

xiii) ATOJ15:

Source	df	Type III SS	Mean Square	F	Pr>F
Model	1	0.4891	0.4891	0.77	0.384
Error	89	56.8713	0.639		
Total	90	57.3604			

xiv) ATOJ75:

Source	df	Type III SS	Mean Square	F	Pr>F
Model	1	0.7824	0.7824	1.96	0.1652
Error	89	35.5569	0.3995		
Total	90	36.3393			

xv) ATOJ200:

Source	df	Type III SS	Mean Square	F	Pr>F
Model	1	0.2317	0.2317	0.59	0.4438
Error	89	34.8425	0.3915		
Total	90	35.0742			

Appendix D

Table D-1: Subjects' Data for Study 2

SUBJ								
	FSEN2	FSEN12	VTOJ1	VTOJ7				
	BLAN2	BLAN12	FLICK2	FLICK12	CHAS2	CHAS12		
	AFUS15	AFUS100	ATOJ15	ATOJ75	ATOJ200			
	IWSA1	IWLA1	NWSA1	NWLA1	IWST1	IWLT1	NWST1	NWLT1
	IWSA2	IWLA2	NWSA2	NWLA2	IWST2	IWLT2	NWST2	NWLT2
	IQ	AGE						
001	0.04150	0.01325	036.97095	228.11450				
	209.90	366.74	03.42	18.56	15.98	19.52		
	02.280	01.920	021.330	026.405	022.100			
	83.33	90.00	90.00	93.33	1485.70	1648.57	1883.33	1836.23
	83.33	76.67	96.67	86.67	0606.23	0931.67	0805.43	0801.43
	108	19						
002	0.06695	0.01830	033.52995	227.15660				
	227.79	333.29	22.22	43.57	33.87	38.97		
	04.095	03.050	414.960	126.650	859.185			
	76.67	80.00	86.67	83.33	1133.17	0872.80	1461.27	1236.47
	76.67	80.00	83.33	83.33	0689.70	1048.47	0952.13	1139.97
	108	18						
003	0.05095	0.01880	048.30205	115.18335				
	223.71	376.26	04.76	21.29	19.50	26.65		
	03.890	03.015	018.600	068.420	068.950			
	60.00	73.33	90.00	93.33	1089.53	0858.67	1059.07	0865.03
	86.67	76.67	83.33	80.00	0638.13	0857.30	1217.10	0750.40
	113	18						
004	0.03760	0.01180	026.07810	085.32800				
	166.93	271.19	04.12	17.26	21.07	33.07		
	03.030	03.045	034.810	071.680	067.340			
	73.33	83.33	90.00	96.67	0942.17	0818.20	1096.87	0945.63
	73.33	73.33	90.00	80.00	0754.80	0649.07	0525.37	0963.80
	132	25						
007	0.03630	0.01380	044.35715	257.28600				
	234.48	242.21	12.89	27.59	22.76	33.14		
	03.115	02.760	052.665	122.945	119.815			
	70.00	66.67	90.00	90.00	0843.30	0789.87	0716.57	0662.67
	73.33	80.00	80.00	83.33	1001.47	0787.93	1079.17	1136.73
	108	19						
008	0.02965	0.01680	066.72405	090.95040				
	203.94	256.56	02.99	04.02	15.06	19.68		
	02.650	02.420	089.245	150.115	118.910			
	83.33	83.33	86.67	90.00	0829.17	0741.23	0962.57	0927.63
	86.67	80.00	83.33	73.33	0461.07	0592.80	0847.03	0765.13
	105	18						
009	0.03705	0.01230	080.53500	240.99850				
	222.43	345.65	06.69	22.62	16.68	27.80		
	04.175	02.970	035.245	058.155	114.835			
	70.00	76.67	86.67	93.33	0815.00	0674.10	0696.27	0657.47
	66.67	80.00	90.00	86.67	0437.87	0455.53	0504.73	0683.47
	102	18						
010	0.03025	0.01045	032.68440	149.54690				
	142.00	274.28	02.01	06.57	15.31	23.39		
	03.625	02.955	028.530	035.825	049.800			
	86.67	90.00	80.00	90.00	0976.50	0906.37	1004.10	0950.30
	83.33	80.00	90.00	80.00	1039.20	0942.17	0791.17	1156.23
	128	19						

Table D-1 (cont.)

SUBJ	FSEN2	FSEN12	VTOJ1	VTOJ7				
	BLAN2	BLAN12	FLICK2	FLICK12	CHAS2	CHAS12		
	AFUS15	AFUS100	ATOJ15	ATOJ75	ATOJ200			
	IWSA1	IWLA1	NWSA1	NWLA1	IWST1	IWLT1	NWST1	NWLT1
	IWSA2	IWLA2	NWSA2	NWLA2	IWST2	IWLT2	NWST2	NWLT2
	IQ	AGE						
011	0.03920	0.01750	038.05925	093.34495				
	133.40	209.08	02.25	11.36	13.48	22.87		
	03.410	02.670	034.390	043.060	064.405			
	86.67	83.33	80.00	80.00	1070.70	0813.43	1681.60	1241.17
	83.33	80.00	80.00	76.67	0772.87	0756.27	0794.30	1054.90
	133	19						
012	0.04195	0.01085	106.59700	535.61095				
	303.60	350.98	07.56	18.56	16.54	23.81		
	06.040	03.030	132.770	145.455	351.375			
	70.00	70.00	80.00	86.67	1049.10	0774.03	1076.13	0920.73
	66.67	76.67	83.33	83.33	0528.47	0620.70	0677.43	0652.47
	095	19						
013	0.04470	0.01640	034.36825	232.30100				
	208.79	386.32	15.58	48.31	19.32	29.04		
	03.780	02.860	024.460	051.090	068.645			
	76.67	80.00	83.33	76.67	1160.13	0986.80	0962.03	0899.23
	80.00	76.67	73.33	73.33	0602.87	0449.23	0546.10	0797.23
	105	18						
014	0.04765	0.01860	067.63895	183.21825				
	231.80	280.63	10.03	23.01	16.68	24.02		
	05.005	03.865	053.695	040.055	148.930			
	80.00	73.33	93.33	90.00	0782.37	0712.57	0890.17	0994.63
	86.67	76.67	93.33	86.67	0687.67	0989.27	0722.37	0791.47
	116	18						
016	0.03960	0.00795	080.22480	161.30395				
	016.72	120.47	01.88	03.66	18.51	26.66		
	02.700	02.950	140.210	131.420	201.845			
	70.00	66.67	83.33	80.00	0927.50	0860.63	0772.70	1216.20
	70.00	63.33	80.00	76.67	0827.83	1239.17	1245.97	1334.50
	095	45						
017	0.03570	0.00810	120.08185	162.53800				
	244.16	376.11	04.01	04.61	18.99	20.55		
	03.500	02.990	066.450	251.345	168.385			
	90.00	96.67	86.67	80.00	0608.90	0498.57	0746.47	0690.47
	83.33	86.67	83.33	83.33	0547.97	0690.10	0778.70	0683.83
	108	54						
018	0.04760	0.01550	045.80360	231.02155				
	233.67	327.68	11.36	12.18	15.57	21.47		
	02.525	02.705	017.025	030.090	056.815			
	66.67	80.00	83.33	90.00	0823.67	0917.30	0927.47	0723.07
	73.33	73.33	93.33	93.33	0860.73	0556.23	0553.27	1102.33
	095	18						
019	0.02585	0.01225	073.30705	152.18210				
	120.32	174.54	24.41	61.52	20.03	29.03		
	02.905	02.985	042.365	084.745	103.435			
	86.67	90.00	96.67	90.00	0955.37	0774.07	1114.57	0901.77
	86.67	90.00	93.33	83.33	0585.43	0479.43	0772.97	0642.27
	117	43						

Table D-1 (cont.)

SUBJ	FSEN2	FSEN12	VTOJ1	VTOJ7				
	BLAN2	BLAN12	FLICK2	FLICK12	CHAS2	CHAS12		
	AFUS15	AFUS100	ATOJ15	ATOJ75	ATOJ200			
	IWSA1	IWLA1	NWSA1	NWLA1	IWST1	IWLT1	NWST1	NWLT1
	IWSA2	IWLA2	NWSA2	NWLA2	IWST2	IWLT2	NWST2	NWLT2
	IQ	AGE						
021	0.03270	0.01025	041.55460	135.90620				
	151.74	211.17	07.35	13.29	16.68	20.56		
	03.170	02.815	048.940	112.745	131.850			
	76.67	63.33	80.00	90.00	1095.50	1352.63	1292.53	1104.20
	73.33	63.33	76.67	73.33	0662.13	1527.30	1195.23	1101.70
	068	18						
022	0.04870	0.01820	036.25295	127.01480				
	324.53	357.23	05.98	23.81	19.66	28.06		
	05.325	02.625	078.745	105.460	115.560			
	73.33	56.67	76.67	70.00	0770.70	0714.70	0840.77	0817.63
	70.00	56.67	80.00	70.00	0507.17	0579.73	0632.57	0638.17
	090	18						
023	0.03420	0.01480	088.40475	152.27945				
	219.96	322.07	03.79	11.39	17.60	21.12		
	07.710	03.495	085.840	192.250	261.400			
	83.33	83.33	96.67	93.33	0977.07	1712.93	1310.47	1005.33
	76.67	80.00	83.33	83.33	0746.60	0823.47	0693.43	1023.70
	118	34						
025	0.02895	0.01450	076.30050	199.68230				
	154.78	272.56	04.00	21.87	13.81	19.18		
	02.845	03.065	117.880	110.105	105.960			
	80.00	80.00	100.0	90.00	0978.53	0621.27	0803.20	0726.77
	83.33	90.00	90.00	86.67	0375.30	0499.27	0328.10	0681.27
	129	29						
026	0.05265	0.02025	076.28900	309.31025				
	197.34	224.04	01.83	04.34	14.54	23.82		
	04.455	03.030	052.565	097.530	129.100			
	73.33	76.67	50.00	70.00	0858.43	0720.77	0889.90	0718.23
	76.67	66.67	60.00	70.00	0963.40	1016.63	0974.40	0691.93
	086	18						
027	0.04655	0.01600	027.32760	099.20495				
	126.74	301.13	06.53	18.22	12.66	22.61		
	03.570	03.045	039.325	095.240	116.810			
	80.00	83.33	93.33	90.00	1058.27	0737.63	1152.23	0899.53
	83.33	83.33	90.00	86.67	1072.67	0840.73	1059.90	1504.93
	124	19						
029	0.02785	0.00950	016.83050	099.87755				
	197.31	200.31	07.28	17.51	18.51	23.21		
	03.755	02.845	030.160	038.230	069.140			
	83.33	76.67	93.33	80.00	0900.70	0884.87	0857.73	0867.53
	86.67	70.00	86.67	93.33	0619.30	0438.43	0665.23	0640.10
	135	18						
030	0.03870	0.01050	054.27395	145.20175				
	153.07	228.01	09.10	25.29	18.19	29.03		
	02.540	02.455	088.670	121.580	111.760			
	83.33	70.00	80.00	80.00	0723.20	0760.77	1049.03	0954.27
	73.33	70.00	83.33	90.00	0601.80	0741.40	1029.47	1103.30
	073	19						

Table D-1 (cont.)

SUBJ								
	FSEN2	FSEN12	VTOJ1	VTOJ7				
	BLAN2	BLAN12	FLICK2	FLICK12	CHAS2	CHAS12		
	AFUS15	AFUS100	ATOJ15	ATOJ75	ATOJ200			
	IWSA1	IWLA1	NWSA1	NWLA1	IWST1	IWLT1	NWST1	NWLT1
	IWSA2	IWLA2	NWSA2	NWLA2	IWST2	IWLT2	NWST2	NWLT2
	IQ	AGE						
031	0.03365	0.01600	037.98755	046.24330				
	126.41	242.40	02.01	03.56	14.41	23.20		
	03.860	03.015	020.805	050.890	094.210			
	93.33	83.33	83.33	80.00	0856.13	0710.43	0976.40	0786.50
	86.67	80.00	76.67	63.33	0632.23	0816.00	0475.57	0833.00
	118	26						
032	0.03940	0.01195	042.15890	138.13280				
	232.13	308.46	04.30	04.69	16.68	24.37		
	03.115	02.080	027.690	022.480	044.185			
	76.67	76.67	90.00	90.00	1249.30	0984.07	1048.17	0941.80
	73.33	90.00	86.67	86.67	0629.00	1131.33	1325.13	0687.93
	124	18						
033	0.05565	0.01410	042.16245	156.73755				
	171.21	386.32	02.87	07.00	14.65	17.91		
	03.535	03.400	081.845	069.515	104.075			
	73.33	86.67	86.67	93.33	0845.47	0808.10	0843.83	0617.83
	76.67	90.00	83.33	83.33	0518.27	0596.07	0674.07	0773.50
	099	18						
034	0.02930	0.01345	071.38765	193.94885				
	210.98	285.46	04.86	21.69	16.25	28.30		
	02.480	03.120	020.915	045.180	076.110			
	86.67	93.33	93.33	90.00	1192.97	1173.23	1090.47	0984.43
	86.67	90.00	83.33	90.00	0598.73	0525.30	0522.87	0506.00
	135	19						
035	0.03165	0.01190	037.89280	148.64690				
	116.26	266.47	03.71	19.18	14.41	19.18		
	02.155	01.940	023.400	034.535	129.925			
	80.00	90.00	80.00	86.67	1556.60	1781.10	1709.33	1934.77
	76.67	90.00	76.67	80.00	0442.53	0851.47	0589.60	0557.03
	128	24						
036	0.05425	0.01975	104.17310	218.52780				
	237.84	293.01	03.24	07.61	13.46	18.53		
	02.935	04.100	064.115	091.795	072.620			
	86.67	93.33	90.00	90.00	0969.67	0716.03	1047.87	0870.13
	80.00	80.00	93.33	86.67	0725.27	0579.87	0751.37	0701.63
	133	18						
037	0.03795	0.00960	045.39100	141.63470				
	162.59	157.76	01.99	03.47	08.91	20.74		
	03.050	03.050	066.905	060.185	205.760			
	93.33	90.00	93.33	86.67	1251.50	1036.70	1061.57	0978.50
	90.00	86.67	90.00	93.33	0741.50	0640.07	0754.27	0865.87
	121	35						
038	0.06650	0.02120	028.10845	138.74080				
	158.43	210.93	06.92	12.64	18.20	24.86		
	02.610	02.865	040.650	055.065	174.390			
	90.00	76.67	90.00	93.33	0977.60	1101.97	1112.53	1076.40
	93.33	80.00	90.00	86.67	0764.13	0639.60	0903.60	0948.93
	119	18						

Table D-1 (cont.)

SUBJ								
	FSEN2	FSEN12	VTOJ1	VTOJ7				
	BLAN2	BLAN12	FLICK2	FLICK12	CHAS2	CHAS12		
	AFUS15	AFUS100	ATOJ15	ATOJ75	ATOJ200			
	IWSA1	IWLA1	NWSA1	NWLA1	IWST1	IWLT1	NWST1	NWLT1
	IWSA2	IWLA2	NWSA2	NWLA2	IWST2	IWLT2	NWST2	NWLT2
	IQ	AGE						
039	0.04505	0.01565	039.34935	232.19385				
	155.66	238.07	02.01	04.99	14.65	22.06		
	02.675	02.950	044.135	059.770	140.240			
	86.67	83.33	93.33	93.33	0791.37	0685.87	0815.67	0688.93
	86.67	86.67	90.00	90.00	0616.67	0552.77	0470.77	0626.27
	135	36						
040	0.05980	0.01195	085.42005	500.55970				
	166.81	319.68	02.94	05.23	16.11	21.47		
	04.210	04.440	180.555	243.255	354.800			
	86.67	80.00	60.00	63.33	1051.43	0824.70	1419.17	1608.40
	76.67	70.00	36.67	50.00	0581.37	0534.83	0588.77	0474.50
	095	41						
042	0.06585	0.01645	069.49240	193.74345				
	226.24	275.71	03.39	14.93	15.84	28.06		
	07.000	04.280	056.660	230.870	122.500			
	53.33	73.33	83.33	70.00	1108.57	0936.67	0751.83	0726.60
	60.00	73.33	70.00	73.33	0854.97	0874.17	0518.73	0930.27
	084	19						
044	0.05150	0.01150	052.67000	128.79725				
	359.97	421.78	03.05	07.61	16.26	22.82		
	02.600	03.015	038.910	041.345	096.960			
	80.00	90.00	93.33	83.33	0804.20	0606.80	0989.90	1057.23
	83.33	90.00	80.00	83.33	0467.63	0774.87	0761.20	1009.57
	132	18						
045	0.03870	0.01465	068.89945	175.07310				
	174.43	345.13	07.10	27.14	16.99	26.18		
	04.215	02.045	064.330	152.550	119.235			
	80.00	66.67	80.00	83.33	1201.53	0918.60	1007.70	0853.50
	70.00	66.67	83.33	80.00	0758.80	0973.50	0931.03	0957.43
	095	18						
046	0.03380	0.01510	074.68185	226.51320				
	174.36	316.92	10.00	33.63	18.99	36.99		
	02.940	03.130	022.905	074.085	109.970			
	83.33	76.67	93.33	93.33	0758.43	0712.93	0831.97	0796.07
	90.00	83.33	86.67	76.67	0488.27	0597.23	0509.93	0554.50
	119	19						
047	0.05940	0.01305	054.84065	163.59010				
	153.13	240.73	02.01	09.99	15.58	29.03		
	03.535	03.310	070.595	129.335	129.500			
	93.33	76.67	93.33	93.33	0986.37	0960.30	0914.17	0829.63
	86.67	76.67	93.33	86.67	0584.90	0696.53	0767.93	0611.17
	124	20						
048	0.03845	0.01395	047.04110	193.46760				
	100.23	157.29	02.96	10.68	13.34	18.22		
	01.930	02.690	031.000	047.130	116.855			
	90.00	86.67	90.00	93.33	1209.67	1113.13	1268.53	1074.43
	86.67	86.67	83.33	86.67	0417.87	0644.47	0918.07	1020.77
	128	19						

Table D-1 (cont.)

SUBJ								
SUBJ	FSEN2	FSEN12	VTOJ1	VTOJ7				
	BLAN2	BLAN12	FLICK2	FLICK12	CHAS2	CHAS12		
	AFUS15	AFUS100	ATOJ15	ATOJ75	ATOJ200			
	IWSA1	IWLA1	NWSA1	NWLA1	IWST1	IWLT1	NWST1	NWLT1
	IWSA2	IWLA2	NWSA2	NWLA2	IWST2	IWLT2	NWST2	NWLT2
	IQ	AGE						
049	0.06085	0.01605	078.42110	139.40155				
	129.95	218.55	04.19	06.41	16.40	19.02		
	05.845	02.970	216.690	118.140	133.240			
	70.00	83.33	76.67	86.67	1886.20	1270.37	1740.07	1521.80
	66.67	83.33	90.00	86.67	0678.40	0919.33	0635.30	1040.07
	105	18						
050	0.04280	0.01955	058.90615	180.80930				
	116.26	383.06	04.32	18.37	15.19	25.95		
	03.730	02.770	021.545	038.060	107.470			
	76.67	86.67	80.00	76.67	0565.43	0531.80	0664.23	0842.43
	83.33	86.67	80.00	86.67	0795.83	0957.60	0795.37	0702.20
	084	18						
052	0.04195	0.01505	099.99845	118.25900				
	226.00	491.91	09.95	20.82	18.67	25.29		
	02.495	03.015	041.895	062.715	115.030			
	66.67	73.33	70.00	73.33	1142.70	0990.83	1707.53	1468.30
	66.67	80.00	56.67	73.33	0696.87	0582.07	0646.27	1152.33
	111	32						
062	0.05745	0.01420	070.51985	186.55010				
	137.97	195.18	02.64	06.89	14.29	19.87		
	03.640	02.930	053.380	014.250	097.645			
	73.33	76.67	86.67	80.00	0520.87	0843.73	0911.20	1018.13
	73.33	76.67	86.67	80.00	0579.73	0628.77	0585.73	0674.27
	113	18						
063	0.04380	0.01790	062.49660	186.48865				
	284.40	326.19	02.18	12.94	14.29	22.06		
	02.315	03.000	065.440	088.125	084.360			
	60.00	70.00	80.00	76.67	0769.40	0799.87	0632.03	0952.73
	66.67	73.33	86.67	86.67	1140.90	1085.27	1363.03	1167.10
	133	18						
064	0.05560	0.01770	068.32665	219.26270				
	205.28	347.99	12.94	27.80	15.57	27.10		
	03.395	03.000	007.785	037.605	033.640			
	43.33	66.67	76.67	66.67	0533.37	0520.53	0971.03	1063.30
	50.00	73.33	63.33	76.67	0596.93	0425.20	0881.47	0481.63
	124	18						
065	0.05345	0.01980	097.95610	270.50825				
	285.00	443.46	18.08	42.17	13.57	17.51		
	04.395	02.830	086.790	054.025	175.850			
	73.33	63.33	76.67	70.00	0702.23	0783.03	0665.47	0830.00
	70.00	63.33	70.00	73.33	0584.47	0565.93	0589.73	0712.37
	076	18						
066	0.03680	0.01295	036.43690	058.83310				
	074.22	126.75	04.08	04.98	14.41	23.59		
	02.845	02.725	025.730	039.795	027.600			
	90.00	93.33	90.00	93.33	0797.27	0815.40	0834.53	1009.63
	93.33	93.33	86.67	83.33	0424.13	0489.03	0535.63	0612.70
	135	32						

Table D-1 (cont.)

SUBJ	FSEN2	FSEN12	VTOJ1	VTOJ7				
	BLAN2	BLAN12	FLICK2	FLICK12	CHAS2	CHAS12		
	AFUS15	AFUS100	ATOJ15	ATOJ75	ATOJ200			
	IWSA1	IWLA1	NWSA1	NWLA1	IWST1	IWLT1	NWST1	NWLT1
	IWSA2	IWLA2	NWSA2	NWLA2	IWST2	IWLT2	NWST2	NWLT2
	IQ	AGE						
067	0.04185	0.01145	039.69440	055.51575				
	164.04	157.29	02.01	11.95	14.78	16.88		
	03.005	02.920	044.445	059.665	075.410			
	83.33	83.33	93.33	86.67	0744.10	0696.40	0921.10	0796.83
	90.00	86.67	86.67	90.00	0582.10	0887.97	0673.77	0767.77
	099	19						
068	0.05270	0.01235	034.63030	105.40890				
	190.50	251.06	04.38	19.06	16.68	30.89		
	02.700	01.920	046.985	042.830	111.180			
	70.00	70.00	90.00	73.33	0519.33	0848.07	0882.87	0868.57
	73.33	76.67	90.00	70.00	0838.00	0675.57	0601.70	0556.23
	121	25						
069	0.06510	0.01805	090.12295	202.22800				
	140.77	210.93	02.27	07.82	16.69	23.59		
	02.765	02.750	012.280	050.065	040.010			
	86.67	86.67	83.33	93.33	1288.90	1080.47	1048.37	1222.20
	90.00	83.33	86.67	76.67	0475.73	0775.13	0684.77	1172.03
	118	24						
070	0.05310	0.01755	041.33930	135.46775				
	195.18	268.25	02.08	03.05	13.61	18.19		
	03.770	03.115	015.105	054.615	078.840			
	66.67	73.33	80.00	83.33	0690.07	0642.57	0960.63	0599.43
	70.00	83.33	86.67	83.33	0713.83	0484.07	0797.53	0658.37
	108	18						
071	0.08435	0.01270	024.64420	052.37890				
	362.73	574.38	25.06	45.88	20.89	35.45		
	02.950	03.000	022.685	065.135	086.790			
	76.67	76.67	90.00	83.33	0827.80	0954.33	0911.43	0903.53
	76.67	80.00	90.00	90.00	0809.67	0778.60	0961.97	0781.23
	099	18						
072	0.06380	0.01235	041.08500	116.06600				
	150.21	129.01	03.14	06.31	16.56	23.24		
	03.115	03.290	057.445	075.940	110.565			
	73.33	73.33	80.00	73.33	0537.30	0615.63	0722.27	0745.87
	76.67	80.00	83.33	73.33	0741.93	0848.90	0850.30	0887.90
	124	22						
073	0.03480	0.01220	031.84450	086.68155				
	222.09	316.92	06.70	12.61	15.04	18.85		
	04.935	03.690	017.750	022.045	024.285			
	80.00	66.67	96.67	93.33	0847.13	0951.73	0804.43	0769.27
	70.00	66.67	83.33	93.33	0596.53	0585.30	0588.17	0749.27
	099	18						
074	0.02620	0.01400	054.36360	163.07680				
	099.44	146.37	02.76	03.36	14.67	24.90		
	05.250	02.980	095.750	068.755	227.180			
	83.33	76.67	86.67	86.67	0975.10	1070.17	1083.10	1168.40
	83.33	66.67	90.00	90.00	0426.10	0853.00	0683.27	0713.37
	076	18						

Table D-1 (cont.)

SUBJ	FSEN2 BLAN2 AFUS15 IWSA1 IWSA2 IQ	FSEN12 BLAN12 AFUS100 IWLA1 IWLA2 AGE	VTOJ1 FLICK2 ATOJ15 NWSA1 NWSA2	VTOJ7 FLICK12 ATOJ75 NWLA1 NWLA2	 CHAS2 ATOJ200 IWST1 IWST2	 CHAS12 IWLT1 IWLT2	 NWST1 NWST2	 NWLT1 NWLT2
075	0.04025	0.01230	038.21455	106.86990				
	250.56	244.60	02.01	01.61	15.05	18.21		
	03.125	01.920	064.945	103.120	156.915			
	80.00	70.00	80.00	83.33	0578.93	0571.83	0588.20	0473.80
	80.00	73.33	93.33	80.00	0645.50	0703.77	0557.13	0703.93
	135	18						
076	0.03475	0.01535	041.46100	122.84335				
	216.78	351.11	21.82	25.74	20.00	29.61		
	02.650	02.535	033.285	046.415	095.060			
	86.67	90.00	93.33	93.33	0565.67	0632.83	0600.43	0623.20
	90.00	83.33	86.67	90.00	0401.83	0454.47	0533.30	0712.13
	116	18						
077	0.05175	0.01385	075.02145	274.25720				
	195.18	285.35	11.95	16.14	18.51	31.67		
	06.755	03.130	199.020	216.180	175.280			
	80.00	86.67	93.33	90.00	0549.13	0606.03	0810.50	0538.80
	76.67	76.67	93.33	83.33	0754.20	0658.93	1004.10	0869.17
	105	18						
078	0.06885	0.02375	045.97555	553.77080				
	140.46	305.72	11.54	19.18	17.13	23.39		
	03.815	02.640	052.335	054.285	136.300			
	66.67	66.67	80.00	80.00	0796.83	0804.00	0671.90	0817.63
	76.67	63.33	80.00	83.33	0926.27	0870.07	1005.77	1184.77
	087	18						
079	0.04675	0.01410	049.97025	140.88820				
	120.18	190.14	02.01	07.56	15.84	21.47		
	03.290	02.465	031.185	136.830	079.790			
	83.33	80.00	90.00	86.67	0748.60	0644.27	0684.20	0838.73
	80.00	76.67	93.33	93.33	0724.50	0888.07	0398.83	0749.90
	099	18						
081	0.04655	0.01185	035.72400	170.98550				
	268.41	339.14	03.78	10.57	14.53	28.78		
	06.995	03.740	089.990	205.200	129.755			
	83.33	80.00	66.67	73.33	0809.20	0556.20	0993.57	0783.80
	83.33	83.33	86.67	86.67	0951.90	1235.70	1228.67	1190.97
	108	18						
082	0.04795	0.01685	046.21065	080.59120				
	140.35	255.40	01.94	01.90	13.57	21.10		
	02.910	04.310	021.055	029.365	038.930			
	93.33	83.33	83.33	86.67	1055.13	1153.75	0994.33	0967.07
	90.00	80.00	96.67	76.67	0591.97	0991.70	0899.43	0927.87
	135	18						
084	0.06435	0.01630	032.48345	113.84470				
	261.62	300.46	29.03	33.96	16.26	22.06		
	08.415	03.515	330.360	095.615	068.245			
	73.33	70.00	56.67	63.33	0728.50	0720.77	0612.27	0924.13
	83.33	80.00	76.67	73.33	0793.10	0946.97	0969.60	0743.80
	105	18						

Table D-1 (cont.)

SUBJ	FSEN2	FSEN12	VTOJ1	VTOJ7				
	BLAN2	BLAN12	FLICK2	FLICK12	CHAS2	CHAS12		
	AFUS15	AFUS100	ATOJ15	ATOJ75	ATOJ200			
	IWSA1	IWLA1	NWSA1	NWLA1	IWST1	IWLT1	NWST1	NWLT1
	IWSA2	IWLA2	NWSA2	NWLA2	IWST2	IWLT2	NWST2	NWLT2
	IQ	AGE						
085	0.12090	0.01765	045.53030	136.02110				
	125.46	275.80	12.04	23.68	18.71	29.54		
	09.625	03.845	071.250	198.910	283.475			
	53.33	86.67	76.67	56.67	1589.23	1636.93	1523.73	1579.40
	53.33	66.67	53.33	73.33	1591.57	1126.00	0629.50	0886.53
	090	18						
086	0.04725	0.01240	027.13025	115.44380				
	205.44	248.85	03.08	13.94	16.68	21.46		
	02.705	02.625	091.065	065.505	097.555			
	86.67	96.67	83.33	73.33	0976.07	0997.87	0746.93	0910.20
	83.33	96.67	80.00	73.33	0724.83	0614.23	0739.63	0562.77
	124	20						
089	0.05740	0.01935	114.23880	349.15965				
	287.54	804.23	21.07	35.84	23.39	28.57		
	18.120	07.195	067.305	139.460	184.155			
	86.67	76.67	80.00	83.33	0634.73	0737.37	1073.63	1053.10
	86.67	80.00	80.00	93.33	0460.10	0654.90	0945.90	0809.63
	083	33						
091	0.03450	0.01245	025.51030	118.31515				
	036.92	169.15	02.01	05.30	16.14	27.61		
	02.600	01.855	023.985	026.140	074.060			
	86.67	80.00	93.33	93.33	0812.20	0939.03	1026.40	1027.00
	90.00	86.67	83.33	83.33	0729.47	0711.13	1234.27	1027.37
	105	19						
093	0.08375	0.02095	044.00385	152.99955				
	163.98	261.94	02.92	07.97	15.17	22.44		
	09.265	03.070	016.530	032.745	078.820			
	83.33	90.00	76.67	86.67	0723.43	0618.17	0667.43	0665.17
	83.33	93.33	86.67	93.33	0362.33	0635.80	0433.17	0660.50
	128	18						
094	0.05015	0.01515	049.37235	167.22985				
	372.70	354.50	20.57	25.32	19.00	23.63		
	02.945	03.030	083.395	106.785	159.920			
	63.33	70.00	90.00	90.00	1101.80	0942.73	1055.97	1011.80
	66.67	76.67	83.33	80.00	0728.00	0732.73	0594.60	0833.07
	116	18						
095	0.07150	0.02605	081.08145	121.63895				
	172.72	292.80	04.54	18.13	16.27	20.76		
	03.400	02.470	235.455	118.420	471.055			
	60.00	70.00	90.00	76.67	1051.37	1003.00	0907.93	0855.23
	53.33	63.33	83.33	86.67	0947.67	0944.27	0593.00	0912.47
	087	18						
096	0.05910	0.01575	041.36040	160.57475				
	132.43	161.54	02.63	05.78	14.65	18.85		
	02.810	03.030	100.500	077.140	153.540			
	66.67	73.33	96.67	80.00	0490.23	0519.13	0482.10	0468.60
	66.67	70.00	96.67	80.00	0479.67	0494.37	0443.13	0559.90
	102	18						

Table D-1 (cont.)

SUBJ								
	FSEN2	FSEN12	VTOJ1	VTOJ7				
	BLAN2	BLAN12	FLICK2	FLICK12	CHAS2	CHAS12		
	AFUS15	AFUS100	ATOJ15	ATOJ75	ATOJ200			
	IWSA1	IWLA1	NWSA1	NWLA1	IWST1	IWLT1	NWST1	NWLT1
	IWSA2	IWLA2	NWSA2	NWLA2	IWST2	IWLT2	NWST2	NWLT2
	IQ	AGE						
098	0.04200	0.01575	043.27685	107.36655				
	134.57	158.78	07.02	12.27	16.11	23.24		
	03.065	03.110	041.365	052.700	098.380			
	70.00	73.33	70.00	73.33	0911.83	1467.17	0716.87	0816.77
	70.00	70.00	70.00	66.67	0466.10	0710.37	0531.23	0557.10
	124	18						
100	0.03530	0.00955	032.50375	081.58670				
	189.00	280.63	02.01	06.04	14.53	17.68		
	02.630	02.895	010.780	039.180	037.720			
	86.67	76.67	86.67	93.33	0716.07	0668.67	0575.20	0935.33
	86.67	76.67	83.33	86.67	0755.17	0771.90	0673.50	1129.40
	108	18						
101	0.05285	0.01440	039.37780	187.27865				
	170.65	220.23	14.04	35.46	19.51	29.57		
	05.145	03.245	018.925	044.085	095.420			
	66.67	80.00	76.67	63.33	0625.03	1343.87	0662.43	0785.27
	73.33	86.67	80.00	66.67	0545.07	1025.50	1055.00	0864.30
	090	18						
102	0.03485	0.01215	077.25645	170.67125				
	164.04	222.66	03.34	06.26	14.79	15.19		
	03.455	02.920	088.625	098.600	173.965			
	76.67	86.67	83.33	83.33	0553.20	0601.97	0761.07	0627.80
	76.67	90.00	83.33	90.00	0787.70	0649.10	0603.07	0692.43
	118	40						
103	0.05775	0.01095	074.31370	205.07020				
	166.81	199.71	02.01	03.75	14.16	19.36		
	07.300	02.950	055.760	150.560	261.710			
	76.67	90.00	56.67	56.67	0453.10	0467.13	0616.60	0729.13
	76.67	90.00	56.67	70.00	0499.37	0514.77	0672.10	0639.23
	121	32						
104	0.04020	0.01635	042.13420	105.02835				
	180.34	203.95	01.99	10.94	14.53	19.03		
	02.965	02.575	007.630	022.855	045.635			
	73.33	80.00	93.33	90.00	1028.57	0868.33	0689.10	0629.03
	76.67	80.00	86.67	83.33	0595.37	0638.70	0518.50	0919.03
	108	18						
105	0.04445	0.01595	062.09155	299.88060				
	186.93	280.85	04.46	05.89	12.69	19.36		
	03.060	02.985	095.920	080.725	092.940			
	80.00	66.67	86.67	86.67	0679.53	0685.90	0580.67	0695.97
	80.00	76.67	86.67	83.33	0722.47	0511.10	0588.67	0628.87
	102	18						

N.B.: SUBJ: Subject Number
FSEN2, FSEN12: Flicker Sensitivity at 2 and 12 Hz respectively
VTOJ1, VTOJ7 (ms): Visual Temporal Order Judgment at 1 and 7 c/d respectively
BLAN2, BLAN12 (ms): Visible Persistence (based on the judgment of a blank) at 2 and 12 c/d respectively
FLICK2, FLICK12 (ms): Visible Persistence (based on the judgment of a flicker) at 2 and 12 c/d respectively
CHAS2, CHAS12 (ms): Flicker Fusion at 2 and 12 c/d respectively
AFUS15, AFUS100 (ms): Auditory Fusion at 15 and 100 ms respectively
ATOJ15, ATOJ75, ATOJ200 (ms): Auditory Temporal Order Judgment at 15, 75 and 200 ms respectively
IWSA1, IWLA1 (%): Irregular Words Accuracy, Single / Continuous (Line) condition (first session)
NWSA1, NWLA1 (%): Nonsense Words Accuracy, Single / Continuous (Line) condition (first session)
IWST1, IWLT1 (ms): Irregular Words Reaction time, Single / Continuous (Line) condition (first session)
NWST1, NWLT1 (ms): Nonsense Words Reaction time, Single / Continuous (Line) condition (first session)

Table D-1 (cont.)

N.B.: IWSA2, IWLA2 (%): Irregular Words Accuracy, Single / Continuous (Line) condition (second session)
NWSA2, NWLA2 (%): Nonsense Words Accuracy, Single / Continuous (Line) condition (second session)
IWST2, IWLT2 (ms): Irregular Words Reaction time, Single / Continuous (Line) condition (second session)
NWST2, NWLT2 (ms): Nonsense Words Reaction time, Single / Continuous (Line) condition (second session)
IQ: Nonverbal Reasoning Skills measured by Advanced Raven's Progressive Matrices
AGE: Age

Appendix D (cont.)

Summary Tables of Study 2

Table D-2: Summary Tables of Repeated Measures ANOVA on Visible Persistence (BLAN and FLICK)

i) Main Effect of Task Type:

Source	df	Type III SS	Mean Square	F	Pr>F
Model	1	882.96	883.96	1942.38	0.0001
Error	78	35.4569	0.4546		
Total	79	918.4169			

ii) Main Effect of Spatial Frequency:

Source	df	Type III SS	Mean Square	F	Pr>F
Model	1	33.9109	33.9109	367.06	0.0001
Error	78	7.2061	0.0924		
Total	79	41.117			

iii) Task Type x Spatial Frequency:

Source	df	Type III SS	Mean Square	F	Pr>F
Model	1	4.1743	4.1743	50.72	0.0001
Error	78	6.4197	0.0823		
Total	79	10.594			

Table D-3: Summary Tables of Repeated Measures ANOVA on the Auditory Measures

i) Within-Subject Effects among the Five Tasks:

Source	df	Type III SS	Mean Square	F	Pr>F
Model	4	921.9627	230.4907	1191.45	0.0001
Error	312	60.3577	0.1935		
Total	316	982.3204			

ii) Contrast: AFUS15 vs AFUS100:

Source	df	Type III SS	Mean Square	F	Pr>F
Mean	1	3.6268	3.6268	34.34	0.0001
Error	78	8.2378	0.1056		
Total	79	11.8646			

iii) Contrast: ATOJ15 vs ATOJ75:

Source	df	Type III SS	Mean Square	F	Pr>F
Mean	1	12.1007	12.1007	33.12	0.0001
Error	78	28.4976	0.3654		
Total	79	40.5983			

iv) Contrast: ATOJ15 vs ATOJ200:

Source	df	Type III SS	Mean Square	F	Pr>F
Mean	1	51.812	51.812	165.44	0.0001
Error	78	24.4278	0.3132		
Total	79	76.2398			

v) Contrast: ATOJ75 vs ATOJ200:

Source	df	Type III SS	Mean Square	F	Pr>F
Mean	1	13.8343	13.8343	48.46	0.0001
Error	78	22.2675	0.2855		
Total	79	36.1018			

Table D-4: Summary Tables of Repeated Measures ANOVA on Reading Accuracy (session 1)

i) Main Effect of Word Type:

Source	df	Type III SS	Mean Square	F	Pr>F
Model	1	0.3843	0.3843	22.69	0.0001
Error	78	1.3207	0.0169		
Total	79	1.705			

ii) Main Effect of Presentation Mode:

Source	df	Type III SS	Mean Square	F	Pr>F
Model	1	0.0014	0.0014	0.29	0.5901
Error	78	0.3801	0.0049		
Total	79	0.3815			

iii) Word Type x Presentation Mode:

Source	df	Type III SS	Mean Square	F	Pr>F
Model	1	0.0203	0.0203	2.44	0.1222
Error	78	0.6485	0.0083		
Total	79	0.6688			

Table D-5: Summary Tables of Repeated Measures ANOVA on Reading Latency (session 1)

i) Main Effect of Word Type:

Source	df	Type III SS	Mean Square	F	Pr>F
Model	1	0.3193	0.3193	8.17	0.0055
Error	78	3.0482	0.0391		
Total	79	3.3675			

ii) Main Effect of Presentation Mode:

Source	df	Type III SS	Mean Square	F	Pr>F
Model	1	0.0839	0.0839	3.38	0.0697
Error	78	1.9347	0.0248		
Total	79	2.0186			

iii) Word Type x Presentation Mode:

Source	df	Type III SS	Mean Square	F	Pr>F
Model	1	0.0008	0.0008	0.05	0.8201
Error	78	1.1899	0.0153		
Total	79	1.1907			

Table D-6: Summary Tables of Repeated Measures ANOVA on Reading Accuracy (Practice effect between session 1 and 2)

i) Main Effect of Word Type:

Source	df	Type III SS	Mean Square	F	Pr>F
Model	1	0.4029	0.4029	18.1	0.0001
Error	78	1.7357	0.0223		
Total	79	2.1386			

ii) Main Effect of Time:

Source	df	Type III SS	Mean Square	F	Pr>F
Model	1	0.0036	0.0036	0.72	0.3975
Error	78	0.3841	0.0049		
Total	79	0.3877			

iii) Word Type x Time:

Source	df	Type III SS	Mean Square	F	Pr>F
Model	1	0.0163	0.0163	3.75	0.0565
Error	78	0.3391	0.0043		
Total	79	0.3554			

Table D-7: Summary Tables of Repeated Measures ANOVA on Reading Latency (Practice effect between session 1 and 2)

i) Main Effect of Word Type:

Source	df	Type III SS	Mean Square	F	Pr>F
Model	1	0.5372	0.5372	11.87	0.0009
Error	78	3.5297	0.0453		
Total	79	4.0669			

ii) Main Effect of Time:

Source	df	Type III SS	Mean Square	F	Pr>F
Model	1	5.5267	5.5267	49.6	0.0001
Error	78	8.6915	0.1114		
Total	79	14.2182			

iii) Word Type x Time:

Source	df	Type III SS	Mean Square	F	Pr>F
Model	1	0.0384	0.0384	1.25	0.2663
Error	78	2.3907	0.0306		
Total	79	2.4291			

Table D-8: Summary Tables of Repeated Measures ANOVA on Reading Accuracy (session 2)

i) Main Effect of Word Type:

Source	df	Type III SS	Mean Square	F	Pr>F
Model	1	0.1722	0.1722	10.43	0.0018
Error	78	1.2875	0.0165		
Total	79	1.4597			

ii) Main Effect of Presentation Mode:

Source	df	Type III SS	Mean Square	F	Pr>F
Model	1	0.0000	0.0000	0	0.9896
Error	78	0.6275	0.008		
Total	79	0.6275			

iii) Word Type x Presentation Mode:

Source	df	Type III SS	Mean Square	F	Pr>F
Model	1	0.0085	0.0085	1.73	0.1924
Error	78	0.3928	0.0049		
Total	79	0.4013			

Table D-9: Summary Tables of Repeated Measures ANOVA on Reading Latency (session 2)

i) Main Effect of Word Type:

Source	df	Type III SS	Mean Square	F	Pr>F
Model	1	0.9227	0.9227	23.15	0.0001
Error	78	3.1084	0.0399		
Total	79	4.0311			

ii) Main Effect of Presentation Mode:

Source	df	Type III SS	Mean Square	F	Pr>F
Model	1	0.8543	0.8543	22.39	0.0001
Error	78	2.9764	0.0382		
Total	79	3.8307			

iii) Word Type x Presentation Mode:

Source	df	Type III SS	Mean Square	F	Pr>F
Model	1	0.001	0.001	0.02	0.882
Error	78	3.5252	0.0452		
Total	79	3.5262			

Appendix D (cont.)

Table D-10: Subjects' Data for Study 2: Discriminant Function Analyses

SUBJ	WORD	FSEN2	FSEN12	BLAN2	BLAN12	
		AFUS15	AFUS100	ATOJ15	ATOJ75	ATOJ200
		IRRA	NWDA	IQ	AGE	
026	1	0.05265	0.02025	197.34	224.04	
		04.455	03.030	052.565	097.530	129.100
		75.00	60.00	086	18	
040	1	0.05980	0.01195	166.81	319.68	
		04.210	04.440	180.555	243.255	354.800
		83.33	61.67	095	41	
103	1	0.05775	0.01095	166.81	199.71	
		07.300	02.950	055.760	150.560	261.710
		83.33	56.67	121	32	
003	2	0.05095	0.01880	223.71	376.26	
		03.890	03.015	018.600	068.420	068.950
		66.67	91.67	113	18	
004	2	0.03760	0.01180	166.93	271.19	
		03.030	03.045	034.810	071.680	067.340
		78.33	93.33	132	25	
007	2	0.03630	0.01380	234.48	242.21	
		03.115	02.760	052.665	122.945	119.815
		68.33	90.00	108	19	
009	2	0.03705	0.01230	222.43	345.65	
		04.175	02.970	035.245	058.155	114.835
		73.33	90.00	102	18	
014	2	0.04765	0.01860	231.80	280.63	
		05.005	03.865	053.695	040.055	148.930
		76.67	91.67	116	18	
021	2	0.03270	0.01025	151.74	211.17	
		03.170	02.815	048.940	112.745	131.850
		70.00	85.00	068	18	
025	2	0.02895	0.01450	154.78	272.56	
		02.845	03.065	117.880	110.105	105.960
		80.00	95.00	129	29	
064	2	0.05560	0.01770	205.28	347.99	
		03.395	03.000	007.785	037.605	033.640
		55.00	71.67	124	18	
073	2	0.03480	0.01220	222.09	316.92	
		04.935	03.690	017.750	022.045	024.285
		73.33	95.00	099	18	
094	2	0.05015	0.01515	372.70	354.50	
		02.945	03.030	083.395	106.785	159.920
		66.67	90.00	116	18	
095	2	0.07150	0.02605	172.72	292.80	
		03.400	02.470	235.455	118.420	471.055
		65.00	83.33	087	18	

Table D-10 (cont.)

SUBJ	WORD	FSEN2	FSEN12	BLAN2	BLAN12	
		AFUS15	AFUS100	ATOJ15	ATOJ75	ATOJ200
		IRRA	NWDA	IQ	AGE	
096	2	0.05910	0.01575	132.43	161.54	
		02.810	03.030	100.500	077.140	153.540
		70.00	88.33	102	18	
104	2	0.04020	0.01635	180.34	203.95	
		02.965	02.575	007.630	022.855	045.635
		76.67	91.67	108	18	

N.B.: SUBJ: Subject Number
WORD: Reading Group (1=Irregular Word Readers, 2=Nonsense Word Readers)
FSEN2, FSEN12: Flicker Sensitivity at 2 and 12 Hz respectively
BLAN2, BLAN12 (ms): Visible Persistence (based on the judgment of a blank) at 2 and 12 c/d respectively
AFUS15, AFUS100 (ms): Auditory Fusion at 15 and 100 ms respectively
ATOJ15, ATOJ75, ATOJ200 (ms): Auditory Temporal Order Judgment at 15, 75 and 200 ms respectively
IRRA, NWDA (%): Accuracy of Irregular / Nonsense Words respectively
IQ: Nonverbal Reasoning Skills measured by Advanced Raven's Progressive Matrices
AGE: Age

Appendix D (cont.)

Summary Tables of Study 2: Discriminant Function Analyses

Table D-11: Summary Tables of MANOVA on the Sensory Measures ("Irregular Word" Readers vs "Nonsense Word" Readers)

i) FSEN2:

Source	df	Type III SS	Mean Square	F	Pr>F
Model	1	0.1742	0.1742	2.88	0.1116
Error	14	0.8462	0.0604		
Total	15	1.0204			

ii) FSEN12:

Source	df	Type III SS	Mean Square	F	Pr>F
Model	1	0.0211	0.0211	0.31	0.5864
Error	14	0.9513	0.0679		
Total	15	0.9723			

iii) BLAN2:

Source	df	Type III SS	Mean Square	F	Pr>F
Model	1	0.0339	0.0339	0.55	0.4710
Error	14	0.8649	0.0618		
Total	15	0.8988			

iv) BLAN12:

Source	df	Type III SS	Mean Square	F	Pr>F
Model	1	0.0385	0.0385	0.62	0.4454
Error	14	0.8738	0.0624		
Total	15	0.9123			

Table D-11 (cont.)

v) AFUS15:

Source	df	Type III SS	Mean Square	F	Pr>F
Model	1	0.3949	0.3949	8.34	0.0119
Error	14	0.6629	0.0473		
Total	15	1.0578			

vi) AFUS100:

Source	df	Type III SS	Mean Square	F	Pr>F
Model	1	0.0394	0.0394	1.93	0.1860
Error	14	0.2848	0.0203		
Total	15	0.3241			

vii) ATOJ15:

Source	df	Type III SS	Mean Square	F	Pr>F
Model	1	1.1711	1.1711	1.21	0.2903
Error	14	13.5748	0.9696		
Total	15	14.7458			

viii) ATOJ75:

Source	df	Type III SS	Mean Square	F	Pr>F
Model	1	1.8269	1.8269	5.26	0.0378
Error	14	4.8596	0.3471		
Total	15	6.6864			

ix) ATOJ200:

Source	df	Type III SS	Mean Square	F	Pr>F
Model	1	1.8482	1.8482	3.36	0.0883
Error	14	7.7107	0.5508		
Total	15	9.5589			

Appendix E

Table E-1: Subjects' Data for Study 3

SUBJ	GROUP	READS	READP	SPELLS	SPELLP	AGE	IQ
		IWSA	IWLA	NWSA	NWLA	WORD	
		AFUS15	AFUS100	ATOJ15	ATOJ75	ATOJ200	
		BLAN2	BLAN12	FSEN2	FSEN12		
112	02	102	55	093	32	26	135
		73.33	76.67	86.67	80.00	3	
		07.050	02.360	093.705	129.645	175.650	
		255.22	275.71	0.02355	0.01510		
114	04	100	50	114	82	18	119
		70.00	73.33	66.67	73.33	3	
		02.905	03.015	128.905	123.345	111.620	
		132.82	209.14	0.01455	0.00825		
115	01	114	82	120	91	28	120
		90.00	86.67	76.67	80.00	1	
		02.815	01.990	037.995	039.780	086.520	
		056.19	179.24	0.01850	0.00820		
116	01	116	86	116	86	18	119
		86.67	80.00	83.33	93.33	3	
		04.140	02.280	013.515	068.125	075.080	
		141.98	149.43	0.02110	0.01335		
117	04	104	61	110	75	21	113
		70.00	73.33	90.00	83.33	2	
		02.410	01.970	035.980	034.220	074.725	
		141.78	139.34	0.01790	0.00720		
118	04	109	73	120	91	18	113
		70.00	73.33	80.00	83.33	2	
		03.445	02.385	005.900	021.650	026.070	
		074.85	209.14	0.01985	0.01375		
119	01	118	88	118	88	18	130
		80.00	83.33	90.00	83.33	3	
		02.990	02.820	041.960	073.685	065.400	
		167.65	206.12	0.03145	0.01445		
120	01	115	84	114	82	18	095
		76.67	73.33	86.67	86.67	2	
		07.770	03.030	047.615	054.160	024.220	
		229.84	282.94	0.02180	0.00835		
122	04	104	61	111	77	18	113
		60.00	70.00	80.00	80.00	2	
		03.455	03.570	028.955	062.250	091.945	
		171.21	309.39	0.02180	0.01475		
123	03	123	94	107	68	19	116
		76.67	73.33	90.00	86.67	2	
		02.765	03.000	017.495	032.565	055.260	
		165.80	417.90	0.03400	0.01910		
124	01	110	75	116	86	36	121
		93.33	80.00	90.00	80.00	3	
		02.540	02.875	025.335	065.620	066.545	
		171.21	174.54	0.02210	0.01345		

Table E-1 (cont.)

SUBJ	GROUP	READS	READP	SPELLS	SPELLP	AGE	IQ
		IWSA	IWLA	NWSA	NWLA	WORD	
		AFUS15	AFUS100	ATOJ15	ATOJ75	ATOJ200	
		BLAN2	BLAN12	FSEN2	FSEN12		
125	04	109	73	111	77	18	090
		83.33	73.33	63.33	63.33	1	
		04.435	02.310	237.370	173.985	170.905	
		126.28	379.52	0.01940	0.01255		
126	02	104	61	098	45	20	105
		73.33	66.67	86.67	86.67	2	
		03.155	03.015	134.540	121.585	220.545	
		382.99	545.69	0.02785	0.01370		
127	03	114	82	107	68	19	109
		73.33	83.33	86.67	86.67	3	
		02.890	02.525	068.755	060.120	143.115	
		165.42	266.36	0.02100	0.01315		
128	03	110	75	104	61	18	128
		63.33	80.00	80.00	80.00	3	
		03.365	02.985	039.020	036.825	102.310	
		167.05	170.23	0.03360	0.01455		
129	02	101	53	095	37	33	096
		76.67	73.33	73.33	90.00	3	
		02.950	02.685	044.355	045.235	074.165	
		153.78	229.95	0.02825	0.00985		
130	04	104	61	114	82	19	135
		83.33	73.33	80.00	83.33	3	
		03.390	02.655	018.530	052.050	027.535	
		216.45	220.23	0.02650	0.02115		
131	03	110	75	109	73	18	099
		80.00	66.67	86.67	93.33	2	
		03.500	02.760	062.445	089.940	109.625	
		227.79	389.44	0.04625	0.02500		
132	01	115	84	111	77	18	133
		86.67	80.00	86.67	73.33	3	
		04.025	03.000	071.925	109.175	090.240	
		249.26	296.38	0.04010	0.02485		
134	02	108	70	103	58	22	128
		76.67	83.33	73.33	80.00	3	
		04.715	03.015	037.815	053.330	140.240	
		107.38	179.04	0.01210	0.01215		
136	04	109	73	113	81	18	092
		76.67	86.67	83.33	93.33	3	
		02.860	02.925	044.985	073.790	158.595	
		242.49	570.20	0.02970	0.01265		
137	02	101	53	107	68	21	105
		70.00	86.67	93.33	73.33	3	
		03.475	02.780	075.385	102.580	151.360	
		268.21	479.23	0.02235	0.01440		
138	02	099	47	098	45	18	119
		56.67	76.67	66.67	53.33	3	
		07.435	02.885	271.010	221.835	135.310	
		214.97	240.18	0.03620	0.01550		

Table E-1 (cont.)

SUBJ	GROUP	READS	READP	SPELLS	SPELLP	AGE	IQ
		IWSA	IWLA	NWSA	NWLA	WORD	
		AFUS15	AFUS100	ATOJ15	ATOJ75	ATOJ200	
		BLAN2	BLAN12	FSEN2	FSEN12		
139	02	105	63	102	55	18	119
		83.33	70.00	50.00	70.00	1	
		03.015	02.980	013.830	017.910	070.795	
		113.19	264.45	0.02835	0.00860		
140	02	102	55	105	63	18	099
		80.00	66.67	93.33	86.67	2	
		02.875	03.500	129.750	197.260	236.945	
		250.56	316.46	0.01795	0.01210		
141	02	108	70	109	73	18	108
		80.00	63.33	80.00	76.67	3	
		04.265	02.525	033.495	029.880	064.575	
		277.38	336.28	0.03665	0.02090		
142	03	113	81	105	63	18	108
		70.00	56.67	76.67	70.00	2	
		03.710	02.390	059.635	115.025	098.375	
		209.34	222.34	0.02770	0.01475		
144	01	114	82	113	81	18	092
		83.33	80.00	90.00	83.33	3	
		03.005	03.030	101.215	107.980	187.535	
		104.92	148.06	0.03765	0.02020		
145	01	115	84	121	92	18	105
		76.67	83.33	80.00	90.00	3	
		03.160	02.295	042.620	075.260	081.535	
		158.43	455.27	0.02535	0.01410		
146	01	120	91	116	86	18	119
		86.67	83.33	96.67	93.33	2	
		02.735	02.860	043.845	063.390	079.650	
		107.42	161.42	0.01840	0.00725		
147	01	113	81	113	81	18	116
		83.33	63.33	93.33	93.33	2	
		03.065	01.960	050.740	043.715	070.155	
		170.14	164.41	0.02055	0.01230		
149	01	114	82	113	81	18	099
		76.67	76.67	83.33	93.33	2	
		02.895	01.970	028.875	037.840	086.665	
		225.67	386.32	0.03160	0.01560		
150	02	107	68	103	58	21	087
		73.33	53.33	80.00	86.67	2	
		03.655	03.175	130.450	118.445	220.520	
		246.38	260.71	0.03165	0.01435		
151	02	107	68	104	61	18	087
		60.00	70.00	73.33	86.67	2	
		03.000	02.355	015.725	057.875	089.440	
		238.29	287.87	0.02970	0.02095		
152	02	104	61	107	68	27	112
		83.33	83.33	93.33	86.67	3	
		02.480	02.235	134.290	134.295	141.010	
		067.58	155.12	0.02415	0.01065		

Table E-1 (cont.)

SUBJ	GROUP	READS	READP	SPELLS	SPELLP	AGE	IQ
		IWSA	IWLA	NWSA	NWLA	WORD	
		AFUS15	AFUS100	ATOJ15	ATOJ75	ATOJ200	
		BLAN2	BLAN12	FSEN2	FSEN12		
153	01	111	77	119	90	47	112
		73.33	93.33	86.67	90.00	3	
		03.910	02.570	022.870	107.395	080.845	
		155.10	222.26	0.02465	0.01130		
154	04	108	70	114	82	18	135
		80.00	83.33	86.67	93.33	3	
		01.960	02.525	018.120	038.500	071.230	
		124.42	165.73	0.04465	0.01920		
155	04	108	70	116	86	19	099
		90.00	80.00	83.33	83.33	3	
		06.125	03.180	050.440	091.675	066.065	
		237.76	330.67	0.03855	0.01720		
156	02	104	61	107	68	18	108
		76.67	70.00	80.00	83.33	3	
		02.720	03.430	056.240	146.270	161.915	
		259.58	378.39	0.04895	0.02520		
157	01	111	77	121	92	19	108
		86.67	80.00	80.00	86.67	3	
		01.690	01.930	029.615	058.200	086.180	
		079.53	194.47	0.02105	0.01075		
158	02	108	70	107	68	19	105
		66.67	60.00	76.67	86.67	2	
		02.660	02.315	085.935	074.275	132.865	
		245.64	228.00	0.02185	0.01465		
159	01	110	75	114	82	18	116
		76.67	80.00	73.33	70.00	3	
		03.830	02.860	017.340	080.385	144.370	
		161.27	208.04	0.01690	0.00945		
160	01	120	91	113	81	19	116
		83.33	90.00	86.67	83.33	3	
		02.965	02.790	063.905	059.090	101.485	
		188.44	260.31	0.01355	0.00910		
162	01	120	91	121	92	18	133
		86.67	83.33	93.33	83.33	3	
		03.190	02.420	066.275	056.580	074.475	
		149.14	293.64	0.02230	0.01450		
171	01	111	77	112	79	23	133
		76.67	90.00	83.33	90.00	3	
		03.395	02.750	054.265	049.705	068.430	
		228.80	302.13	0.03595	0.01380		
172	02	101	53	107	68	25	127
		83.33	76.67	73.33	63.33	1	
		02.935	02.920	019.875	035.845	091.205	
		131.02	176.30	0.01905	0.01070		
173	02	096	39	100	50	27	118
		70.00	73.33	83.33	90.00	2	
		03.980	02.935	057.515	107.905	123.815	
		177.59	228.96	0.03355	0.01465		

Table E-1 (cont.)

SUBJ	GROUP	READS	READP	SPELLS	SPELLP	AGE	IQ
		IWSA	IWLA	NWSA	NWLA	WORD	
		AFUS15	AFUS100	ATOJ15	ATOJ75	ATOJ200	
		BLAN2	BLAN12	FSEN2	FSEN12		
174	02	107	68	098	45	18	124
		56.67	66.67	90.00	90.00	2	
		03.750	03.000	105.080	099.345	148.695	
		240.88	295.43	0.03345	0.01990		
175	04	108	70	110	75	23	116
		86.67	86.67	86.67	90.00	3	
		03.635	02.650	074.340	078.305	137.770	
		193.32	435.71	0.02230	0.01910		
176	02	100	50	095	37	18	108
		70.00	56.67	46.67	56.67	1	
		06.730	03.015	051.160	061.605	092.460	
		131.02	210.57	0.02605	0.01290		
177	02	105	63	105	63	20	124
		83.33	80.00	86.67	73.33	3	
		02.075	02.715	030.130	065.100	077.580	
		085.87	220.56	0.01730	0.00945		
178	02	108	70	102	55	18	106
		63.33	73.33	86.67	90.00	2	
		02.525	01.610	149.950	210.010	200.015	
		126.56	242.21	0.02220	0.00975		
179	02	098	45	093	32	18	090
		63.33	73.33	73.33	73.33	3	
		03.130	03.015	024.700	070.305	067.155	
		209.56	223.63	0.03780	0.02545		
180	02	108	70	103	58	37	105
		80.00	80.00	93.33	96.67	2	
		02.500	02.440	076.740	076.865	125.565	
		154.45	190.28	0.01915	0.00865		
181	02	103	58	104	61	18	113
		56.67	70.00	76.67	90.00	2	
		03.630	02.665	105.145	167.230	112.170	
		116.09	298.55	0.02535	0.01215		
182	02	092	30	108	70	17	113
		70.00	70.00	73.33	80.00	3	
		02.805	02.500	065.915	041.910	085.425	
		130.20	240.45	0.02715	0.01050		
183	02	095	37	102	55	18	105
		63.33	53.33	73.33	73.33	2	
		04.510	03.015	027.540	016.245	033.385	
		145.54	220.72	0.02325	0.01410		
184	01	111	77	120	91	18	113
		83.33	80.00	93.33	80.00	3	
		02.905	02.025	057.710	102.680	120.735	
		131.02	221.60	0.02430	0.01085		
185	02	104	61	104	61	18	092
		80.00	66.67	93.33	80.00	2	
		05.170	03.085	047.760	094.885	200.960	
		149.37	169.30	0.02440	0.01340		

Table E-1 (cont.)

SUBJ	GROUP	READS IWSA AFUS15 BLAN2	READP IWLA AFUS100 BLAN12	SPELLS NWSA ATOJ15 FSEN2	SPELLP NWLA ATOJ75 FSEN12	AGE WORD ATOJ200	IQ
186	02	092 66.67 02.170 304.50	30 56.67 02.970 620.93	103 73.33 331.600 0.04025	58 80.00 339.980 0.02235	21 2 309.820	095
187	01	122 83.33 02.610 072.25	93 83.33 02.695 186.75	112 80.00 022.445 0.02435	79 80.00 051.680 0.01415	17 3 034.115	109
188	01	116 80.00 02.490 096.06	86 86.67 01.940 168.98	121 90.00 011.980 0.02905	92 86.67 016.685 0.01905	19 3 037.435	095
189	02	094 40.00 03.610 108.89	34 53.33 01.745 246.73	099 73.33 099.795 0.02445	47 63.33 082.670 0.01215	17 2 132.110	090
190	02	106 83.33 02.950 200.27	66 83.33 02.980 245.76	108 86.67 038.635 0.01905	70 90.00 085.140 0.01375	34 3 116.845	100
191	02	094 56.67 03.305 167.06	34 66.67 02.970 230.45	100 73.33 066.855 0.03020	50 63.33 051.380 0.01890	18 3 082.955	116
192	02	091 63.33 05.040 206.12	27 66.67 03.405 314.18	102 40.00 256.700 0.04845	55 56.67 305.775 0.02170	19 1 259.190	105
193	02	091 63.33 03.170 205.28	27 43.33 02.965 255.39	090 73.33 042.765 0.02220	25 63.33 066.380 0.01225	25 2 126.355	118
195	02	092 60.00 04.915 159.76	30 60.00 02.350 191.16	105 43.33 109.430 0.03970	63 60.00 173.725 0.01625	19 3 183.985	087
196	01	111 86.67 02.675 119.20	77 86.67 02.350 147.51	119 80.00 075.285 0.02735	90 83.33 074.660 0.01235	29 3 214.970	135
197	02	093 46.67 02.620 219.31	32 66.67 03.030 278.02	104 73.33 036.855 0.02770	61 73.33 074.315 0.02710	18 2 075.160	105
198	02	103 73.33 02.290 139.49	58 80.00 04.685 234.26	098 70.00 073.440 0.02705	45 80.00 092.915 0.01885	18 3 189.730	124

Table E-1 (cont.)

SUBJ	GROUP	READS IWSA AFUS15 BLAN2	READP IWLA AFUS100 BLAN12	SPELLS NWSA ATOJ15 FSEN2	SPELLP NWLA ATOJ75 FSEN12	AGE WORD ATOJ200	IQ
201	04	106	66	115	84	17	108
		56.67	60.00	93.33	86.67	2	
		03.045	02.435	033.020	042.835	065.745	
		157.16	325.05	0.04670	0.01355		
202	04	107	68	121	92	43	127
		90.00	90.00	83.33	90.00	3	
		04.365	02.535	117.215	071.370	079.920	
		213.34	253.38	0.03820	0.02225		
204	04	097	42	111	77	18	113
		76.67	80.00	60.00	76.67	1	
		10.955	02.985	056.345	091.660	172.350	
		108.36	161.42	0.02055	0.01015		
205	01	115	84	123	94	18	124
		90.00	90.00	96.67	93.33	3	
		02.680	01.775	021.375	026.630	040.115	
		121.75	240.64	0.02900	0.01595		
206	01	110	75	111	77	18	092
		73.33	86.67	80.00	76.67	3	
		03.390	03.270	005.130	030.500	047.690	
		257.07	376.39	0.02175	0.01570		
207	02	099	47	108	70	36	096
		86.67	80.00	76.67	73.33	3	
		06.555	03.395	045.865	099.610	138.505	
		069.15	162.85	0.02940	0.01575		
210	02	099	47	093	32	34	108
		80.00	60.00	66.67	63.33	3	
		03.890	02.535	204.095	422.355	327.200	
		256.87	314.95	0.03410	0.01260		
211	01	118 88	116	86	18	133	
		83.33	83.33	83.33	86.67	3	
		02.535	01.960	016.275	023.395	055.450	
		261.33	269.35	0.02600	0.01270		
212	04	104	61	113	81	18	113
		76.67	76.67	83.33	70.00	3	
		04.380	02.390	031.035	062.355	065.585	
		193.52	238.59	0.03150	0.01680		
213	02	089	23	096	39	25	118
		70.00	70.00	56.67	63.33	1	
		02.955	02.970	056.385	064.225	113.815	
		164.10	410.81	0.02550	0.00925		
214	02	088	21	093	32	18	113
		46.67	56.67	53.33	43.33	3	
		04.020	03.600	099.130	056.375	224.965	
		123.35	203.80	0.02620	0.01690		
215	03	112	79	103	58	17	119
		76.67	76.67	90.00	76.67	3	
		03.185	02.985	053.660	038.705	074.085	
		186.93	293.46	0.02110	0.01165		

Table E-1 (cont.)

SUBJ	GROUP	READS	READP	SPELLS	SPELLP	AGE	IQ
		IWSA	IWLA	NWSA	NWLA	WORD	
		AFUS15	AFUS100	ATOJ15	ATOJ75	ATOJ200	
		BLAN2	BLAN12	FSEN2	FSEN12		
216	03	110	75	108	70	29	118
		83.33	83.33	76.67	83.33	3	
		01.985	02.620	075.625	084.075	193.270	
		193.24	200.31	0.02910	0.02325		
217	01	114	82	110	75	17	105
		76.67	76.67	86.67	83.33	3	
		02.895	02.015	099.020	123.955	156.200	
		153.01	363.61	0.04925	0.01085		
218	04	109	73	113	81	18	095
		73.33	76.67	76.67	63.33	3	
		07.235	03.790	069.860	068.250	167.135	
		204.60	410.34	0.02910	0.01505		
221	01	115	84	118	88	18	128
		83.33	76.67	90.00	96.67	2	
		03.620	02.920	026.130	030.015	138.285	
		107.42	293.01	0.03435	0.01290		
222	02	098	45	100	50	29	112
		66.67	73.33	90.00	73.33	2	
		02.660	02.965	106.100	131.725	111.510	
		149.14	193.77	0.02715	0.01350		
223	04	101	53	112	79	28	129
		76.67	80.00	76.67	80.00	3	
		02.445	02.210	069.810	082.305	084.050	
		171.54	290.83	0.02045	0.01150		
224	01	113	81	116	86	18	095
		70.00	60.00	83.33	90.00	2	
		06.210	02.985	065.285	068.395	094.870	
		062.17	200.61	0.01580	0.01060		
225	04	108	70	119	90	26	112
		90.00	86.67	90.00	86.67	3	
		01.920	02.925	013.625	019.585	065.610	
		177.26	309.78	0.02925	0.01265		
226	04	105	63	114	82	19	095
		76.67	83.33	80.00	70.00	3	
		05.540	02.970	032.495	060.500	120.910	
		250.38	273.30	0.03565	0.01625		
227	04	107	68	111	77	17	116
		83.33	83.33	96.67	83.33	3	
		03.120	02.875	032.980	076.640	078.445	
		088.90	150.59	0.01645	0.00885		
228	02	107	68	095	37	19	089
		80.00	80.00	56.67	73.33	1	
		03.810	01.985	138.200	109.730	186.675	
		264.54	393.00	0.02960	0.01990		
230	02	102	55	107	68	18	128
		70.00	70.00	83.33	100.0	2	
		02.175	02.515	092.645	056.170	176.130	
		124.46	172.91	0.01965	0.01020		

Table E-1 (cont.)

SUBJ	GROUP	READS IWSA AFUS15 BLAN2	READP IWLA AFUS100 BLAN12	SPELLS NWSA ATOJ15 FSEN2	SPELLP NWLA ATOJ75 FSEN12	AGE WORD ATOJ200	IQ
232	02	104 83.33 03.560 109.34	61 86.67 02.205 095.33	105 86.67 031.995 0.01105	63 90.00 070.360 0.00845	21 3 116.035	099
233	04	109 83.33 03.015 160.97	73 80.00 02.155 191.84	116 80.00 038.950 0.02040	86 70.00 049.425 0.00965	18 3 059.565	116
234	01	111 76.67 03.090 186.77	77 83.33 01.745 226.15	115 60.00 044.440 0.01875	84 70.00 095.110 0.01560	17 1 086.525	105
235	01	118 93.33 02.780 133.31	88 86.67 02.830 410.03	122 90.00 118.225 0.04595	93 86.67 129.110 0.01835	55 3 145.670	135
236	02	108 86.67 03.575 235.98	70 76.67 03.065 360.75	109 80.00 042.795 0.03340	73 76.67 031.985 0.01765	18 3 067.715	099
237	01	111 70.00 02.635 119.16	77 83.33 02.935 252.62	113 83.33 015.390 0.03715	81 90.00 054.525 0.02005	18 2 063.155	108
238	01	111 80.00 02.415 181.99	77 80.00 02.160 376.28	114 93.33 027.415 0.02590	82 86.67 044.485 0.01575	18 2 106.240	116
239	02	108 76.67 03.015 134.62	70 73.33 03.050 158.84	105 86.67 041.365 0.02120	63 76.67 067.695 0.01355	18 3 114.965	119
240	04	107 86.67 02.590 194.49	68 83.33 03.030 298.17	112 76.67 032.355 0.01275	79 93.33 065.005 0.00720	27 3 072.515	135
241	02	107 80.00 02.685 210.82	68 63.33 03.045 236.38	102 90.00 024.545 0.02430	55 90.00 035.625 0.00810	18 2 064.320	113

N.B.: SUBJ: Subject Number
GROUP: Reading Group (1=Good Reader / Good Speller, 2=Normal Reader / Normal Speller) (3=Good Reader / Normal Speller, 4=Normal Reader / Good Speller)
READS, READP: WRAT Reading Standard Score, Percentile respectively
SPELLS, SPELLP: WRAT Spelling Standard Score, Percentile respectively
AGE: Age
IQ: Nonverbal Reasoning Skills measured by Advanced Raven's Progressive Matrices
IWSA, IWLA (%): Irregular Words Accuracy, Single / Continuous (Line) condition
NWSA, NWLA (%): Nonsense Words Accuracy, Single / Continuous (Line) condition
WORD: Word-Type Reader (1=Irregular Word Readers, 2=Nonsense Word Readers)
AFUS15, AFUS100 (ms): Auditory Fusion at 15 and 100 ms respectively
ATOJ15, ATOJ75, ATOJ200 (ms): Auditory Temporal Order Judgment at 15, 75 and 200 ms respectively
BLAN2, BLAN12 (ms): Visible Persistence (based on the judgment of a blank) at 2 and 12 c/d respectively
FSEN2, FSEN12: Flicker Sensitivity at 2 and 12 Hz respectively

Appendix E (cont.)

Summary Tables of Study 3

Table E-2: Summary Tables of MANOVA on the Sensory Measures ("Irregular Word" Readers vs "Nonsense Word" Readers)

i) FSEN2:

Source	df	Type III SS	Mean Square	F	Pr>F
Model	1	0.0338	0.0338	0.43	0.5168
Error	42	3.3177	0.0790		
Total	43	3.3515			

ii) FSEN12:

Source	df	Type III SS	Mean Square	F	Pr>F
Model	1	0.0738	0.0738	0.67	0.4180
Error	42	4.6315	0.1103		
Total	43	4.7053			

iii) BLAN2:

Source	df	Type III SS	Mean Square	F	Pr>F
Model	1	0.3131	0.3131	1.99	0.1655
Error	42	6.6021	0.1572		
Total	43	6.9152			

iv) BLAN12:

Source	df	Type III SS	Mean Square	F	Pr>F
Model	1	0.0026	0.0026	0.02	0.8829
Error	42	4.8948	0.1165		
Total	43	4.8974			

Table E-2 (cont.)

v) AFUS15:

Source	df	Type III SS	Mean Square	F	Pr>F
Model	1	0.4774	0.4774	4.58	0.0383
Error	42	4.3806	0.1043		
Total	43	4.8580			

vi) AFUS100:

Source	df	Type III SS	Mean Square	F	Pr>F
Model	1	0.0072	0.0072	0.18	0.6764
Error	42	1.7132	0.0408		
Total	43	1.7204			

vii) ATOJ15:

Source	df	Type III SS	Mean Square	F	Pr>F
Model	1	0.2206	0.2206	0.31	0.5828
Error	42	30.2259	0.7197		
Total	43	30.4465			

viii) ATOJ75:

Source	df	Type III SS	Mean Square	F	Pr>F
Model	1	0.0387	0.0387	0.08	0.7789
Error	42	20.3222	0.4839		
Total	43	20.3609			

ix) ATOJ200:

Source	df	Type III SS	Mean Square	F	Pr>F
Model	1	0.2576	0.2576	0.82	0.3702
Error	42	13.1864	0.3140		
Total	43	13.4440			

Table E-3: Summary Tables of Repeated Measures ANOVA on Reading Accuracy

Source	df	Type III SS	MS	F	Pr>F
GROUP	1	1.5019	1.5019	32.37	0.0001
Error	75	3.4794	0.0464		
WORD	1	0.2863	0.2863	12.9	0.0006
WORD x GROUP	1	0.0240	0.0240	1.08	0.3015
Error (WORD)	75	1.6649	0.0222		
LINE	1	0.0001	0.0001	0.01	0.9251
LINE x GROUP	1	0.0007	0.0007	0.08	0.7811
Error (LINE)	75	0.6639	0.0089		
WORD x LINE	1	0.0038	0.0038	0.38	0.5380
WORD x LINE x GROUP	1	0.0035	0.0035	0.35	0.5568
Error (WORD x LINE)	75	0.7530	0.0100		
Total	307	8.3815			

N.B.: GROUP: Main Effect of Reading Group (Good vs Normal)
WORD: Main Effect of Word Type (Irregular vs Nonsense)
WORD x GROUP: WORD x GROUP Interaction
LINE: Main Effect of Presentation Mode (Single vs Continuous)
LINE x GROUP: LINE x GROUP Interaction
WORD x LINE: WORD x LINE Interaction
WORD x LINE x GROUP: WORD x LINE x GROUP Interaction

Table E-4: Summary Tables of MANOVA on the Sensory Measures (Good Readers vs Normal Readers)

i) FSEN2:

Source	df	Type III SS	Mean Square	F	Pr>F
Model	1	0.0114	0.0114	0.12	0.7281
Error	75	7.0269	0.0937		
Total	76	7.0383			

ii) FSEN12:

Source	df	Type III SS	Mean Square	F	Pr>F
Model	1	0.0687	0.0687	0.74	0.3914
Error	75	6.9307	0.0924		
Total	76	6.9994			

iii) BLAN2:

Source	df	Type III SS	Mean Square	F	Pr>F
Model	1	0.6080	0.6080	3.85	0.0535
Error	75	11.8475	0.1580		
Total	76	12.4555			

iv) BLAN12:

Source	df	Type III SS	Mean Square	F	Pr>F
Model	1	0.0351	0.0351	0.3	0.5826
Error	75	8.6402	0.1152		
Total	76	8.6753			

Table E-4 (cont.)

v) AFUS15:

Source	df	Type III SS	Mean Square	F	Pr>F
Model	1	0.1616	0.1616	1.79	0.1850
Error	75	6.7712	0.0903		
Total	76	6.9328			

vi) AFUS100:

Source	df	Type III SS	Mean Square	F	Pr>F
Model	1	0.3328	0.3328	9.4	0.0030
Error	75	2.6560	0.0354		
Total	76	2.9888			

vii) ATOJ15:

Source	df	Type III SS	Mean Square	F	Pr>F
Model	1	7.1074	7.1074	13.31	0.0005
Error	75	40.0349	0.5338		
Total	76	47.1423			

viii) ATOJ75:

Source	df	Type III SS	Mean Square	F	Pr>F
Model	1	2.5018	2.5018	6.34	0.0140
Error	75	29.6124	0.3948		
Total	76	32.1142			

ix) ATOJ200:

Source	df	Type III SS	Mean Square	F	Pr>F
Model	1	3.7434	3.7434	16.07	0.0001
Error	75	17.4675	0.2329		
Total	76	21.2109			

Table E-5: Summary Tables of MANCOVA on the Sensory Measures (Good Readers vs Normal Readers)

i) FSEN2:

Source	df	Type III SS	Mean Square	F	Pr>F
IQ	1	0.0525	0.0525	0.56	0.4579
GROUP	1	0.0022	0.0022	0.02	0.8776
Error	74	6.9744	0.0942		
Total	76	7.0383			

ii) FSEN12:

Source	df	Type III SS	Mean Square	F	Pr>F
IQ	1	0.1847	0.1847	2.03	0.1588
GROUP	1	0.0221	0.0221	0.24	0.6237
Error	74	6.7460	0.0912		
Total	76	6.9994			

iii) BLAN2:

Source	df	Type III SS	Mean Square	F	Pr>F
IQ	1	0.0591	0.0591	0.37	0.5444
GROUP	1	0.4850	0.4850	3.04	0.0852
Error	74	11.7885	0.1593		
Total	76	12.4555			

iv) BLAN12:

Source	df	Type III SS	Mean Square	F	Pr>F
IQ	1	0.0544	0.0544	0.47	0.4956
GROUP	1	0.0155	0.0155	0.13	0.7158
Error	74	8.5858	0.1160		
Total	76	8.6753			

Table E-5 (cont.)

v) AFUS15:

Source	df	Type III SS	Mean Square	F	Pr>F
IQ	1	0.1061	0.1061	1.18	0.2812
GROUP	1	0.0960	0.0960	1.07	0.3052
Error	74	6.6650	0.0901		
Total	76	6.9328			

vi) AFUS100:

Source	df	Type III SS	Mean Square	F	Pr>F
IQ	1	0.0392	0.0392	1.11	0.2956
GROUP	1	0.3695	0.3695	10.45	0.0018
Error	74	2.6168	0.0354		
Total	76	2.9888			

vii) ATOJ15:

Source	df	Type III SS	Mean Square	F	Pr>F
IQ	1	0.0882	0.0882	0.16	0.6872
GROUP	1	7.0622	7.0622	13.08	0.0005
Error	74	39.9467	0.5398		
Total	76	47.1423			

viii) ATOJ75:

Source	df	Type III SS	Mean Square	F	Pr>F
IQ	1	0.2489	0.2489	0.63	0.4309
GROUP	1	1.9916	1.9916	5.02	0.0281
Error	74	29.3636	0.3968		
Total	76	32.1142			

ix) ATOJ200:

Source	df	Type III SS	Mean Square	F	Pr>F
IQ	1	0.0259	0.0259	0.11	0.7414
GROUP	1	3.6680	3.6680	15.56	0.0002
Error	74	17.4417	0.2357		
Total	76	21.2109			

Appendix F

University of Wollongong

Department of Psychology

CONSENT FORM

I, ______________________________, agree to participate in experiments for Agnes Au's phD thesis. (Under the supervision of Prof. William Lovegrove)

I have been told and am fully aware of what is involved in this study. I acknowledge that I may discontinue participation and can ask any question at any time.

In addition to this, it is understood that any data that may be collected from me will remain anonymous.

Any enquiries regarding the conduct of this research may be forwarded to the secretary of the University of Wollongong Human Research Ethics Committee.

Signed________________________

Date__________________________

Subject Number________________

Appendix G

Subject's Information Sheet

Name:______________________________________

Subject No:_________________

Age:__________________ Sex:______________

Do you have any visual defects? (e.g., wearing glasses if you are short-sighted is not considered a visual defect) ________________________

Do you have any hearing problems?___________________

Do you have epilepsy, migraine or other severe headaches quite often?__________

Are you English speaking?___________________

Would you please kindly leave your address and phone number so that we can contact you for participation in other tests. Thank you.

Address:____

____

____

Phone:____