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A Study of Computer-Based Task Performance Under Thermal Stress

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A visual-visual dual computer task was designed to test the effect of the thermal environment on dual task performance. The temperatures selected for testing were 20 and 35 °C Wet Bulb Globe Temperature (WBGT). 34 volunteers were randomly assigned to 1 of the 2 temperature conditions. Individual differences in single task performance were controlled by equating the baselines of single task performance. Once individual differences in single task capacity were controlled, statistically significant differences in performance were demonstrated.

Mean accuracy was computed over a 1-hr testing period in each temperature condition. Participants' mean accuracy in the 35° condition (38.18%) was substantially lower than in the 20° condition (50.88%).

dual task thermal environment cognitive performance

1. INTRODUCTION

For nearly five decades researchers have investigated thermal stress effects on human cognitive performance. Although much data have been collected, relatively little consensus has been reached with regard to either the true nature of thermal stress effects, or an existing mechanism for predicting human performance under thermal stress. Several factors have likely contributed to the substantial variation in the findings of previous thermal stress investigations. Among these are the use of various cognitive tasks with different sensitivities to thermal stress (Hockey, 1986), and the use of different thermal stress variables and levels. Additionally, previous investigations have generally not addressed the issue of individual variations in task performance.

Variation in the type and number of tasks performed is one potential source of variation among previous investigations of thermal stress effects. Many studies found performance decrements, during thermal stress, that were generally greater for more difficult tasks. Some studies involving simultaneous tasks, however, have found performance of at least one task or task component to be unaffected during thermal stress. For example, C.R. Bell, Provins, and Hiorns (1964) reported more missed signals, but no vigilance deficits. P.A. Bell (1978) also reported no effects of heat on a primary pursuit motor task although a secondary number-processing task was adversely affected. Yet another group of studies has found performance facilitation for some tasks, during thermal stress, although generally accompanied by performance decrements on other tasks. Nunneley, Dowd, Myhre, Stribley, and McNee's (1979) study of three tracking tasks, however, found no performance decrement on two tasks and strictly performance facilitation on the other. Other investigators have reported initial periods of improved performance under thermal stress, followed by declining performance (Fine & Kobrick, 1978; Grether, 1973; Poulton & Kerslake, 1965); although Provins and Bell (1970) reported an initial benefit with no long-term performance breakdown.

Bursill (1958) used the concept of attentional narrowing under heat stress to account for performance decrement on a concurrent peripheral visual reaction

time task. This explanation was seemingly contradicted by Azer, McNall, and Leung's (1972) finding that field of awareness was not significantly affected by heat stress. It should be noted, however, that Bursill conducted his study at a higher effective temperature (ET).

As reported here, Provins and Bell (1970) reported an initial benefit with a temperature similar to Bursill's (1958), but contrary to Bursill, found no long-term performance breakdown. The inconsistency of these findings may be due to differences in the difficulty levels of the tasks employed in each study. Bursill used a centrally located pursuit meter, which imposed great attentional demands, whereas Provins and Bell used a Serial Reaction Time (SRT), which is regarded as less difficult.

Iampietro, Chiles, Higgins, and Gibbons (1969) found no impairment of time sharing ability on paired combinations of arithmetic, monitoring, and tracking tasks, after 30 min at 35 °C, ET. A performance decrement was detected, however, soon after 5 min of exposure to 38.3 °C ET. These researchers suggested that this time shared performance deny the participant the attentional resources, which are available in single task performance.

Various attempts to weight different thermal factors and integrate them into a single index have also led to the use of many different thermal variables across studies. Consequently, this lack of agreement on thermal variable choice is another potential source of variance in experimental results. Effective temperature (ET) and wet bulb globe temperature (WBGT) represent two attempts to identify a single thermal variable. ET incorporates dry bulb temperature (i.e., the reading of a typical mercury thermometer), humidity, and air speed. The WBGT measure incorporates the radiation effect, and is calculated as follows:

$$\text{WBGT} = 0.7 \text{ wbt} + 0.1 \text{ dbt} + 0.2 \text{ gt},$$

where wbt is wet bulb temperature, dbt is dry bulb temperature, and gt is globe temperature. Wet bulb temperature is obtained by placing a wet wick over the mercury bulb. When air passes over the wick, evaporation and consequently cooling occurs. The cooling that results from evaporation is nearly independent of air speed and can be used to calculate the humidity. Globe temperature is obtained by taking a thin copper sphere, painted flat black, placing a thermometer at the center, and allowing the thermometer to reach equilibrium. The present study employed WBGT, as it is now typically regarded as the standard thermal variable in human performance research.

2. SYNTHESIS OF PREVIOUS FINDINGS

The apparent lack of consistency across thermal stress investigations has led several authors to review the literature in an attempt to synthesize various findings. Wing (1965), Grether (1973), Ramsey and Morrissey (1978), Kobrick and Fine (1983), Ramsey (1983, 1995), P.A. Bell and Greene (1982), Griffiths (1975), Hancock (1984), Pepler (1963), and Poulton (1970) have contributed such efforts. While attempting to account for duration, temperature range, and task type, Ramsey and Morrissey (1978) developed isodecrement curves that indicated that decrements in more complex dual tasks were almost independent of exposure time, though very sensitive to temperature increases above about 30 °C. Hancock's efforts (1989) suggested that the inverted U-curve of arousal theory be supplanted by a dynamic model for human performance that was based on the concept of adaptability in both physical and psychological terms. A more recent study by Ramsey (1995) converted, where possible, all temperature measures to WBGT, and accounted for task type by dividing task types into two categories, which were (a) mental, cognitive, very simple perceptual motor, sensory, time estimation, reaction time, and so forth, and (b) other perceptual motor tasks, including tracking, vigilance, vehicle or machine operation, complex or dual tasks, and so forth. Despite these efforts, the large volume of previous research findings remains generally unreconciled.

The present study involved a dual visual-visual task, which would be part of Ramsey's category 2 (1995). Ramsey concluded that, for category 2 tasks, there is an onset of statistically significant performance decrement in the range 30–33 °C WBGT. Dual tasks were indicated to be more difficult and to demand perceptual motor skills, more closely approximating industrial and military tasks (Ramsey, 1995).

Lack of consideration, by previous investigations, for individual differences in single task performance was a source of variation that the present study attempted to address specifically. This study controlled for individual, task performance differences by equating the baselines of single task performance. Investigations in the attention literature have previously employed this methodology (e.g., Irwin-Chase, 1995; Somberg & Salthouse, 1982). Another technique that some investigators have used to account for individual performance differences is based on the concept of training. This method of extended practice, however, has been criticized as an alternative to equating baselines (Guttentag, 1989; Lane, 1979; Somberg & Salthouse, 1982).

3. OBJECTIVE

The present study aimed to investigate possible differences in dual task performance at two ambient temperature conditions. The confounding effect of individual task performance differences was controlled by equating the baselines of single task performance. The dual task environment was selected due to its high cognitive demand. A dual visual-visual task was specifically selected to assure that similar cognitive resources were being tapped.

4. METHODS

4.1. Participants

Thirty-four University of Louisville, KY, USA students volunteered to participate in the present study, and were equally divided into two groups. One group was exposed to 20 °C WBGT thermal condition during testing, whereas the other was exposed to 35 °C WBGT condition. The participants wore long pants and short sleeve shirts when exposed to both thermal conditions. The 20 °C group had an age range of 19–35, a mean age of 25.5, and had 8 males and 9 females. The 35 °C group had an age range of 19–41, a mean age of 25.1, and had 9 males and 8 females.

4.2. Experimental Design

This study used a between-participants design with two testing conditions, 20 and 35 °C WBGT. Participants were evenly and randomly distributed among two groups, with each group assigned to one of the two conditions. Each participant repetitively performed dual visual tasks during a single testing session. Accuracy for each individual component of the dual task was recorded as a binary variable, with a 1 indicating success and a 0 indicating failure. Accuracy for both tasks was similarly recorded as a binary variable, with a 1 indicating success on both individual tasks and a 0 indicating failure on either or both tasks.

4.3. Experimental Procedure

In the procedure for the present study (adapted from Somberg & Salthouse, 1982, and Irwin-Chase, 1995), each participant was repetitively presented with a dual visual task, consisting of two concurrent visual tasks. For each repetition, the participants responded, for each individual task, as to whether

a stimulus was present or absent. The presence or absence of the stimulus as well as its location was randomly determined for each task and for each repetition.

The dual visual task was a shared attention task, with participants required to detect the presence or absence of a visual signal on each of two concurrent tasks. The task was run on a laptop computer.

In the \times portion of the dual task, an imaginary rectangle (14.92° visual angle) was centered on the computer screen. At each corner of this rectangle, two equal and intersected lines were drawn to form an \times (1.79° visual angle). The intersection of the two lines lay at the four corners of the imaginary rectangle. The target, when present, was a small line (1.19° visual angle) extending from a vertex of one of the four \times s. The line could originate from any of the four vertices of an \times , and extend in a direction of 0, 90, 180, or 270° . Thus, if the signal was present there were 16 possible line locations, all of which were equally likely. The participants responded by pressing, with the left hand, a marked YES or NO key on the left side of the keyboard to indicate the presence or absence of the signal.

In the $+$ portion of the dual task, a second imaginary rectangle (9.55° visual angle) was also centered on the screen, concentric to the outer rectangle, Task \times . Two intersecting lines of equal length were drawn in order to make a $+$ (1.79° visual angle) in which the intersection of the two lines lay at the four corners of the imaginary rectangle. The target, when present, was a small line (1.19° visual angle) extending from a vertex of one of the four $+$ s. The direction of the line (45, 135, 225, or 315°) could be on any of the four vertices of the $+$ as well as at any one of the four $+$ s. Again, there were 16 possible positions of the target, when present, all being equally likely. The participants responded by pressing, with the right hand, a marked YES or NO key on the right side of the keyboard to indicate the presence or absence of the signal.

The experiment began with a brief explanation of the dual task and visual examples of each of the two individual tasks alone. This was followed by a series of 32 trials that allowed participants to become familiar with the dual task environment. No data were recorded in these two practice periods.

Following the practice periods, a single portion of the dual task (the \times portion) was presented to each participant and difficulty levels of trials were manipulated such that performance in the baseline task for each individual was in the range of 80–90%. The difficulty levels were manipulated by adjusting stimulus duration. The duration was increased or decreased until the appropriate performance level was achieved. The initial stimulus duration was 1,000 ms. Average accuracy level was computed every 10 trials. Stimulus duration was increased by 50 msec, for the next set of 10 trials, if the average was below

80–90%, and was decreased by 50 msec, for the next set of trials, if the average was above 80–90%. The program ended when the average was in the 80–90% range.

With the baseline stimulus duration determined for each participant, the participant was ready to enter the environmental chamber, which was set at either 20 or 35 °C WBGT. The dual task required the participants to answer both tasks as to presence or absence of stimuli. The stimulus duration was held constant at the baseline value. After each trial, the participant was prompted to hit the space bar to initiate a new trial. Thus, the participant controlled the inter-trial duration. Participants were required to respond during the stimulus duration. Responses attempted after this time were logged as incorrect. Participation in the thermal environment lasted 60 min. Participants were instructed to work for the entire time.

4.4. Statistical Analysis

Differences between performances, at the 20 and 35 °C conditions, on the \times task, the + task, and the combined dual task were analyzed with Mann-Whitney tests for independent samples. Performance was the percentage of correct responses over a 1-hr period. Ability to equally share attention between the \times and + tasks, at the 20 and 35 °C conditions, was assessed by evaluating paired t tests (at $p < .05$ level) between the \times and + task performances at each condition. The t test was applied only to examine differences between the \times and + tasks.

4.5. Equipment

4.5.1. Environmental chamber

An environmental chamber was used, which permitted control of light, temperature, humidity and noise. The Wet Bulb Globe Temperature Index was employed, and a digital readout of temperature and humidity was checked with a Wet Bulb Psychrometer (Reuter-Stokes, USA).

4.5.2. Computer and software

The dual visual task was programmed on a Gateway 2000 Solo laptop computer, using the software package, Microcomputer Experimental Laboratories (MEL), from Psychological Software Tools (Pittsburgh, PA, USA).

4.5.3. Workstation design

A template, placed over the keyboard, revealed only the necessary keys for participant responses. A wooden hand rest prevented participants from inadvertently striking an incorrect key. Participants sat in an adjustable chair with the laptop placed on a table in front of them. Participants were instructed to adjust the seat and hand rest to their comfort.

5. RESULTS

The Mann-Whitney U Test indicated that performances on the \times task and the combined dual task were significantly better at the 20 °C condition than at the 35 °C condition ($p = .008$ and $p = .014$, respectively; Table 1). Performance on the $+$ task did not differ significantly between the 20 and 35 °C conditions ($p = .469$, Table 1). A paired t test between the \times and $+$ task performances at 20 °C indicated that these performances did not significantly differ ($p = .68$, Table 2). At 35 °C, however, a paired t test demonstrated a significant difference between the \times and $+$ task performances ($p = .003$, Table 3). Figure 1 displays the results graphically.

TABLE 1. Test Statistics From Mann-Whitney U Test, 20 Versus 35 °C

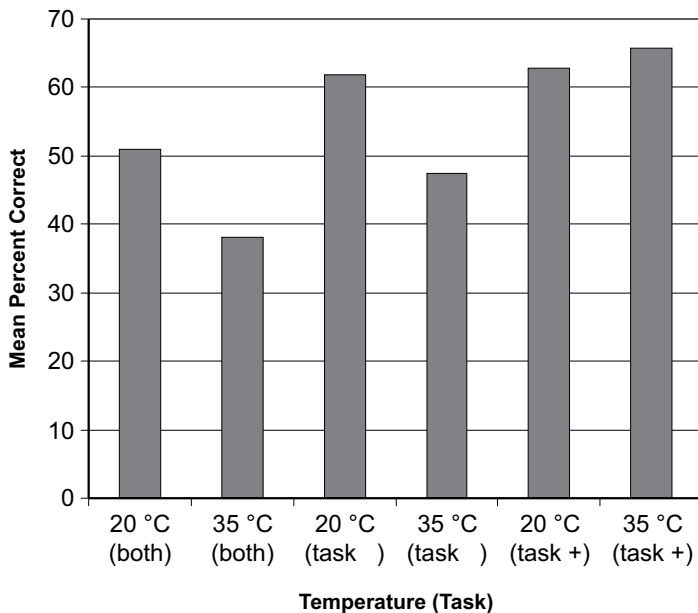
Statistics	Number of Trials	Accuracy Task \times	Accuracy Task $+$	Accuracy on Both
Mann-Whitney U	143.5	67.5	123.5	73.5
Wilcoxin W	296.5	220.5	276.5	226.5
Z	-0.034	-2.654	-0.724	-2.448
Significance (2-tailed)	.973	.008	.469	.014

TABLE 2. T Test on Task $+$ Versus Task \times in the 20 °C Condition

Paired Differences	20 °C				
Pair 1	M	SD	SEM	t	Significance (2-tailed)
Accuracy task \times					
	1.00	9.96	2.42	.414	.684
Accuracy task $+$					

TABLE 3. *T* Test on Task + Versus Task × in the 35 °C Condition

Paired Differences	35 °C				
Pair 1	<i>M</i>	<i>SD</i>	<i>SEM</i>	<i>t</i>	Significance (2-tailed)
Accuracy task ×	18.35	21.8	5.29	3.471	.003
Accuracy task +					

**Figure 1. Accuracy measures.**

6. DISCUSSION AND CONCLUSIONS

This study was motivated by the often contradictory findings in the existing literature on the effects of thermal stress on cognitive performance. Previous studies have generally not addressed the issue of individual variations in task performance. The present investigation has taken specific measures to account for individual task performance differences. This investigation attempted to control for individual differences in capacity by equating baselines of single task performance and to require similar capacity for each component of the task by selecting a dual visual-visual task.

The results of this study suggested that performance on a dual task, in which each component requires similar capacity, is adversely affected by

changing the thermal environment from 20 to 35 °C WBGT. Performance decrements were found for the × task component and for the combined dual task; however changing the thermal environment did not appear to affect performance on the + task component. Consequently, overall task performance decrements may be expected for a dual task, similar in nature to the one used in this study, upon changing the thermal environment from 20 to 35 °C WBGT; however, it remains possible that performance on one component of a dual task may tolerate the thermal environment change better than the other.

Paired *t*-tests results indicated that participants could devote similarly effective cognitive resources to both the × and + task components at 20 °C WBGT, but that they were significantly more effective on the + task component at 35 °C WBGT, despite demonstration, in a pilot study, that the × and + task components were equally loading the cognitive resources. It seems reasonable to conclude that very subtle differences in one or more aspect of two tasks may be sufficient to allow cognitive resources to be allocated and utilized more effectively for one task, under a more severe thermal environment. Consequently, performance on one task, under a harsher thermal environment, may be superior to performance on a seemingly similar task.

It can be hypothesized that the more central location of the + task component may be the characteristic that enabled participants of the current study to devote greater attention to this component under the 35 °C WBGT thermal condition.

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