The affects of heat strain and dehydration on cognitive function

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Abstract
Many groups have investigated cognitive performance during hyperthermia and dehydration, with few demonstrating convincing and unequivocal influences. Some reports show neither thermal nor hydration-induced influences, others have found improved, whilst some report reduced cognitive performance. This confusion has arisen due to methodological limitations that have resulted in many previous experiments not being optimally designed to evaluate these effects. For instance, few studies have appropriately induced hyperthermia and dehydration, and then clamped these states during the cognitive challenge. Many investigators have used physical exercise to induce these states, yet exercise may independently affect cognitive performance. Furthermore, task difficulty has rarely been controlled across cognitive functions, with the difficulty level for many tasks being too low, whilst inter-task comparisons have often been performed across different levels of difficulty. The former introduces bias, such that only performance decrements can be observed, whilst the latter renders it almost impossible to compare either the baseline data or subsequent changes in cognitive performance during altered thermal and hydration states. As a consequence of these limitations, our understanding of the affects of these stresses upon cognitive performance is less than optimal, and this study was designed to address these design limitations.

Keywords
function, strain, cognitive, dehydration, affects, heat

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The effects of heat strain and dehydration on cognitive function

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Introduction

Many groups have investigated cognitive performance during hyperthermia and dehydration, with few demonstrating convincing and unequivocal influences. Some reports show neither thermal-nor hydration-induced influences, others have found improved, whilst some report reduced cognitive performance. This confusion has arisen due to methodological limitations that have resulted in many previous experiments not being optimally designed to evaluate these effects. For instance, few studies have appropriately induced hyperthermia and dehydration, and then clamped these states during the cognitive challenge. Many investigators have used physical exercise to induce these states, yet exercise may independently affect cognitive performance. Furthermore, task difficulty has rarely been controlled across cognitive functions, with the difficulty level for many tasks being too low, whilst inter-task comparisons have often been performed across different levels of difficulty. The former introduces bias, such that only performance decrements can be observed, whilst the latter renders it almost impossible to compare either the baseline data or subsequent changes in cognitive performance during altered thermal and hydration states. As a consequence of these limitations, our understanding of the affects of these stresses upon cognitive performance is less than optimal, and this study was designed to address these design limitations.

Methods

Eight physically active men participated in six experimental trials, delivered in a balanced order, and at intervals >7 d. Before every trial, pre-experimental preparation ensured each subject was tested in a clamped thermal state (thermoneutral: mean body temperature: ~36.5°C; moderate hyperthermia: ~38.5°C), and at one of three hydration levels (euhydration: 0%; mild dehydration: 3%; moderate dehydration: 5%). These hydration states were then investigated at each level of thermal strain, resulting in six trials, with the control state being thermoneutral and euhydrated. Dehydration was achieved using intermittent, warm-water immersion (39-41°C: 2.5-3.5 h), with the desired state maintained throughout the trial using controlled (isotonic) fluid administration. Thermal clamping, using a water-perfusion garment, water bath and insulated clothing ensured sustenance of the target body temperatures.

Hydration status was tracked throughout each trial via changes in semi-nude mass, relative to the pre-experimental body mass, which itself was the average of three consecutive daily measurements obtained from the mornings preceding each trial. Core temperature was derived as the mean of three site measurements: oesophagus, auditory canal and rectum. Skin temperatures were measured from eight sites (forehead, scapula, chest, upper arm, forearm, hand, thigh, calf), with mean skin temperature calculated as an area-weighted average. All temperatures were recorded at 15-s intervals. Mean body temperature was determined using temperature-specific weightings of mean core (thermoneutral: 80%; hyperthermia: 90%) and mean skin temperatures.

Three cognitive tasks were performed within each trial: (1) a visual perceptual task was administered at two levels of difficulty (easy and difficult); (2) a working memory (n-back) task was delivered at a difficulty level approximately equal to that of the easy perceptual task; and (3) a
letter identification task was administered to evaluate the effect of these treatments on visual acuity, since this can confound data interpretation when cognitive tasks rely upon visual cues. These tasks were administered in a counterbalanced order, which was randomly assigned to each subject. The difficulty level used for each subject for the visual perceptual tasks was determined during a preliminary experimental session. The variables recorded and analysed from these tasks were performance accuracy (percentage of correct responses) and reaction time (ms). Data were analysed using factorial ANOVA, where the independent variables were thermal status (two levels) and hydration state (three levels), and the primary dependent variable was cognitive function, with task accuracy and reaction time being compared across trials.

Results and Discussion
The target hydration states (mass changes) were achieved within every trial: thermoneutral: -0.2% (SD 0.2), -3.1% (SD 0.2) and -5.1% (SD 0.2); moderate hyperthermia: -0.9% (SD 0.9), -3.3% (SD 0.3) and -5.1% (SD 0.5). Each of these states differed significantly from one another (F[2,14]=468.43, p<0.01), and there was no interaction between hydration and body temperature (p=0.14). Mean body temperature was clamped at each hydration level: 36.2°C (SD 0.3), 36.2°C (SD 0.3) and 36.4°C (SD 0.3) for the thermoneutral trials at 0%, 3% and 5% dehydration (respectively); and similarly at 38.4°C (SD 0.3), 38.3°C (SD 0.3) and 38.3°C (SD 0.3) for the moderate hyperthermia trials. These thermal states differed significantly (F[1,7]=600.35, p<0.01), and without an interaction between temperature and hydration (p=0.07). These outcomes were interpreted to mean that previous methodological limitations had been successfully overcome by manipulating and clamping both the thermal and hydration status of every subject prior to commencing each trial, and throughout the ensuing cognitive function tests.

To distinguish between the influence of these treatments on these cognitive domains, the accuracy for the working memory and easy perceptual tasks from the thermoneutral, euhydrated trials were matched: 83.0% (SD 11.3) and 84.9% (SD 9.8), respectively. The fact that difficulty did not differ significantly verifies that the task difficulty manipulation was achieved successfully (t(7)=-0.427, p=0.68). There were no indications of differences in accuracy for the letter identification task, as a function of the thermal (p=0.68) or hydration manipulations (p=0.46), or their interactions (p=0.31). Thus, the following cognitive performance changes occurred independently of variations in visual acuity.

To evaluate the thermal and hydration effects on task difficulty, comparisons were made for both task accuracy and reaction time between the easy and difficult perceptual tasks, as a function of the thermal and hydration states. For performance accuracy, there was a main effect of difficulty level (F[1,7]=8.11, p=0.03), where accuracy was higher in the easy compared to the more difficult perceptual task (Figure 1), but there was no main effect for either temperature (p=0.18) or hydration (p=0.89), and no interaction (p=0.79). Furthermore, difficulty level did not interact with either temperature (p=0.56) or hydration (p=0.41), nor was the interaction between temperature and hydration state significant (p=0.55). For reaction time, there was a main effect of temperature (F[1,7]=29.88, p<0.01), with faster reaction times generally being evident when subjects were hyperthermic (Figure 1), and there was also a main effect of hydration state (F[2,14]=7.36, p<0.01), such that reaction time was faster when 5% dehydrated relative to the euhydrated (p<0.01) and 3% dehydrated state (Figure 1; p=0.01). Similarly, difficulty level did not interact with either temperature (p=0.80) or hydration (p=0.83), nor the interaction of temperature and hydration (p=0.22).
The affect of temperature and hydration status on cognitive performance accuracy (left) and reaction time (right). Bars represent the six separate trials, with adjacent bars for thermoneutral (white) and hyperthermia (grey) at each of three hydration levels: euhydration (cross hatched), 3% (stippled) and 5% dehydration (horizontal). Data are means ± SEM.

To evaluate the impact of these thermal and hydration states on cognitive task type (domain), comparisons were made for both performance accuracy and reaction time between the working memory task and easy-perceptual tasks, as a function of these thermal and hydration states (Figure 1). For performance accuracy, there were no main effects for task type \( (p=0.58) \), temperature \( (p=0.11) \) or hydration state \( (p=0.52) \), and there were no significant interactions (all \( p>0.05 \)). However, for reaction time, there was a main effect of temperature \( (F[1,7]=43.16, p<0.01) \), with slower reactions generally being observed when subjects were thermoneutral relative to the hyperthermic state (Figure 1), but there were no main effects for task type \( (p=0.06) \) or hydration level \( (p=0.08) \), and the interaction between temperature and hydration was not significant \( (p=0.13) \). Furthermore, there was no interaction between task type and either temperature \( (p=0.32) \) or hydration state \( (p=0.59) \), nor was the interaction between task type, temperature and hydration significant \( (p=0.21) \).

Conclusions

The main findings of this study were significantly faster reaction times when subjects were moderately hyperthermic (relative to the thermoneutral), and this was independent of both task difficulty and the cognitive domain. There was also an improvement in reaction time (perceptual tasks only) with increased dehydration. Furthermore, there was no evidence of a simultaneous decrease in accuracy within any of these comparisons. Thus, there was no trade-off evident between speed and accuracy within these data, with subjects demonstrating improvement as a function of both increasing temperature and the level of dehydration. These observations imply that, under more rigidly controlled experimental conditions, neither mild dehydration nor mild hyperthermia appear to have adverse consequences for performance within these cognitive domains.