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Effects of Thermal Stress on Dual Task Performance and Attention Allocation

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Effects of Thermal Stress on Dual Task Performance and Attention Allocation


Photo courtesy of the U.S. Army

The results of this study showed an inability to allocate attention, while maintaining accurate performance, under thermal stress.

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A visual-visual dual task was designed to test the effect of the thermal environment on dual task performance and attention allocation. The temperatures selected for testing were 20 and 35°C Wet Bulb Globe Temperature (WBGT) in experiment 1 and 25, 30 and 35°C Wet Bulb Globe Temperature (WBGT) in experiment 2. In experiment 1, 34 volunteers were randomly assigned to one of the two temperature conditions. A variable representing accuracy on both tasks was coded such that a correct response was assigned only if the participant answered correctly on both tasks. In experiment 2, 42 volunteers were randomly assigned to one of three temperature conditions and instructed vary the amount of attention allocated to each task. 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 one-hour testing period in each temperature condition. Participants' mean accuracy in the 35°C condition (38.18%) was substantially less than in the 20°C condition (50.88%). Further, statistically significant differences in performance were detected: in the ability to equally divide attention, effectively allocate attention, and in the relative divided attention cost under thermal stress.

For nearly five decades researchers have been investigating the effects of heat on human cognitive performance. Although much data has been collected, there is relatively little in the way of agreement either as to the true nature of the effects of heat, or an existing predictive mechanism of human performance under thermal stress. In fact, the findings across studies in this area are inconclusive. The contradictory results of individual studies have led several authors to review the research in an attempt to synthesize the various findings. Wing (1965) was an early contributor in this attempt. Grether (1973) analyzed over 50 studies, Ramsey and Morrissey (1978) over 100 studies, Kobrick and Fine (1983) over 90 studies, and Ram-

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sey (1995) compiled approximately 160 studies of heat and human performance cited in the literature and summarized them in a graphical format. Many thorough review articles currently exist (see also, Bell & Greene, 1982; Griffiths, 1975; Hancock, 1984; Pepler, 1963; Poulton, 1970; Ramsey, 1983).

The Heat Index

One area that has received much attention is the definition of the heat stimulus experienced by the subject. Various attempts have been made to weigh the different factors into a single index. One such attempt is known as effective temperature (ET), which incorporates dry bulb temperature, humidity and air speed. Dry bulb temperature is simply the reading of a typical mercury thermometer. Wet bulb temperature is obtained by placing a wet wick over the mercury bulb and when air passes over the wick, evaporation and consequently cooling occurs. The cooling which results from evaporation is nearly independent of air speed and can be used to calculate the humidity.

Another well-known index is the wet bulb globe temperature (WBGT), which also incorporates radiation. WBGT is calculated using:

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

where wbt is the wet bulb temperature, dbt is the dry bulb temperature, and gt is the globe temperature.

The globe temperature is obtained by taking a thin copper sphere, painted flat black, and placing a thermometer at the center and allowing the thermometer to reach equilibrium (Hygge, 1991). The choice of temperature scale has also been a source of confusion in the past. As Wet Bulb Globe Temperature has become something of the standard index in performance studies, this study employs the WBGT index.

Past Studies

Many surveys of the literature on heat stress and performance begin with historic studies by Mackworth (1950; 1961) and Pepler (1953). Mackworth (1950) investigated the effects of thermal environments on human performance over 45 years ago. Using the clock test, Mackworth (1950) studied the effects on subjects exposed to 70°F, 79°F, 87.5°F, and 97°F on the effective temperature index (ET). He discovered, as did Pepler (1953), that performance was better at moderate temperatures, rather than at either extreme.

Past experiments, in addition to employing different temperature index measures, also differ on the type and number of tasks performed. The more difficult the task and the more tasks performed simultaneously, the greater the decrements in performance, when any decrement was found.

In some research, subjects have performed simultaneous tasks with the results not always being decrements on more than one task. For example, Bursill (1958) found simultaneous tracking and signal detection decrements and Azer, McNall, and Leung (1972) reported central tracking and peripheral reaction time decrements associated with heat, while Bell, Provins, and Hiorns (1964) reported more missed signals but no vigilance deficits. In addition, Bell (1978) reported no effects of heat on a primary pursuit motor task but did find effects of heat on a secondary number-processing task.

Bursill (1958) used the concept of attentional narrowing under heat stress to account for performance decrement on a concurrent peripheral visual reaction time task. Azer, McNall, and Leung (1972) found that the field of awareness was not significantly affected by the heat stress. This conflicts with the findings of Bursill. It should be noted, however, that Bursill conducted his study at a higher Effective Temperature (ET).

Provins and Bell (1970) reported an initial beneficial effect for a temperature similar to that used in Bursill (1958), and in contradiction 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 pursuitmeter, which imposed great attentional demands, whereas Provins and Bell used a Serial Reaction Time (SRT) which is thought to be less difficult.

Iampietro, Chiles, Higgins and Gibbons (1969) describe time sharing ability on paired combinations of arithmetic, monitoring and tracking tasks as unimpaired after 30 minutes at 35°C, E.T. At a higher temperature, 38.3°C, E.T., a performance decrement was detected after approximately 5 minutes of exposure. These researchers indicated that this time-shared performance denies the subject the attentional resources, which are available in single task performance.

Some studies have reported facilitation of performance in heat. Most studies reporting facilitating effects of high temperatures also report performance decrements, although Nunneley, Dowd, Myhre, Stribley, and McNee (1979) found no decrement in performance on two tracking tasks and strictly facilitation of performance on another tracking task. Fine and Kobrick (1978) found slightly improved performance for 3 hr of exposure to heat for a variety of cognitive tasks with performance deteriorating beyond the 3-hr exposure. Other studies report only an initial stimulating effect of heat (e.g., Fine & Kobrick, 1978; Grether, 1973; Poulton & Kerslake, 1965; Provins & Bell, 1970), that declines over time.

Ramsey and Morrissey (1978) accounted for the type of work involved, duration, and temperature range. These researchers reviewed past data and developed isodecrement curves using regression. The results that are relevant to this study, indicated that in more complex dual tasks, decrements were almost independent of exposure time, though very sensitive to temperature increases above about 30°C.

Hancock (1989) indicated that in order to understand stress and performance, one must consider the type of demands placed on an individual by a particular task or group of tasks. It appears that human performance is much more complex that the inverted-U curve implies (see Figure 1 below). In contrast to this arousal model, Hancock describes a dynamic model based on the concept of adaptability in both physical and psychological terms.

In Hancock and Vasmatzidis (1998) the authors argue for task performance level to be the primary criterion for exposure. This challenges the basis of the current stress limits. The authors' contention is that efficient and error-free performance is the principle criterion for contemporary high-technology work. Further to continue exposure after behavioral performance breakdown, but before physiological breakdown is both hazardous and inefficient. They go on to present a description of these performance thresholds and how the thresholds based on performance may be incorporated into new safety standards.

A comprehensive study, which took into account the type of task involved and converted, where possible, all temperature measures over to WBGT is Ramsey (1995). By dividing task types into two categories, Ramsey (1995) acknowledged the differentially sensitive nature of task type. The two categories were:

1. Mental, cognitive, very simple perceptual motor, sensory, time estimation, reaction time, etc.;
2. Other perceptual motor tasks, including tracking, vigilance, vehicle or machine operation, complex or dual tasks, etc.

It is category 2 that is of main interest here, as it contains the classification dual tasks. Ramsey's conclusion in regard to the category 2 tasks (above) is that there is an onset of a statistically significant decrement in performance in the range 30°C-33°C WBGT. Examining Ramsey (1995) and taking a subsection of the studies, that employed complex tasks, reveals some interesting results. In the temperature range 33°C-37° C WBGT and the time of exposure range 0-120 min, there are 27 studies included. Of these 27, only six show a statistically significant decrement; nine of 27 show a partial decrement; 11 of 27 show no decrement; and one shows facilitation of performance. This collection of results is far from conclusive.

Studies on the effect of heat have generally yielded inconsistent results. This is partly due to the fact that different kinds of cognitive work are differentially sensitive to thermal stress (Hockey, 1986). The majority of the work in heat and human performance has been concerned with sustained attention or vigilance tasks. Studies in this area have employed a variety of temperature scales (e.g. Effective Temperature, WBGT, Dry Bulb Temperature); have required the performance of multiple tasks that may draw from different cognitive resources; were often ambiguous about task emphasis: and rarely, if ever, obtained a baseline of subject performance.

While many past surveys of the literature have focused on the first two difficulties mentioned above (i.e., Temperature index and Task type), the issue of individual differences in mental capacity has not been properly dealt with in the literature. Key studies from the literature are summarized in Table 1, below.

The area of most difficulty in past studies is the virtual absence of concern for individual differences in single task performance. Equating the baselines of performance in a study of this type is critical. If one is truly to get to the amount of attentional demand a stressor may place on a subject, one must first know that all subjects are performing at the same level with the same amount of available capacity in the control condition. Only by equating the baselines of performance across all subjects can we control the amount of remaining capacity or available resources.

The idea of equating baselines is not absent from the literature on attention in general. Many studies have employed this important methodology (e.g., Somberg & Salthouse, 1982; Irwin-Chase, 1995). It is simply not prevalent in the literature concerning heat and performance. A close analogy to equating the

Table 1: Summary of Relevant Studies

Study	Findings of Decrement	Findings of No Effect	Findings of Enhancement
Mackworth (1950)	Performance better at moderate, rather than at extremes		
Pepler (1953)	Performance better at moderate, rather than at extremes		
Bursill (1958)	Tracking and signal detection		
Azer, et.al. (1972)	Central tracking and peripheral RT		
Bell, et.al. (1964)	More missed signals	No vigilance deficits	
Bell (1978)	Effects only on secondary task	No effects on primary task	
Bursill (1958)	Attentional Narrowing		
Azer, et.al. (1972)		Field of awareness not affected	
Provins and Bell (1970)		No long-term performance breakdown	Initial beneficial effect
Iampietro, et.al. (1969)	Time-sharing decrement		
Nunneley, et.al. (1979)		No decrement on two tracking tasks	Facilitation on another tracking task
Fine and Kobrick (1978)	Performance deteriorating after 3 hrs. of exposure		Slightly improved on variety of cognitive tasks
Grether (1973)		Stimulation declines over time	Initial stimulating effect
Poulton and Kerslake (1965)		Stimulation declines over time	Initial stimulating effect
Provins and Bell (1970)		Stimulation declines over time	Initial stimulating effect
Ramsey and Morrissey (1978)	Dual-tasks very sensitive to >30 C, using regression		
Ramsey (1995)*	30-33 C yields decrement in performance on complex tasks		

*Taking a close look at the graph in Ramsey (1995), in temp. range 33-37 degrees C and exposure 0-120 minutes, we find 27 studies. Of these 27 studies, as labeled, only 6 show a significant decrement, 9 show a partial decrement, 11show no decrement, and 1 shows facilitation of performance.

baselines of performance is found in the concept of training. If subjects are trained to a specified level of proficiency, one could argue that the task is equally difficult for all participants. This, however, is not persuasive. The method of extended practice has been criticized as an invalid method of equating baselines (Guttentag, 1989; Lane, 1979; Somberg & Salthouse, 1982). Subjects will invariably differ in the time taken to achieve a threshold of performance and this difference in the amount of practice may exert significantly on the ability to detect overall differences in performance. Any differences may, in fact, be due to differences in the level of automaticity.

The basis of this study, consequently, was to equate the baselines of single task performance. The baselines were gathered on only a single task and either task could have been chosen. An earlier study (Irwin-Chase, 1995) indicated that each task (both visual in nature) was equally discriminable. It can be therefore assumed that performance on one single task should approximately equal performance on the second task. The baseline was represented as duration of stimulus presentation. Once the baseline was obtained, it was used for each subject throughout the study.

OBJECTIVES

The present study aimed to investigate possible differences in dual task performance and ability to allocate attention at different 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.

METHOD

Participants

Thirty-four University of Louisville students volunteered to participate for Experiment 1 in the present study, and were equally divided into two groups. One group was exposed to 20°C (WBGT) thermal condition during testing, while the other was exposed to 35° C (WBGT) condition. In Experiment 2, 42 volunteers were randomly assigned to one of three temperature conditions and instructed vary the amount of attention allocated to each task. Individual differences in single task performance were controlled by equating the baselines of single task performance. The participants wore long pants and short sleeve shirts when exposed to both thermal conditions.

Experimental Design

This study used a between subjects 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.

Experimental Procedure

In the procedure for the present study (adapted from Somberg and 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 subjects responded, for each individual task, as to whether a stimulus was present or absent. The presence or absence of the stimulus as well 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 X portion of the dual task, an imaginary rectangle (1.7 cm X 2.4 cm) was centered on the computer screen. At each corner of this rectangle, two 0.4 cm lines intersected to form an 'X'. The signal, when present, was a small line (0.14 cm) extending from the center of any one of the four X's. The line could originate from any of the four vertices of an X, and extend in a direction of 0°, 90°, 180°, or 270°. Thus, if the signal was present there were sixteen 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 (1.0 cm X 1.4 cm) was also centered on the screen, concentric to the outer rectangle. At each corner of this inner rectangle, two 0.3 cm lines intersected to form an '+'. The signal, when present, was a small line (0.1 cm) extending from the center of any one of the four +'s. The line could originate from any of the four vertices of a +, and extend in a direction of 45°, 135°, 225°, or 315°. Thus, if the signal was present there were sixteen possible line locations, all of which were 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 warm-up periods. Following the warm-up periods, a single portion of the dual task (the X 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 1000 msec. 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 subject 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 subject was prompted to hit the space bar to initiate a new trial. Thus, the subject 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 minutes. Participants were instructed to work for the entire time.

Equipment

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.

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 (City, State).

Workstation Design

A template, placed over the keyboard, revealed only the necessary keys for subject responses. A wooden hand rest prevented subjects 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.

Table 2: Test Statistics from Mann-Whitney U Test (20°C vs. 35°C)

	Number of Trials	Accuracy Task X	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	-.034	-2.654	-.724	-2.448
Sig. (2-tailed)	.973	.008	.469	.014

Table 3: *t* Test on Task X vs. Task + in the 20° C Condition

Paired Differences	20 Degrees				
Pair 1	Mean	Standard Deviation	SEM	*t*	Sig. (2-tailed)
Accuracy Task + vs. Accuracy Task X	1.00	9.96	2.42	.414	.684

Table 4: *t* Test on Task X vs. Task + in the 35°C Condition

Paired Differences	35 Degrees				
Pair 1	Mean	Standard Deviation	SEM	*t*	Sig. (2-tailed)
Accuracy Task + vs. Accuracy Task X	18.35	21.8	5.29	3.471	.003

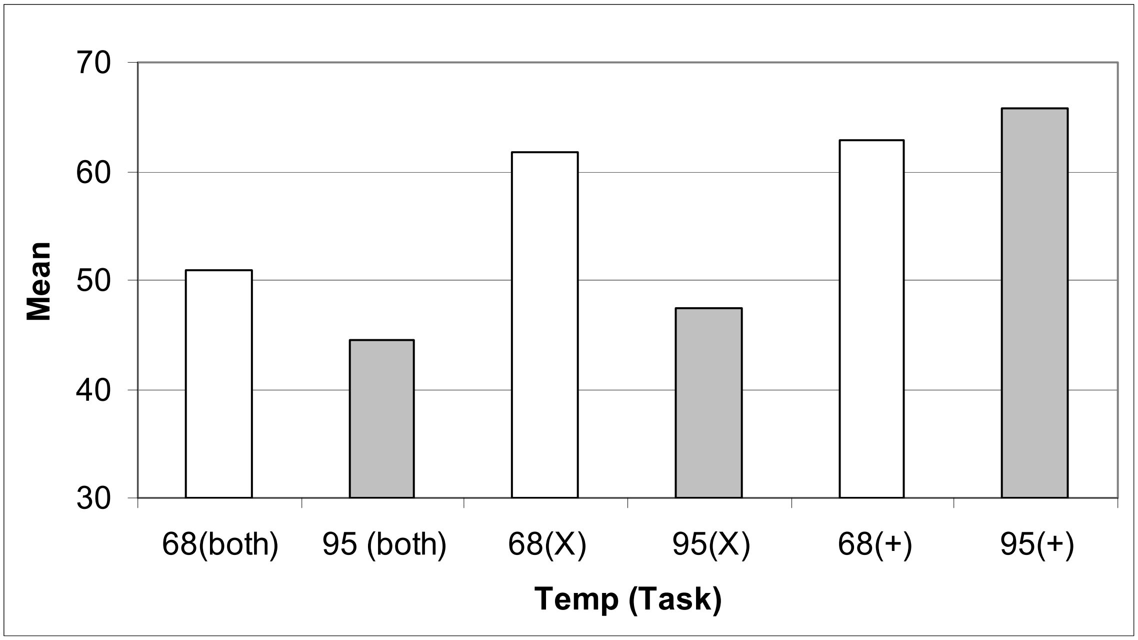

Figure 1. All accuracy measures.

RESULTS

Experiment 1

The Mann-Whitney U Test indicated that performances on the X task and the combined dual task were significantly better at the 20°C condition than at the 35°C condition ($p = 0.008$ and $p = 0.014$, respectively) (Table 2). Performance on the + task did not differ significantly between the 20°C and 35°C conditions ($p = 0.469$) (Table 2). A paired t-test between the X and + task performances and 20°C indicated that these performances did not significantly differ ($p = 0.68$) (Table 3). At 35°C, however, a paired t-test demonstrated a significant difference between the X and + task performances ($p = 0.003$) (Table 4). Figure 1 illustrates the results in a graphical format.

Experiment 2

Attention-sharing. In a separate, repeated-measures 3 x 2 ANOVA with Temp and Task as factors, only one emphasis condition (the 50/50) was used. The main effect of Temperature was significant $F(2, 39) = 86.32$, $p < .05$. There were significant differences detected due to heat, $F(2, 39) = 9.99$, $p < .05$, in the Task by Temp interaction term. The Scheffe post-hoc statistic was computed to compare temperature conditions within individual emphasis conditions. All temperature comparisons for every emphasis conditions for Task X were significant. Nearly all of the post-hoc comparisons for Task + were significant, however in the Task + 0 condition, no differences were significant. It appears that as in experiment 1 the performance on Task + was both more accurate and more stable than for Task X under heat. This result was found in spite of the fact that subjects perform equally well on both tasks under comfortable conditions.

Attention Allocation. A 3 x 2 x 5 repeated measures ANOVA was conducted with three levels of temperature (i.e., 25-, 30-, and 35^{o}C WBGT), two levels of task (X and +), and five levels of emphasis (i.e., 100/0, 75/25, 50/50, 25/75, and 0/100). A main effect of Task was significant, $F(1, 39) = 49.38$, $p < .05$. There was also a significant main effect of Emphasis (condition), $F(4, 156) = 188.59$, $p < .05$. Also significant were the Task by Temp, $F(2, 39) = 12.89$, $p < .05$ and Emphasis by Temp $F(8, 156) = 2.428$, $p < .05$ interactions.

There was a clear detrimental effect of heat and limiting analysis to the 50/50 condition replicates the findings from Experiment 1. The attention sharing aspect of Experiment 1 is a special case of attention allocation, known as the equal emphasis condition (50/50).

Performance Operating Characteristics (POC). To adequately measure the effect of heat on divided attention, it is necessary to examine the extent to which a subject's performance on one task (i.e., Task X) varies as a function of performance on another concurrent task (i.e., Task +). Norman and Bobrow (1975) introduced Performance Operating Characteristics (POC) as a method of conducting this type of analysis. In a dual task situation, performance on Task X can be plotted as a function of performance on Task +.As more resources are allocated to one task, the available resources for performance of the concurrent task are diminished. Consequently, the data may display a negative correlation between levels of performance on the two tasks (Somberg and Salthouse, 1982). Sperling (1978; Sperling & Melchner, 1978) and Kinchla (1980) have derived empirical POCs by instructing subjects to vary the relative emphasis given to each of the concurrent tasks. Differences in divided attention ability can be detected by the existence of separate POCs.

One can plot a Functional Performance Region (FPR) from subject performance data. The FPR is the area mapped out by performance at the extreme ends of attention allocation. Performance on Task X is plotted as a function of performance on Task +. A rectangle is then formed by treating performance on the X100/+0 condition as a point in the upper left corner of the rectangle and performance on the X0/+100 condition as a point in the lower right corner of the rectangle. The intermediary emphasis conditions are plotted accordingly. If subjects were perfectly able to allocate their attention, the upper left and lower right points would be (0, 100) and (100, 0), respectively. Further, all three intermediary points would be located in the upper right corner of the rectangle (i.e., in the (100, 100) position) if optimal performance were achieved.

The extent to which the (25, 75), (50, 50), and (75, 25) conditions are shifted down and to the left reflects a "cost" of attending to more than one task at a time. The region of the FPR lying above and to the right of the performance curve is known as the region of Divided Attention Cost (DAC). The area of the FPR can be easily calculated with the formula:

(max. X – min. X) x (max. + – min. +).

Taking the mean performance of all participants in temperature 1 (25°C WBGT) of Experiment 2 as an example leads to the following results as shown in Table 6.

Table 5: Experiment 2 Summary Data

Temp	FPR	DAC	Relative DAC
25	928.16	268.82	0.29
30	738.58	300.29	0.41
35	629.40	334.01	0.53

Note. Temperatures in °C. FPR = (max. task X – min task X) x (max. task + – min. task +) (78.88 – 51.13) x (86.35 – 52.90) = 928.16.

Once the FPR is calculated, the remaining points can be inserted and the area above and to the right of the resulting curve can be calculated. This area is termed the Divided Attention Cost (DAC). The DAC is typically calculated by dropping a series of triangles and rectangles and summing their areas together. Any method that accurately determines the area above the curve, but inside the total FPR would suffice. The Relative DAC is simply the ratio of DAC to that particular subject's FPR. The Relative DAC (RDAC) is a measure of divided attention cost relative to the individual's overall Functional Performance Region (FPR), see Table 5.

Performance in the three temperature conditions at each of the five emphasis conditions is given below in Tables 6, 7, and 8.

A one-way ANOVA with three levels of temperature was conducted on the Relative Divided Attention Cost (RDAC) and differences were significant, F(2, 30) = 3.365, $p < .05$. Subjects in the highest temperature condition demonstrated the highest Relative DAC and differences between all temperature conditions were significant. The overall performance data is presented in the graphs below for temperature conditions 25-, 30-, and 35°C in Figures 3, 4, and 5 respectively.

As in Experiment 1, subjects were unable to perform attention sharing in the 35°C condition. Overall performance was significantly poorer in both the 30- and 35°C conditions, compared to the 25°C condition.

Referring to Table 1 (Summary of Past Studies), the results from the experiments outlined here are in moderate agreement with only 6 of the articles listed in the table. As a significant difference in performance was found, no significant enhancement, and perceptual (attentional) narrowing was detected; the results are in disagreement with several of the studies listed.

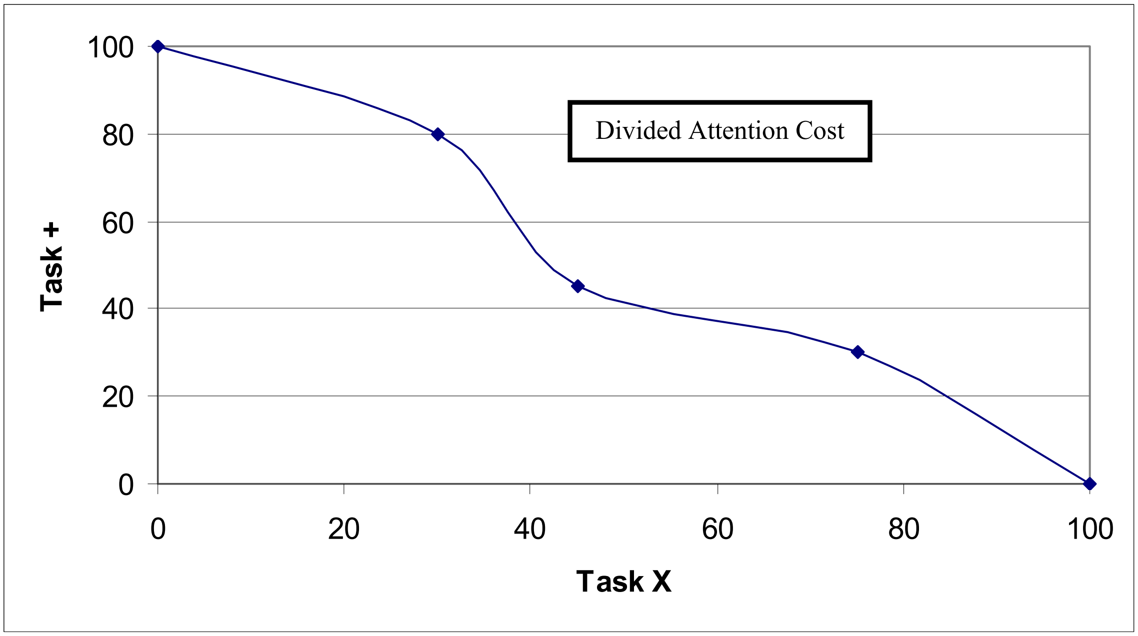

Figure 2. Divided attention abilities (FPR).

Table 6: Mean Performance in the 25°C Condition

Emphasis	100X/0+	75X/25+	50X/50+	25X/75+	0X/100+
Task X	78.88	76.11	69.53	61.80	51.13
Task +	52.90	64.48	78.15	83.45	86.35

Table 7: Mean Performance in the 30°C Condition

Emphasis	100X/0+	75X/25+	50X/50+	25X/75+	0X/100+
Task X	78.88	76.11	69.53	61.80	51.13
Task +	52.90	64.48	78.15	83.45	86.35

Table 8: Mean Performance in the 35°C Condition

Emphasis	100X/0+	75X/25+	50X/50+	25X/75+	0X/100+
Task X	78.88	76.11	69.53	61.80	51.13
Task +	52.90	64.48	78.15	83.45	86.35

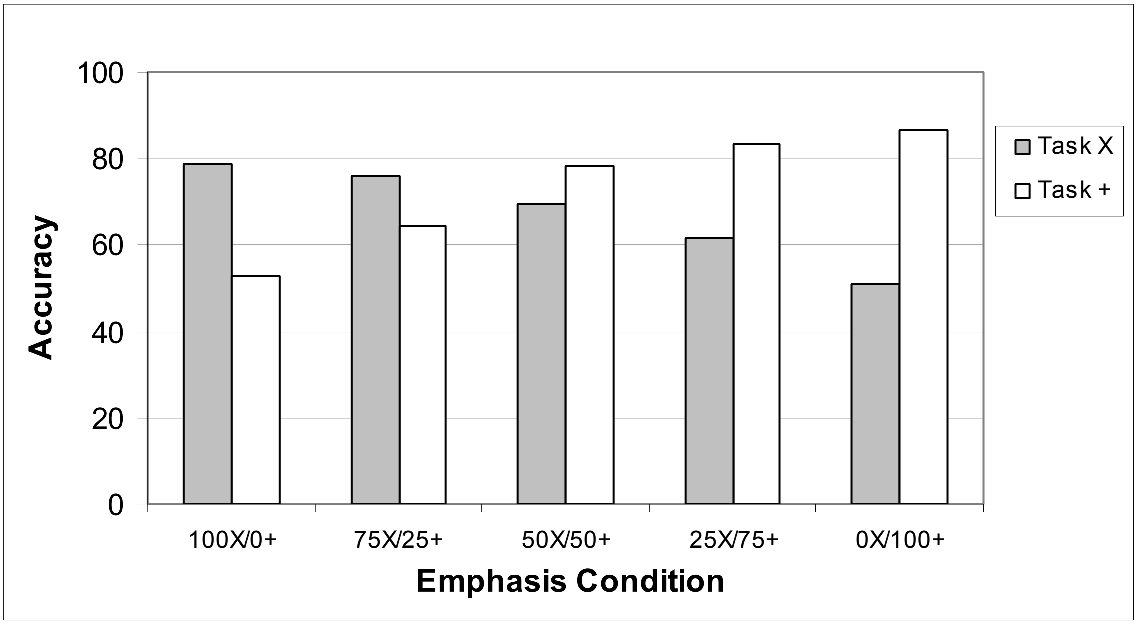

Figure 3. Performance for 25°C.

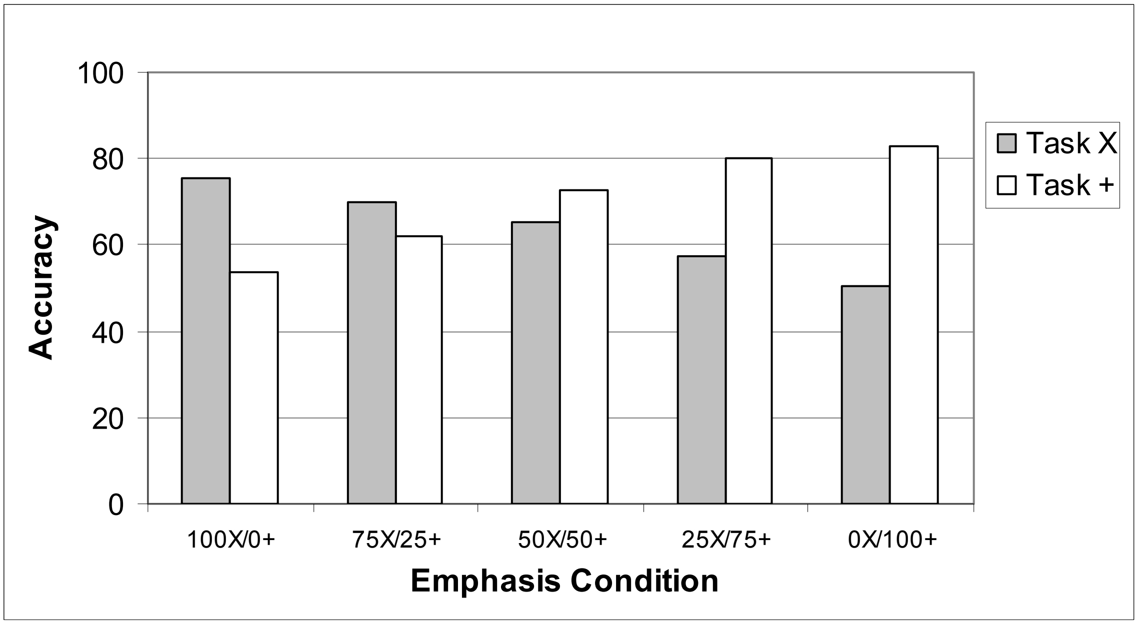

Figure 4. Performance for 30°C.

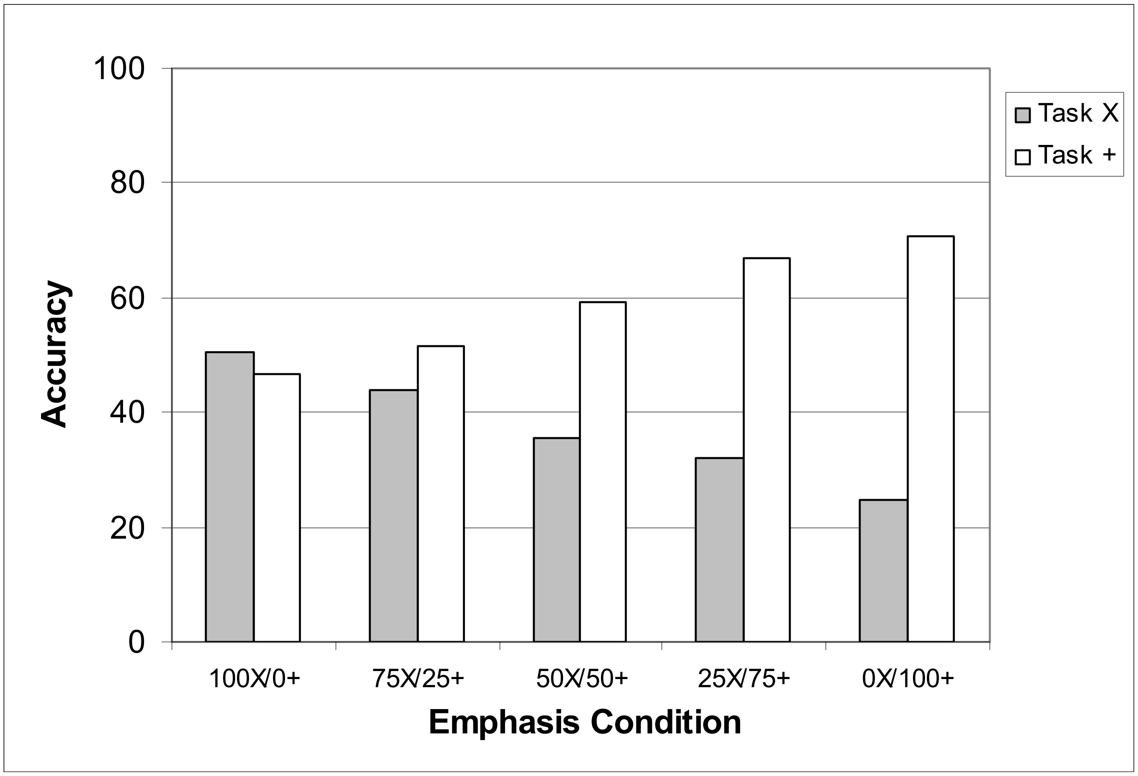

Figure 5. Performance for 35°C.

The ones for which there is some agreement are Bursill (1958); Azer, et.al. (1972); Bell, et.al. (1964) [but not Bell (1978)]; Iampietro, et.al. (1969); Ramsey and Morrissey (1978); and to an extent Ramsey (1995).

One theme that loosely binds the aforementioned studies is an awareness of the differentially sensitive nature of various cognitive tasks. Simple tasks seem to be relatively unaffected by heat. More complex and dual tasks appear to be more sensitive to the effects of heat, as one might think.

In summary, the results of this study showed:

- a significant negative effect on performance due to heat,
- some evidence of attentional narrowing,
- an onset of performance decrement at 30°C WBGT,
- inability for subjects to equally divide their attention under thermal stress,
- an inability to allocate attention, while maintaining accurate performance, under thermal stress,
- a need to control for individual differences in task performance,
- efficacy of equating the baselines of task performance to control for these individual differences.

The negative effects of heat included: an inability to equally share attention in both the 30- and 35-degree conditions. While the group data is either monotonically increasing or decreasing, it appears that subjects understood the allocation instructions. However, performance in terms of accuracy was poorer in both the 30- and 35°C conditions than in the 25°C condition. Subjects in the 30- and 35°C conditions demonstrated a lower FPR, while having a higher DAC. This higher ratio in higher temperature conditions yielded significant differences in Relative Divided Attention Cost (RDAC). The cost, computed in RDAC, for attending to more than one task in the 30- and 35°C conditions was significantly higher than in the 25°C degree condition.

CONCLUSION

The contradictory findings in the existing body of literature, while quite likely due to a variety of factors, are possibly due, in part, to the lack of concern over controlling for individual differences in capacity. A dual visual-visual task was chosen so that the pool of capacity being tapped would be the same for each portion of the task. Until the true nature of the effect of heat on human performance is determined, researchers are getting ahead of themselves by combining more than one environmental stressor, by selecting seemingly arbitrary tasks that may or may not tap different pools of cognitive resources, and by not controlling for individual differences in cognitive capacity.

Clear differences due to heat existed in Experiment 1. Performance was significantly worse for those in the 35°C condition. Experiment 2 presented some interesting results. The overall ANOVA statistical tests were significant and individual post-hoc tests indicated significant differences between the three temperature conditions at all five levels of emphasis for Task X and for most every combination of Task +. When the 50/50 condition, an example of attention sharing (as in experiment 1), was analyzed significant differences were also detected in 25°C vs. 35°C as well as 30°C vs. 35°C. Collapsing across emphasis conditions produced similar significant results between temperature conditions.

Performance in terms of accuracy was poorer in both the 30- and 35°C conditions than in the 25°C condition. Subjects in the 30- and 35°C conditions demonstrated a lower FPR, while having a higher DAC. This higher DAC coupled with a smaller FPR, yielded significant differences in Relative Divided Attention Cost (RDAC). The cost for attending to more than one task in the higher temperature condition was significantly higher.

This study is further evidence of detrimental effects of heat and furthers the premise that individual differences in performance may play a role in the often, contradictory findings in the literature. It is clear that further analysis is necessary before heat stress standards can be based upon a clear consensus of data. The inability of subjects to equally divide their attention under thermal stress, as well as their difficulty exhibited when called upon to allocate attention, point to clear negative effects on performance due to heat.

The POC analysis was especially striking. The Divided Attention Cost (DAC) was significantly greater in both the 30- and 35°C conditions. In these higher temperature conditions the ability to properly allocate attention was also negatively impacted. This all serves as further evidence of the negative impact of thermal stress. Of note, is the fact that performance, in certain analyses, was negatively impacted even at the middle temperature of 30°C WBGT. Further investigations into the negative impact of environmental conditions should consider individual differences in task performance and control, whenever possible for these confounding effects. Equating the baselines of task performance is one such way of eliminating much of the confounding effect of individual differences in ability and cognitive resource availability.

Future directions for this research include examining the effect of multiple stressors, such as noise, lighting and fatigue in combination with environmental heat. Also, this methodology of equating baselines of task performance could be extended to various types of tasks, such as auditory tasks. A technique to control for individual differences in task performance could prove quite useful in experiments, which take as their aim the description of the effects of stress on human cognitive performance.

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