THE EFFECTS OF DIFFERENT THERMAL ENVIRONMENTAL CONDITIONS ON THE PERFORMANCE OF AUTOMATIC AND CONTROLLED PROCESSES

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This research investigated the effect of four thermal environmental conditions on the performance of automatic and controlled processes. The environmental conditions included temperature and relative humidity combinations of (1) 25°C with 60% r.h., (2) 33°C with 38% r.h., (3) 33°C with 66% r.h., and (4) 33°C with 92% r.h.. These combinations corresponded to vapor pressures of 15 mm Hg, 15 mm Hg, 25 mm Hg, and 35 mm Hg respectively.

To analyze the data from both the automatic and the controlled processing task, data were transformed to an equivalent scale using proportion scores. F-values well below 1 indicated that variability dominated the experiment. Type of processing was the only significant factor in the experiment.

Upon analyzing each task separately, it was discovered that the major source of variability was the controlled processing task. The automatic processing task had no significant main effects or interactions. The three levels of vapor pressure were almost found to be significantly different ($Pr>F=0.07$). All analyses of the controlled

processing task were dominated by variability.

A larger sample size would be needed to find statistically significant differences in observed means and standard deviations. Power analyses indicate hundreds, and in some cases even thousands, more subjects would need to be run for the controlled processing task or proportion score analyses. Although fewer subjects are needed for the automatic processing task, the power of the experiment was very low.

Future researchers are advised to improve or replace the controlled processing task and to use more subjects. In addition, the variability of the experiment should be reduced by (1) choosing a more homogeneous group of subjects, (2) providing an incentive to the subjects to provide a constant level of effort, and (3) using more extreme environmental conditions.

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INTRODUCTION

PROBLEM STATEMENT

Many people live and work in places where the environment is hot and humid. High temperatures and high levels of relative humidity characterize many industries, including those industries that transfer energy into heat. Exposure to extreme heat may cause feelings of discomfort as well as dangerous physiological reactions.

Many previous studies have attempted to predict the effect of heat stress on human performance. Human performance during physical activity is fairly predictable, but human performance during mental activity has not been predictable. Although past research has been inconsistent, it is generally agreed that as heat stress increases, human performance decreases. Several studies have found that humidity may affect performance (Azer, McNall, and Leung, 1972; Pepler, 1958, 1959; Kim, 1991). However, the effect of high levels of humidity has not been adequately isolated from high levels of temperature.

Some past research indicates that less skilled operators seem to be affected by heat stress more than their highly skilled peers. Hancock (1986a) suggested that automatic and controlled processing may account for the difference in performance. Automatic processing is the method in which people deal with highly consistent or routine stimuli, while controlled processing is used for unexpected stimuli and requires much more attention by the operator (Schneider and Shiffrin, 1977b). Earlier studies by Hancock

(1981, 1982a, 1982b) indicated that heat stress affects tasks that require an operator's attention.

The purpose of this research was to investigate the effect of four different levels of thermal environmental conditions, defined by temperature and vapor pressure, on the performance of an automatic processing task and a controlled processing task. The automatic processing task consisted of a typing test, and the controlled processing task consisted of working computerized puzzles. The research objectives were to determine (1) if environmental conditions have an effect on the performance of an automatic processing task or a controlled processing task, (2) which environmental element caused the effect, if any, and (3) the effect of the environmental condition on automatic processing versus controlled processing.

LITERATURE REVIEW

HEAT STRESS

Discussion

Heat stress occurs when heat is not eliminated adequately from the body. Some industrial processes, such as the production and casting of steel, iron, and aluminum, transfer energy into heat (Rodahl and Guthe, 1988). The deep mining industry, which includes the mining of coal and gold, does not produce heat, but the work environment itself is very hot (Rodahl and Guthe, 1988). Not only are the temperatures very hot, but because the underground rocks must often be sprayed with water to avoid dust disease in the lungs, the humidity is often extremely high (Sloan, 1979).

No specific point at which heat stress occurs has been identified. Certain groups of people are more likely to suffer from heat stress. At high levels of thermal stress, tolerance decreases in older individuals (Henschel, 1976). According to Yousef (1987), decreased tolerance is primarily a result of lower aerobic capacity and inadequate circulatory-cardiovascular adjustments. Often, older individuals also have a delay in the onset of sweating and a lower sweat rate, resulting in greater heat storage and a longer time for recovery (Minard, 1973). People that are less acclimatized to the environmental conditions are also more likely to suffer heat stress because several days' exposure to a hot environment enables one to better tolerate heat. This acclimatization is associated with a lower skin temperature, an increased production of sweat, and a reduced heart rate

(Poulton, 1970).

Gender is another factor that may determine who will suffer from heat stress. Burse (1979) indicated that women have a slightly higher body temperature, a higher heart rate, and a lower sweat rate than men. However, Burse (1979) also stated that women do not exhibit the phenomenon of sweat suppression, which is the decline in sweat rate during an exposure. Training in the performance of a task is yet another factor that may determine who will be affected by heat stress. Trained individuals are better able to adjust to heat than those who are untrained (Rodahl and Guthe, 1988).

When the body is exposed to a hot environment, heat is produced. The production of heat results both from the heat generated by the person and heat exchanged with the environment (McBlair, Rumbaugh, and Fozard, 1955). By a process called homeostasis, the body attempts to maintain a core (deep body) temperature of approximately 37°C. If the core temperature deviates even a few degrees, physical and mental work capacities are impaired (Kroemer, Kroemer, and Kroemer-Elbert, 1986). Normal variations of the core temperature can be as much as 1°C throughout the day (Sloan, 1979).

The distribution of blood between the core and the shell of the body affects heat distribution. Blood distribution occurs when the body attempts to maintain the core temperature by changing the periphery (Haymes and Wells, 1986). Vasodilatation occurs when heat is directed away from the core and towards the shell by dilating skin vessels and fully opening superficial veins (Haymes and Wells, 1986). This results in as much as a fourfold increase in blood flow to the shell.

Heat Exchange with the Environment

The body exchanges heat with the environment through four main methods: (1) radiation, (2) conduction, (3) convection, and (4) evaporation (Sanders and McCormick, 1987).

The method of radiation involves heat exchange between two surfaces, such as between a window pane and a person's skin (Kroemer et al, 1986). This heat exchange only occurs if there is a temperature difference between the surfaces, and heat is always radiated from the warmer surface to the colder surface. The amount of heat exchanged depends on factors such as the absorption characteristics of the receiving body, the surface areas participating in the exchange, and the frequency and admission characteristics of the warmer surface (Kroemer et al, 1986).

Heat exchange through conduction occurs when the skin contacts a solid body such as a piece of iron (Kroemer et al, 1986). Heat energy flows via contact from the warmer body to the colder one in an attempt to achieve a thermal equilibrium. Various conduction characteristics and insulation sources determine the amount of heat conducted (Kroemer et al, 1986).

Heat exchange through convection occurs when human skin contacts air and fluids (Hertig, 1973). Again, the heat energy flows from the warmer surface to the colder surface. The amount of heat exchange is a function of (1) the temperature difference between the skin and the air or fluid, and (2) the movement of air or fluid past the surface. Clothing is an attempt to reduce convection, as it traps air (Hertig, 1973).

The most important protection from heat is the evaporation of sweat (Gagge, Stolwijk, and Nishi, 1971), which is the process where water molecules transfer from a liquid state to a vapor state (Kroemer et al, 1986). Heat in the body is lost when moisture (sweat) evaporates from the skin. The evaporative rate depends on the rate of sweat production (Candas, 1979). Vapor pressure is an extremely important factor with respect to evaporation because, in high relative humidity conditions, the air contains a large percentage of water. As a result, the evaporative heat loss is limited by the capacity of the ambient air to accept additional moisture (Hertig, 1973). At temperatures above 85°F, evaporation of sweat accounts for almost all of the heat lost from the body (Rohles, 1975). Sweating at very high levels is usually accompanied by active vasodilatation, which may result in the swelling of the extremities, skin irritation, headaches, and throbbing due to increased blood flow and heart action (Gagge et al, 1971).

Measurement of the Environment

Many heat stress indices can be used to evaluate the environment. Table 1 presents some of the heat stress indices outlined by Goldman (1988). A more detailed explanation of these indices is presented in Appendix A. Various studies evaluating different heat stress indices have had conflicting results (Brief and Confer, 1971; Kerslake, 1972).

TABLE 1
Some heat stress indices

Index	Author
Effective Temperature	Houghton and Yaglou (1923)
Operative Temperature	Winslow et al (1937)
Corrected Effective Temperature	Bedford (1946)
Predicted 4-hour sweat rate	McArdle et al (1947)
Heat Stress Index	Belding and Hatch (1956)
Wet Bulb Globe Temperature	Yaglou and Minard (1957)
Wet Globe Temperature (WGT)	Botsford (1971)
Standard Effective Temperature	Gagge et al (1971)

Heat Strain

Heat Strain is the subject's response to both heat stress and physiological characteristics of the subject (Kerslake, 1972). The difference between heat stress and heat strain can be seen by comparing it to a physical object, such as a spring, that is subjected to an outside force that compresses it (Kerslake, 1972). The outside force is the stress, and this stress can be described independently of the strain that it produces. The strain that is induced on the spring depends on the physical properties of the spring. For people, the environmental conditions make up the heat stress, while the physiological characteristics of the subject determine the strain that will be induced on the subject. Thus, heat stress that produces a certain level of heat strain in one subject may not produce the same level of heat strain in another.

There are several signs of excessive heat strain on the body. First, sweat rate increases with the strain on the body (Kroemer et al, 1986). Second, increased strain results in an increase in the circulatory activities, primarily the heart rate. Third, the water balance in the body can be affected by heat strain. Dehydration can severely affect the functioning of the body, and, therefore, physical performance.

Other reactions indicate heat strain, but because they are primarily associated with discomfort, these reactions are not considered as important as those described above. These reactions include (1) sensations of discomfort, (2) skin eruptions ("prickly heat") associated with sweating, and (3) heat cramps (Kroemer et al, 1986). While low heat stress levels cause discomfort and fatigue, high levels of heat stress are important to study because of their ability to impair performance. Some of the disorders associated with heat stress, as described by Kroemer et al (1986), can be seen in Table 2.

TABLE 2
Heat illness

Disorder	Symptoms
Transient Heat Fatigue	Decrease in Performance
Heat Rash ("Prickly Heat")	Rash; Discomfort
Fainting	Blackout; Collapse
Heat Cramps	Muscle Spasms
Heat Exhaustion	Weakness; Giddiness; Pale; Moist Skin; Nausea; Headache
Heat Stroke	Hot, dry skin; Confusion; High Core Temperature; Loss of Consciousness; Death

Evidence of impaired performance exists when the body is exposed to excessive heat, in that an additional task is given to the blood. Normally the blood must transport oxygen throughout the body, but under excessive heat conditions the blood must also transport heat from the interior of the body to the skin where it can be dissipated (Nielsen, Savard, and Saltin, 1987). This second function is done to prevent overheating. Temperature regulation takes priority over oxygen transport, which means that the ability of the blood to transport oxygen throughout the body is decreased under excessive heat conditions (Nielsen et al, 1987). The capacity of the heart is not great enough to meet the combined demands of exercise and heat stress (Rowell, 1987). When physical work is performed, the demand for oxygen to muscles is increased, and if the available supply is decreased as a result of excessive heat conditions, the muscles will be forced to work without adequate oxygen. Williams, Wyndham, and Morrison (1967) saw an increased lactate production in subjects exercising in the heat as compared to those exercising in a neutral environment. This study indicated that the function of oxygen transport is of secondary importance to the temperature regulation of the body. Muscles can work anaerobically, which is without oxygen, but this will result in the buildup of lactic acid which may eventually require termination of the muscular work (Kroemer et al, 1986).

Thermal Comfort

ANSI/ASHRAE Standard 55-1992 covers thermal environmental conditions for human occupancy. The purpose of the standard is to specify the combinations of indoor space environment and personal factors that will produce thermal environmental conditions acceptable to 80% or more of the occupants within a space (ASHRAE, 1992). ASHRAE defines thermal comfort as the condition of mind that expresses satisfaction with the thermal environment (ASHRAE, 1992). ASHRAE also states that thermal comfort requires subjective evaluation. This means that what is comfortable for one person may not be comfortable for another. Environmental factors considered are temperature, thermal radiation, humidity, and air speed (ASHRAE, 1992). Personal factors include clothing and activity (ASHRAE, 1992).

The range of environmental conditions that are perceived as comfortable is commonly called the thermal comfort zone. The thermal comfort zone is not dependent on the climate in which a person lives (de Dear, Leow, and Ameen, 1991a; de Dear, Leow, and Ameen, 1991b). This means that people cannot naturally adapt to warmer climates (de Dear et al, 1991a).

The current study consisted of subjects performing sedentary activities while wearing summer clothing. ASHRAE (1992) provided a chart representing the acceptable ranges of temperature and humidity for people in this situation. The upper bound of the range is 79°F ET^* (26°C ET^*). The highest acceptable level of humidity in the range is 60%. All of the ranges are based on a 10% dissatisfaction criteria (ASHRAE, 1992).

Clothing can be extremely important in determining the operative temperative range. In one work situation mentioned by ASHRAE (1992), a difference of 0.45 clo caused the operative temperature to increase by 3°C.

Temperature is more important than humidity in determining the thermal sensation (Rohles and Nevins, 1971; Rohles, Woods, and Morey, 1989). There is, however, a tradeoff between humidity and temperature. For example, a room with a given temperature and relative humidity may be perceived as being the same as a room with a lower temperature and higher relative humidity (Nevins, Gonzalez, Nishi, and Gagge, 1975; Rohles and Nevins, 1971).

Along with determining the proper levels of the thermal environment for comfort, there are other considerations. For example, certain levels of humidity can promote the growth of mold and fungi. Green (1979) found that higher humidity levels cause a reduction in colds, and, therefore, a reduction in absenteeism. Respiratory infections increase at levels below 40%, but levels above 50% have not been adequately investigated (Sterling, Arundel, and Sterling, 1985). Studies focused on the performance of task in a thermally comfortable zone have had varying results (McNall, 1979; Woods, Winakor, Maldonado, Alaghehband, and Adams, 1981).

AUTOMATIC AND CONTROLLED PROCESSES

Various studies of the effect of environmental stress on skilled performance have generally found that skilled performers are less affected by environmental stress than less skilled counterparts. Norman (1982) suggested that poor performance may result from paying too much attention to the application of relevant information. Norman further concluded that skilled performers do not need to concentrate on their actions because they have learned their skills so well that they can perform the task with a minimal amount of conscious attention, almost as if the task was automatic. With repetition, the role of attention is reduced and the entire task may eventually be performed while attention is focused elsewhere (LaBerge, 1975). Dual process attention theories propose that some processes develop in which attentional resources are not reduced when doing the process (Schneider and Fisk, 1982a). Dual process theories assume that there are two qualitatively different forms of human information processing: (1) automatic and (2) controlled.

"Automatic processing" is the method in which people deal with highly consistent, common, or routine stimuli (Schneider and Shiffrin, 1977b). Schneider and Fisk (1982a) added that automatic processing is a learned associative sequence in long term memory. Automatic processes are fast, parallel, fairly effortless, and are not limited by short term memory capacity (Schneider and Fisk, 1982a). Schneider and Shiffrin (1977a) stated that in automatic processes the subject initiates the process, but does not directly control it. Norman (1982) used typing as an example of automatic processing. Norman described asking skilled typists how they type a space: Do they always use the same thumb, or do they alternate thumbs according to the particular words they are typing? According to Norman, many typists do not know what they do, and must answer the question by mentally simulating typing and "observing" how they use the space bar. This supports the idea that the skilled typists type a space automatically, without conscious thought as to how to do it.

In contrast to automatic processing, "controlled processing" is used for unexpected or novel stimuli, and requires more attention by the operator (Schneider and Shiffrin, 1977b). Schneider and Fisk (1982a) added that controlled processing is slower, requires more effort, and is capacity limited. Controlled processing, generally under an individual's direct control, requires little or no practice for asymptotic performance (Fisk and Scerbo, 1987). Because active attention by the subject is required, only one controlled process at a time can be performed without interference. However, the controlled process does not require extended practice to be utilized effectively, and may be set up and altered by the subject in just a few attempts or trials. Table 3 is a summary of differences between automatic and controlled processes (Schneider, Dumais, and Shiffrin, 1984).

TABLE 3
Some characteristics of automatic and controlled processes

Characteristic	Automatic Processing	Controlled Processing
Control	Not Complete	Complete
Practice	Results in gradual improvement	Has little effect
Modification	Difficult	Easy
Performance	High	Low, except when task is simple
Simplicity	Irrelevant	Irrelevant
Awareness	Low	High
Attention	Not required, but may be called	Required
Effort	Little, if any	Much

Since an automatic process is in long term memory (LTM), it requires consistent training over an appreciable period before it develops fully. Automatic processing is difficult to suppress or alter once learned (Schneider and Shiffrin, 1977a). Practice alone will not necessarily lead to automatic processing. Schneider and Fisk (1982b) stated that practice and consistency appear to have a multiplicative effect on performance improvement. Training only results in the development of automatic processing when the subject makes the same response to the stimuli across training trials (Schneider and Fisk, 1982b). If the stimuli in the training trials require different responses, the subject will continue to use controlled processing and performance will improve little with practice. Schneider and Fisk (1982b) stated that although performance on controlled processing tasks may improve somewhat due to familiarization with the task and understanding of instructions, performance does not improve as profoundly as when stimuli are dealt with consistently.

As shown in Table 3, the simplicity of a task does not determine the type of processing used. Both simple and complex tasks can be performed by automatic processes, controlled processes, or both (Fisk and Scerbo, 1987). Several characteristics distinguish between automatic processing and controlled processing (Schneider and Shiffrin, 1977a). These characteristics include (1) capacity limitations and attentional demands, (2) the degree of subject control and ease of alteration, (3) the amount of training before asymptotic levels of performance are reached, and (4) the effects of long-term learning.

Many things that we do in everyday life involve a transition between the two different modes of information processing. Fisk and Scerbo (1987) made this point in a discussion of reading. The beginning reader uses controlled processing, because at this stage reading is slow and requires much attention. The decoding of words may be letter by letter, and as slow as one letter per second. However, when someone becomes more skilled at reading, he or she reads much faster and with little demand on attention. This is very typical of automatic processing.

Schneider, Dumais, and Shiffrin (1984) stated that performance in a given situation is often very different depending on whether automatic or controlled processing is used. Further, performance should improve if the subjects are given extensive, consistent training. Because controlled processes are capacity-limited, reductions in capacity harm controlled processes more than automatic processes. Other research with automatic processing and controlled processing indicates that, unlike controlled processes, automatic processes are reliable even when the situation is suboptimal (Fisk and Scerbo, 1987). Suboptimal situations can include a variety of things, such as vigilance conditions, high mental workload, alcohol ingestion, and environmental stress.

PREVIOUS HEAT STRESS STUDIES

The following literature discussion is not exhaustive. The author did however attempt to include the most relevant studies. Examination of these studies led to the research performed by the experimenter.

Decreased performance of physical activity generally results from heat stress conditions. Some studies have observed changes in physiological responses of subjects that were exposed to heat stress and/or exercise (Wenzel and Ilmarinen, 1977; Berglund and Gonzalez, 1977; Mairiaux, Libert, Candas, and Vogt, 1984).

The effect of heat stress on activities that do not involve physical work is not so predictable. Human performance is more difficult to predict when mental activities are studied. Although the research designs have differed among studies, the general finding is that as heat stress increases, task performance decreases. Although the deterioration of mental performance varies with exposure duration, the point at which deterioration begins is below physiological limits (Wing, 1965). Hancock (1980) postulated that mental performance deterioration begins at higher levels of heat stress (Hancock, 1980). Grether (1973) and Hancock (1981) indicated that the onset of significant decrement in certain cognitive and psychomotor abilities occurs at about 29.4°C (85.0°F) on the Houghton and Yaglou (1923) Effective Temperature Scale. Wyon (1974) reevaluated a 1923 typewriting performance study conducted by the New York State Commission on Ventilation, and found that subjects performed significantly more work at 20°C than they did at 24°C. Bell (1978) found that both noise and heat stress caused significant reductions in the performance of a subsidiary task. Similar results of deteriorating mental performance with increased levels of heat stress have been reported by other researchers (Wilkinson, Fox, Goldsmith, Hampton, and Lewis, 1964; Bell, 1981; Hohnsbein, Piekarski, Kampmann, and Noack, 1984).

Some studies indicated that elevated temperature increased performance, temporarily. Poulton and Kerslake (1965) found reliably better task performance when subjects were exposed to heat than when in a cooler environment. Provins and C. Bell (1970) studied reaction time and found that heat caused an initial beneficial effect, but as the exposure continued, the reaction time slowed. Individuals demonstrated learning during a heat stress study conducted by Nunneley, Dowd, Myhre, and Stribley (1978). This study also indicated that heat induced decrements in performance may occur in particularly new or emergency situations. Further research by Nunneley, Dowd, Myhre, Stribley, and McNee (1979) found that although heat stress did not affect the two most difficult compensatory tracking tasks, a slight but significant improvement was seen in performance on the least difficult of the three tracking tasks. Beshir and Ramsey (1980) found that higher temperatures resulted in increased performance in a perceptual motor task. Poulton and Kerslake (1965) proposed that heat initially stimulates subjects, but as the initial stimulating effect wears off, the deep body temperature begins to rise and performance decreases.

Other studies have yielded conflicting results that could not be easily explained. Chiles (1958) tested subjects who performed complex mental tasks at high Effective Temperatures and found small and insignificant differences in performance when compared to less severe environments. Allnutt and Allan (1973) associated an increased core temperature with an increased speed of performance, and often an increased rate of errors. Increased heat load was associated with faster performance by Epstein, Keren, Moisseiev, Gasko, and Yachin (1980). In studying sedentary activities, Ramsey, Dayal, and Ghahramani (1975) found evidence that humans can perform under adverse conditions for brief periods. The most likely explanation for these studies is that the effect of heat on mental activities is difficult to predict.

A field study, performed in the laundry room of a hospital, found no relationship between worker productivity and thermal stress (Woods et al, 1981). Conditions were near-heat-stress, but the only significant effect on the performance of the workers was workload (Woods et al, 1981).

Other research indicated a possible effect on performance by humidity. Pepler (1958) studied a manual tracking task, a visual watch keeping task, and a high speed decision making task. He found that performance deteriorated between 81°F and 86°F on the Houghton and Yaglou (1923) Effective Temperature scale. It was also noted that the critical region was lower for warm humid climates than for warm dry climates, indicating the importance of humidity. Pepler (1959) attempted to duplicate an earlier experiment by Blockley and Lyman, but found that although subjects were able to align a pointer normally at first, subsequent performance deteriorated rapidly and progressively. Exact replication of Blockley and Lyman's environmental conditions was not possible, as Pepler was forced to achieve the highest Effective Temperature with a higher humidity and lower air temperature. Azer, McNall, and Leung (1972) found a deterioration in dual task performance at the highest level of humidity. Previous work performed at Virginia Tech evaluated tracking performance in heat stress conditions, and found a need for further research regarding humidity and a variety of operator behaviors, including cognitive performance (Kim, 1991).

Research with activity levels higher than sedentary found that 25%-65% relative humidity did not significantly affect male comfort at temperatures below and in the thermal neutral zone (McNall, Jaax, Rohles, Nevins, and Springer, 1967). The same study indicated that for temperatures above the thermally neutral zone, humidity would be a significant factor. For males with a low activity level, the thermal neutral zone is 64°F - 75°F, while the zone for medium activity and high activity levels is 60°F - 73°F and 56°F - 68°F respectively (McNall et al, 1967).

Mackworth (1946, 1961) found that the accuracy of Morse Code message reception was related to increasing Effective Temperature. The summed errors of omission and commission increased as room temperature was elevated, and when the data were divided on the basis of subject competence, less skilled operators were found to be disturbed more and sooner than higher skilled operators. Blockley and Lyman studied pilots in the early 1950s, and found that performance decrements resulting from heat stress were in part countered by superior operator skill level (Pepler, 1958). Over twenty years later, Iampietro, Melton, Higgins, Vaughan, Hoffman, Funkhouser, and Saldivar (1972) found certain routine portions of a simulated flight task to be performed with no significant decrement in heat stress, while other more complex tasks were adversely affected. These studies support the belief that highly skilled operators are better able to withstand heat stress.

Hancock (1986a) found sustained attention to be particularly vulnerable to heat. Hancock found skilled workers to be less affected by heat stress than unskilled workers. These findings are consistent with earlier discussions regarding automatic processing and controlled processing. Automatic processing develops from extensive and consistent practice (Schneider and Fisk, 1982b). Controlled processing is utilized more by less skilled workers, and because controlled processing is more attention demanding, it should be more vulnerable to heat stress.

Schneider and Fisk (1983) found automatic processes to be resource insensitive, while controlled processes are resource sensitive. Therefore, stressors cause less of a decrease in the performance of automatic processing tasks than in controlled processing tasks. However, Schneider and Shiffrin (1977a) indicated that subjects must consume resources to counteract automatic processes. The use of the additional resources to counteract automatic processes results in a significant performance decrement.

Automatic processes appear to be reliable even under suboptimal situations. A vigilance decrement has been observed by Fisk and Schneider (1981) to be significant for controlled processing, but not for automatic processing. Childs (1976) found no significant vigilance decrement for a relatively simple task. Automatic processes are minimally affected by alcohol while controlled processes are substantially affected (Fisk and Schneider, 1982). Similarly, automatic processes are reliable under high mental workload (Schneider and Fisk, 1982b).

Summary of Previous Heat Stress Studies

As demonstrated, many studies have had conflicting results. Yet, the general conclusions of these studies is that as heat stress increases, performance tends to decrease.

Many previous studies have achieved high heat stress conditions on the Houghton and Yaglou (1923) Effective Temperature Scale, but have concentrated on air temperature, not humidity. The possible effect of humidity has been indicated in earlier findings by Pepler (1958, 1959) as well as by Azer, McNall, and Leung (1972).

Automatic processes appear to be more resistant to heat stress than controlled processes, which explains why less skilled subjects are more affected by heat (Hancock, 1986a). Schneider and Fisk (1983) found automatic processes to be resource insensitive and controlled processes to be resource sensitive. This explains why heat stress seems to affect controlled processing more than automatic processing. Hancock (1986b) concluded that heat stress appears to affect tasks that require attention, and controlled processes require more attention than automatic processes. Finally, Kim (1991) indicated a need for further research regarding the effects of humidity with a variety of operator behaviors, including cognitive processes.

PURPOSE OF RESEARCH

Past research on the effect of heat stress on the performance of various tasks indicated that performance by skilled operators was less affected by high temperatures than performance by less skilled operators (Mackworth, 1961; Iampietro et al, 1972; Hancock, 1986a). In addition, automatic processes are less affected by suboptimal conditions than controlled processes (Fisk and Schneider, 1981; Childs, 1976; Fisk and Schneider, 1982; Schneider and Fisk, 1982b).

The effect of high levels of humidity has not been adequately separated from high temperature, although several studies have indicated a possible affect on performance by humidity (Pepler, 1958, 1959; Azer, McNall, and Leung, 1972; Kim, 1991). Rohles (1975) indicated that at temperatures above 85°F almost all of the heat loss from the body is by evaporation. Because high vapor pressure conditions severely hinder evaporation of sweat, the experimenter hypothesized that vapor pressure would significantly affect task performance.

The purpose of this study was to determine the impact of vapor pressure and high temperature on task performance. Four different thermal environmental conditions, with both an automatic processing task and a controlled processing task, were used to analyze task performance. Prior to the experiment, the following hypotheses were formulated by the experimenter:

- High levels of vapor pressure will significantly affect the controlled processing task.
- High levels of vapor pressure will not significantly affect the automatic processing task.
- High levels of temperature will significantly affect the controlled processing task.
- High levels of temperature will not significantly affect the automatic processing task.

EXPERIMENTAL METHOD

SUBJECTS

In this experiment, eight male subjects were studied. All subjects were undergraduate or graduate students at the Texas A&M University, and were paid $5 per hour for their participation. In addition, a $10 bonus was paid to each subject at the completion of the study. Subjects were recruited by placing signs (see Appendix J) in several of the academic buildings on the Texas A&M University campus. Only subjects that met all of the following requirements were allowed to participate:

1) male,

2) expert keyboardist as indicated by the criteria in Appendix B,

3) did not work jigsaw puzzles more than three times per year,

4) must have been willing to participate in all 8 experimental trials, each of which was expected to last approximately one hour,

5) did not need to wear glasses during the experiment,

6) must have completed and signed the screening health questionnaire form that was reviewed by Student Health Services,

7) agreed to follow instructions for the experiment,

8) signed the informed consent form in Appendix D, and

9) was accepted for participation by Donald Freeman, M.D, Staff Physician, Texas A&M University.

Criteria for Subject Removal

A subject was to be removed from the heat chamber if during the experiment his estimated core temperature reached 38.2°C (101°F) along with a 1.2°C (2°F) rise from the initial level. A subject was also to be removed if his heart rate reached 140 beats per minute during the experiment. Given these criteria, no subject was required to be removed from any trial.

Contingency Plan

The Texas A&M University Emergency Medical Services (EMS) were to be called if the estimated core temperature of a subject reached 38.8°C (102°F). If the heart rate remained at 140 beats per minute for 3 minutes following subject removal, or if at any time heart rate reached 180 beats per minute, the Emergency Medical Services were to be called. The Emergency Medical Services were also to be called if any symptoms of heat illness were present, except for cramps. Upon calling the Emergency Medical Services, a subject would have been taken to the shower located down the hall from the environmental chamber. Prior to the beginning of the experiment, the Emergency Medical Services were provided with a schedule of all experimental trials and a summary of the protocol. There were no occasions in which the Emergency Medical Services were called.

Had a subject been withdrawn from a trial, he would have been allowed to continue with the experiment at a later date, as long as the Emergency Medical Services had not been called and he had not been withdrawn from any other trial.

TASK DESCRIPTION

Each experimental trial consisted of either an automatic processing or a controlled processing task. Further descriptions of these tasks are given below.

Automatic Processing Task

Each automatic processing trial consisted of the subject entering two passages of text via the keyboard. The subject was allowed ten minutes for each passage of text, and was provided a three-minute break between them. Subjects entered each of the eight passages of text exactly one time, in random order. This method of text assignment helps prevent bias resulting from presentation order. The passages of text were approximately the same level of difficulty, as indicated by syllabic intensity and stroke intensity. Syllabic intensity is the average number of speech syllables per dictionary word, while stroke intensity is the average number of typewriter strokes per dictionary word (West, 1969). West (1969) indicated that for testing, syllabic intensity should center around 1.54 and stroke intensity around 6.0. This experiment matched these values closely, with a syllabic intensity of 1.5 and stroke intensity of 5.6.

The inputting of keystrokes is called keyboarding (Crawford, Erickson, Beaumont, Robinson, and Ownby, 1983). The primary difference between keyboarding and typewriting is that although typewriting includes keyboarding, typing goes beyond the mere manipulation of keys (Crawford et al, 1983). Crawford et al (1983) define the arranging and typing of letters, tables, reports, and other papers as typewriting. Keyboarding, the entering of text through the letter keys, was studied in this experiment.

The number of five-character words correctly entered per minute was the scale for scoring each passage of text. A trial score was represented by the average of the two separate passages of text minus the pre-trial score. More discussion of this scoring procedure and an example can be seen in Appendix B. The subtraction of the pre-trial score from the experimental trial score was necessary to account for individual differences in typing ability.

Controlled Processing Task

The controlled processing task consisted of the subject working as much of a computerized jigsaw puzzle as possible during a 15 minute period. There were four trials, each with a different jigsaw puzzle. Subjects worked each of the four puzzles exactly once, but in random order. This method of puzzle assignment helps prevent bias resulting from presentation order.

Puzzles were chosen to be approximately the same level of difficulty. Because puzzle difficulty was not quantified, the experimenter had five pilot subjects work a group of puzzles from which the final four would be chosen for the trials. This also ensured that subjects received adequate training for the controlled processing task. Before the puzzles were worked, pilot subjects were trained how to use the puzzle program. Training consisted of a 15-minute session working a puzzle, followed by a 10-minute session working a different puzzle. All questions were answered during the training. By the end of the first training puzzle, all pilot subjects were comfortable with the puzzle program. Upon completion of the training puzzles, each subject worked 11 randomly presented puzzles for 15 minutes each. Pilot subject training appeared adequate and no pilot subjects demonstrated a learning affect. Upon comparing the scores of the pilot subjects, five puzzles appeared to be equally difficult. Four of these puzzles were chosen for the study, and one was chosen as the pre-trial puzzle.

Performance on the puzzle task was measured by subtracting the number of pieces correctly located during the pre-trial from the number of pieces correctly located during the experimental trial. Thus, the differencing of the experimental trial score and the pre-trial score was performed in a similar manner to the automatic processing trials.

EQUIPMENT

The experiment was conducted in the Steed Research and Conditioning Laboratory, located on the campus of the Texas A&M University.

Environmental Chamber

The environmental chamber dimensions are 244 cm (96 inches) in width, 206 cm (81 inches) high, and 366 cm (144 inches) in length. The environmental chamber contains a RHEEM microprocessor-based temperature and relative humidity controller. A heated window is installed in the chamber, allowing subjects to view a computer screen in the control room. When the control room lights are turned off, only the computer screen is visible to the subject.

Although no calibration of the environmental chamber was performed, a thermometer was hung inside the chamber. No external measurement of relative humidity was taken. During the experiment, temperatures within the chamber varied to extremes of approximately 0.5°C above and below the set criteria. The temperatures displayed by the environmental chamber were supported by the hanging thermometer. Relative humidity readings generally varied to extremes of approximately three percent above and below the set criteria.

The environmental chamber was set at the desired environmental conditions approximately 45 minutes before the first trial of the day. The chamber then remained at the set environment until the completion of the last subject at the end of the day.

Questemp°II

The Questemp°II is a personal heat stress indicator. It monitors the human body's temperature via the ear canal, using an offset between the ear and body temperature. The Questemp°II is an electronic assembly that is worn on the pocket or belt, and is linked to the ear canal by a thin, flexible cable. The Questemp°II signals when the user's body temperature rises above a preset alarm level. The hypothalamus is located at the base of the brain, and is the temperature controller for the body. A sensor measures the ear temperature, because it is close to the hypothalamus.

Although temperatures were recorded during experimental trials, the recorded values were cleared during calibration at the beginning of the next trial. Therefore, the experimenter was unable to save the recorded data for future analysis.

Exercise/Pulse Monitor

The Sears Exercise/Pulse Monitor is a mini-computer, designed to monitor the pre-set pulse rate limits without hindering activities. A low and high heart rate limit alarm the experimenter. The pulse sensor is a photo-electric cell that clips to the ear. The display is an LCD type, and shows the time and pulse rate. No subject data are recorded by the unit.

Personal Computer

Both the automatic processing and the controlled processing tasks were performed on a Hewlett Packard Vectra ES/12 personal computer. The monitor and central processing unit were kept outside of the environmental chamber. Only necessary components for the experiment were kept inside. Necessary components included the keyboard, mouse, and mousepad. The monitor was in clear view for the subjects through a heated, one-way window. Subjects were able to see the computer screen, even in humid conditions. The keyboarding tasks, performed with a WordPerfect 5.1 word processor, were standardized typing tests (Fries and Clayton, 1975). Puzzle tasks were performed using Picture Puzzle, a computerized puzzle program written by Software Creations.

Tele-thermometer

The ambient air temperature and chamber wall temperature were measured with a tele-thermometer, manufactured by the Yellow Springs Instrument Company. Attachable surface temperature probes and air temperature probes were used to measure the chamber wall temperature and air temperature respectively.

Sound Level Meter

The sound level was measured in the environmental chamber with a precision impulse integrating sound level meter, Model 1800, manufactured by Quest Electronics.

Wind Meter

The air velocity in the environmental chamber was measured with a wind meter, manufactured by Dwyer Instruments, Inc.

CONTROL OF ENVIRONMENTAL AND PERSONAL FACTORS

Environmental Factors

As stated earlier, the four environmental factors are temperature, thermal radiation, humidity, and air speed. The desired environmental conditions were achieved using two different temperatures and four different relative humidities (with corresponding vapor pressures). The two levels of temperature were used to indicate any significant differences due only to temperature. Four different values of relative humidity were used in the study. The level applied to the lowest temperature was chosen because it marks the edge of the comfort envelope for the given temperature. This vapor pressure was then used for one of the three conditions with 33°C (92°F). The next two levels are equally spaced steps on the vapor pressure scale. Because the temperature was the same for each of the last three environmental conditions, performance differences for these three conditions were expected to indicate an effect of vapor pressure. The actual levels of these factors can be seen in Table 4.

TABLE 4
Experimental Conditions

Environmental Condition	Temperature	Vapor Pressure
EC1	25°C (78°F)	15 mm Hg
EC2	33°C (92°F)	15 mm Hg
EC3	33°C (92°F)	25 mm Hg
EC4	33°C (92°F)	35 mm Hg

Thermal radiation and air speed were not factors of interest in this study and their effect was minimized by holding each of them constant throughout all trials. The fluorescent lights in the environmental chamber were always used at full power, and no additional source of thermal radiation was intentionally presented into the environmental chamber. When experimental trials were performed in which the temperature differed from the previous trial, added radiant heat was minimized by spacing trials at least two days apart. Fifteen hours after a full day of experimental trials, at 33°C (92°F) and 92% relative humidity, the chamber wall surface temperature was measured to be 23.8°C (75°F). The effect of radiant heat coming from the walls of the chamber should therefore be minimal.

ASHRAE (1992) stated that for sedentary persons, it is essential to avoid drafts. There was no air flow presented into the chamber in addition to what resulted from normal chamber operation. The air flow resulting from normal chamber operation included the steam from the humidity control unit and hot air from the temperature control unit. Subjects were not exposed to direct air flow from any source. Air flow was measured by the wind meter during all chamber operations, and was always found to be significantly less than 20 feet per minute. Therefore, the air speed was always found to be within acceptable ASHRAE limits (ASHRAE, 1992). The effects of thermal radiation and air flow should have been minimized.

One question of interest in this study was how human operators perceive vapor pressure. The general public understands relative humidity and may be sensitive to differences in it, but most people probably do not fully understand vapor pressure. Opinions regarding the safety of this research were gathered through conversations with physicians (Barkley, 1993; Rowlett, 1993), review of literature recommended by the physicians (Petersdorf and Root, 1987), and telephone conversations with researchers elsewhere (Jones, 1993; Rohles, 1993; Gonzalez, 1993; Ellis, 1993). The opinions of the researchers are summarized in Appendix H.

Personal Factors

As stated earlier, personal factors include activity level and clothing. These factors were held constant throughout all trials. When considering the activity level, the metabolic rate is of primary concern. Metabolic rate is the rate of energy production in the body which varies with activity and is measured in met units (ASHRAE, 1992). The typing and puzzle tasks were almost sedentary activities with metabolic rates of around 1.2 met.

Clothing insulation values (clo's) measure the insulation value of a garment.

Individual garment values can be summed to determine the insulation value for an entire ensemble (ASHRAE, 1992). Because this experiment was designed to occur during the summer, subjects were dressed in summer clothing. ASHRAE (1992) states that typical summer clothing ensembles have insulation values ranging from 0.35 to 0.6 clo. Subjects in this experiment dressed in ensembles that were approximately 0.4 clo (ASHRAE, 1992). This ensemble consisted of men's briefs, calf length socks, shoes, short-sleeve knit sport shirt, and walking shorts.

Miscellaneous

For the chamber to maintain the set temperature and relative humidity, heating units and the humidity control unit cycled on and off throughout the trials. The noise of these units was measured during various chamber operations. These noise measurements are presented in Table 5.

TABLE 5
Noise levels in the environmental chamber

Chamber Process	Noise Level (DBA)
Humidity Control Unit On (Dehumidifying)	77
Heater and Humidity Control Unit On (Humidifying)	70

EXPERIMENTAL DESIGN

To achieve the research objectives, the experimental design seen in Table 6 was used. The design was a two-way (2 x 4) within subjects design that studied the effects of the four environmental conditions on the two types of processing.

TABLE 6
Experimental design

	Environmental Condition			
Processing	EC1	EC2	EC3	EC4
Automatic	S1 - S8	S1 - S8	S1 - S8	S1 - S8
Controlled	S1 - S8	S1 - S8	S1 - S8	S1 - S8

The eight subjects were assigned to each of the experimental cells. Random presentation of trials to subjects was planned, but due to scheduling constraints, all participants were subjected to the environmental conditions in the same order.

Table 7 illustrates how environmental conditions and tasks were presented to subjects. The assignment of environmental conditions to trials was randomized. All eight subjects were presented the first trial on day one of the experiment and the second trial on day two of the experiment. Subsequent trials were then presented in a similar fashion, with the trial number corresponding to the day of the experiment. Subjects were randomly assigned subject numbers (S1, S2, etc...). That is, subjects were randomly placed into a column heading. All independent variables were treated as fixed-effects variables, and subjects were treated as a random-effect variable.

TABLE 7
Presentation order of trials to subjects

Trial	S1	S2	S3	S4	S5	S6	S7	S8
1	EC3 typing	EC3 puzzle	EC3 typing	EC3 puzzle	EC3 typing	EC3 puzzle	EC3 typing	EC3 puzzle
2	EC3 puzzle	EC3 typing	EC3 puzzle	EC3 typing	EC3 puzzle	EC3 typing	EC3 puzzle	EC3 typing
3	EC2 puzzle	EC2 typing	EC2 puzzle	EC2 typing	EC2 puzzle	EC2 typing	EC2 puzzle	EC2 typing
4	EC2 typing	EC2 puzzle	EC2 typing	EC2 puzzle	EC2 typing	EC2 puzzle	EC2 typing	EC2 puzzle
5	EC4 typing	EC4 puzzle	EC4 typing	EC4 puzzle	EC4 typing	EC4 puzzle	EC4 typing	EC4 puzzle
6	EC4 puzzle	EC4 typing	EC4 puzzle	EC4 typing	EC4 puzzle	EC4 typing	EC4 puzzle	EC4 typing
7	EC1 puzzle	EC1 typing	EC1 puzzle	EC1 typing	EC1 puzzle	EC1 typing	EC1 puzzle	EC1 typing
8	EC1 typing	EC1 puzzle	EC1 typing	EC1 puzzle	EC1 typing	EC1 puzzle	EC1 typing	EC1 puzzle

where:
EC1 = 25°C (78°F) and 15 mm Hg vapor pressure
EC2 = 33°C (92°F) and 15 mm Hg vapor pressure
EC3 = 33°C (92°F) and 25 mm Hg vapor pressure
EC4 = 33°C (92°F) and 35 mm Hg vapor pressure
typing = automatic processing task
puzzle = controlled processing task

INDEPENDENT VARIABLES

For this experiment, the two factors were environmental condition and type of processing. The four levels of the environmental condition were (1) 25°C (78°F) with 60% relative humidity and 15 mm Hg vapor pressure, (2) 33°C (92°F) with 38% relative humidity and 15 mm Hg vapor pressure, (3) 33°C (92°F) with 66% relative humidity and 25 mm Hg vapor pressure, and (4) 33°C (92°F) with 92% relative humidity and 35 mm Hg vapor pressure. The two levels of processing were automatic processing and controlled processing.

Analyses were also conducted in which the independent variable was one of the defining elements of the environmental condition (i.e. temperature and vapor pressure). There were two levels of temperature (25°C and 33°C) and three levels of vapor pressure (15 mm Hg, 25 mm Hg, and 35 mm Hg). Because data were collapsed across levels, unequal cell sizes resulted. Tables 8 and 9 present the levels for each of the defining elements.

TABLE 8
Levels of temperature

Level	N	Temperature	Environmental Condition
1	8	25°C	EC1
2	24	33°C	EC2 EC3 EC4

TABLE 9
Levels of vapor pressure

Level	N	Vapor Pressure	Environmental Condition
1	16	15 mm Hg	EC1 EC2
2	8	25 mm Hg	EC3
3	8	35 mm Hg	EC4

DEPENDENT MEASURES

The dependent measures were the scores of the automatic processing task and controlled processing task. Scores were determined by the method described in the Task Description section.

To compare the two different tasks on an equivalent scale, proportion scores were used. These proportion scores were determined by dividing the experimental trial score by the pre-trial score. This resulted in proportions that related the performance during the experimental trial to the performance in the pre-trial in which the temperature was 25°C (77°F) and the vapor pressure was 12 mm Hg (50% relative humidity).

EXPERIMENTAL PROCEDURE

INITIAL VISIT

During the initial visit, which occurred in the environmental chamber, a potential subject was provided with a written explanation of the study (Appendix C). He could then choose to read and sign the informed consent form and the screening health questionnaire (Appendices D and E). Completion of these forms was required to proceed with the initial visit. The subject was then given instructions for the initial visit (Appendix F). Next, he was tested for expert keyboard ability. If he performed at the level specified in Appendix B, and met all other necessary requirements for participation, automatic and controlled processing tasks were performed. These tasks served as pre-trial scores for future experimental trials. Pre-trial tasks were performed in an environment meeting the middle of the ASHRAE comfort envelope (ASHRAE, 1992). This environment consisted of 24.9°C (77°F), 50% relative humidity, and 12.1 mm Hg vapor pressure. The tasks were identical to the experimental trial tasks. Future trials were scheduled at the conclusion of the initial visit.

All subjects were unfamiliar with computerized puzzle programs, and thus required training. During the initial visit, each subject received training identical to that received by the earlier pilot subjects.

EXPERIMENTAL TRIALS

In all trials, the subject first entered the environmental chamber and received instructions, seen in Appendix G. The heart rate and tympanic temperature monitors were then connected to him. The tympanic temperature monitor was then calibrated. This setup period lasted approximately 15 minutes, and was followed by a 15-minute waiting period during which the subject's core temperature began to rise. During this waiting period, the subject drank 300 ml of lukewarm water. The water was stored in the control room and served to subjects in cups. The water was consumed to avoid dehydration and should not have seriously impacted the results of the study. Upon the conclusion of the waiting period, the subject performed the trial task. The subject was given an unrestricted supply of water throughout all experimental trials.

Grether (1973) stated that a few heat stress studies have used exposure durations as brief as 20-30 minutes, and this is very often too short a time to produce significant heat stress. Because of this, the tasks in this experiment did not begin until the subject had been in the chamber for at least 30 minutes, resulting in total exposures of nearly one hour.

The experiment consisted of four automatic processing trials and four controlled processing trials, each of which lasted approximately one hour. Throughout the experiment, heart rate and estimated core temperature were monitored. If either the heart rate or core temperature exceeded pre-set limits, the subject was to be withdrawn from the heat chamber. Task performance data were also collected for future analysis.

Automatic Processing Trials

The automatic processing task consisted of entering two ten-minute passages of text via the keyboard. Between passages, a subject rested for three minutes, while the work was saved onto a computer disk for later analysis. At the conclusion of the trial, the subject exited the environmental chamber and was thanked for his participation.

Controlled Processing Trials

The controlled processing task consisted of working as much of a computerized jigsaw puzzle as possible during the 15-minute task. The puzzles were manipulated using a mouse on a mouse pad. The presentation of puzzles was consistent. Therefore, although two subjects might not have seen a puzzle during the same condition, the puzzle was presented with all 200 pieces in the same beginning location. This eliminated task variability as a result of puzzle presentation. At the conclusion of the trial, the subject exited the environmental chamber and was thanked for his participation.

RESULTS

The data were analyzed using the Analysis of Variance Procedure within SAS (SAS Institute Inc., 1988). Difference scores for automatic processing and controlled processing are presented in Table 10. Proportions scores are presented in Table 11. Positive difference scores (proportion scores greater than one) indicate mean experimental trial scores greater than the mean pre-trial score; negative difference scores (proportion scores less than one) indicate mean experimental trial scores less than the mean pre-trial score. All conditions experienced positive difference scores (proportion scores greater than one) except for the automatic processing task in environmental condition 4. Appendix I contains the raw data for the experiment.

TABLE 10
Difference score means and standard deviations by environmental condition

Processing Task	EC1	EC2	EC3	EC4
Automatic (wpm)	1.5 (2.8*)	0.8 (3.9)	0.2 (3.2)	-0.5 (2.5)
Controlled (pieces placed)	25.0 (27.6)	20.8 (21.3)	19.3 (22.4)	23.8 (22.8)

* standard deviations are in parentheses

TABLE 11
Proportion score means and standard deviations by environmental condition

Processing Task	EC1	EC2	EC3	EC4
Automatic	1.03 (0.06*)	1.02 (0.12)	1.00 (0.08)	0.98 (0.07)
Controlled	1.51 (0.46)	1.42 (0.39)	1.39 (0.45)	1.45 (0.46)

* standard deviations are in parentheses

The analyses used proportion scores to measure the tasks on the same scale. Because the data were transformed into proportion scores, any results of the analyses were generalizable only to these transformations. The results of the ANOVAs are provided for environmental conditions, temperature, and vapor pressure in Tables 12 through 14 respectively.

TABLE 12
ANOVA of Proportion scores for environmental condition

Source	Degrees of Freedom	Sum of Squares	Mean Squares	F	Pr>F
Between					
S	7	1.33	0.19		
Within					
E	3	0.05	0.02	0.33	0.81
E x S	21	1.12	0.05		
P	1	3.07	3.07	11.23	0.01
P x S	7	1.92	0.27		
E x P	3	0.02	0.01	0.13	0.94
E x P x S	21	1.24	0.06		
Total	63	8.75			

where: E = environmental condition P = type of processing S = subjects

TABLE 13
ANOVA of Proportion scores for temperature

Source	Degrees of Freedom	Sum of Squares	Mean Squares	F	Pr>F
Between					
S	7	1.13	0.16		
Within					
T	1	0.05	0.05	0.48	0.51
T x S	7	0.68	0.10		
P	1	2.46	2.46	13.33	0.01
P x S	7	1.29	0.18		
T x P	1	0.01	0.01	0.10	0.76
T x P x S	7	0.69	0.10		
Total	31	6.31			

where: T = temperature P = type of processing S = subjects

TABLE 14
ANOVA of Proportion scores for vapor pressure

Source	Degrees of Freedom	Sum of Squares	Mean Squares	F	Pr>F
Between					
S	7	1.23	0.18		
Within					
V	2	0.03	0.02	0.26	0.78
V x S	14	0.79	0.06		
P	1	2.74	2.74	10.10	0.02
P x S	7	1.90	0.27		
V x P	2	0.01	0.01	0.11	0.90
V x P x S	14	0.86	0.06		
Total	47	7.56			

where: V = vapor pressure P = type of processing S = subjects

Many analyses of variance produced low F-values. The only significant factor was the type of processing. Proportion scores were higher on the controlled processing task than the automatic processing task. The controlled processing task was more variable than the automatic processing task.

Automatic processing task scores correspond with the severity of the environment (see Table 8). More severe environmental conditions were associated with lower automatic processing scores. The highest automatic processing scores came from the 25°C (78°F) condition, the least severe environment. Scores in the 33°C (92°F) conditions decreased as the vapor pressure increased. This was not the case for controlled processing trials, as the controlled processing scores increased in the order of presentation (ec3, ec2, ec4, ec1). A presentation order effect was not anticipated, because efforts were made to assure adequate training. Further study of subject scores indicated no learning effect. Figure 1 illustrates subject scores, presented in time order. Scores for several subjects decreased over time, contradicting a learning effect.

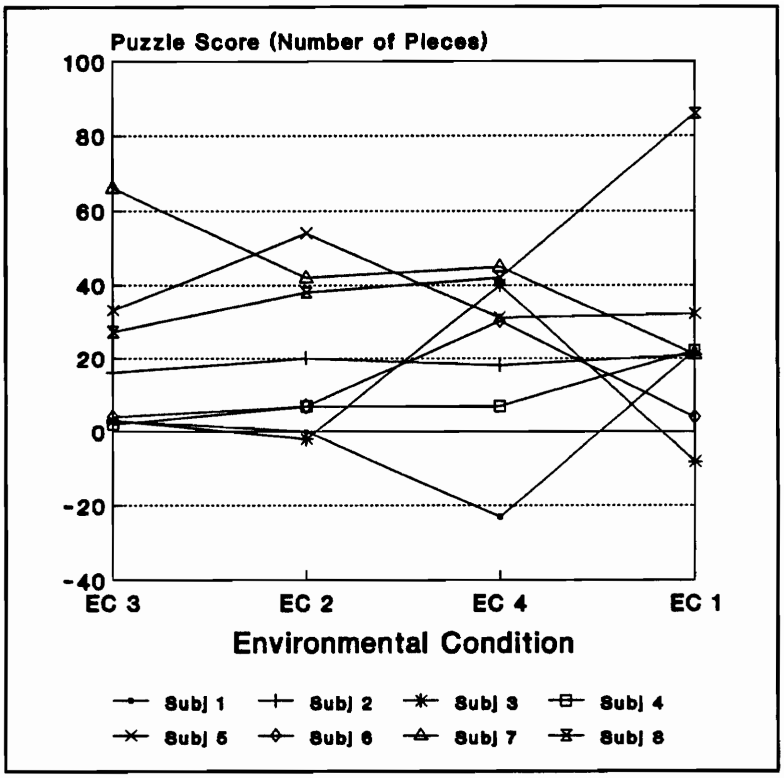

Figure 1: Puzzle scores in presentation order

Equal puzzle difficulty should result in approximately the same mean score (across all conditions). This appeared to be the case for three puzzles, but as seen in Table 15, puzzle number one had a substantially greater mean score than the other three puzzles. An ANOVA test indicated that a statistically significant difference existed between the four puzzles ($Pr > F = .0009$). Upon removal of puzzle number one, no

TABLE 15
Puzzle scores

Puzzle	Mean Difference Score (wpm)	Standard Deviation of Difference Scores	Mean Proportion Score	Standard Deviation of Proportion Scores
1	40.1	26.9	1.78	0.46
2	17.9	22.4	1.36	0.46
3	16.8	17.1	1.35	0.34
4	14.0	15.7	1.30	0.28

difference was found between the other three puzzles. Figure 2 presents the time ordered scores of the puzzles, without puzzle number one. Earlier ANOVAs were then performed without puzzle number one. However, the analysis was now an incomplete block design. There were still equal cell sizes (N=6), but each subject now only saw three of the four environmental conditions (for the controlled processing task). The analysis did not markedly change the results (Pr>F=0.80). Similar results (Pr>F=0.55) were seen upon attempting to control for the difference between puzzles by dividing each trial score by the mean puzzle score.

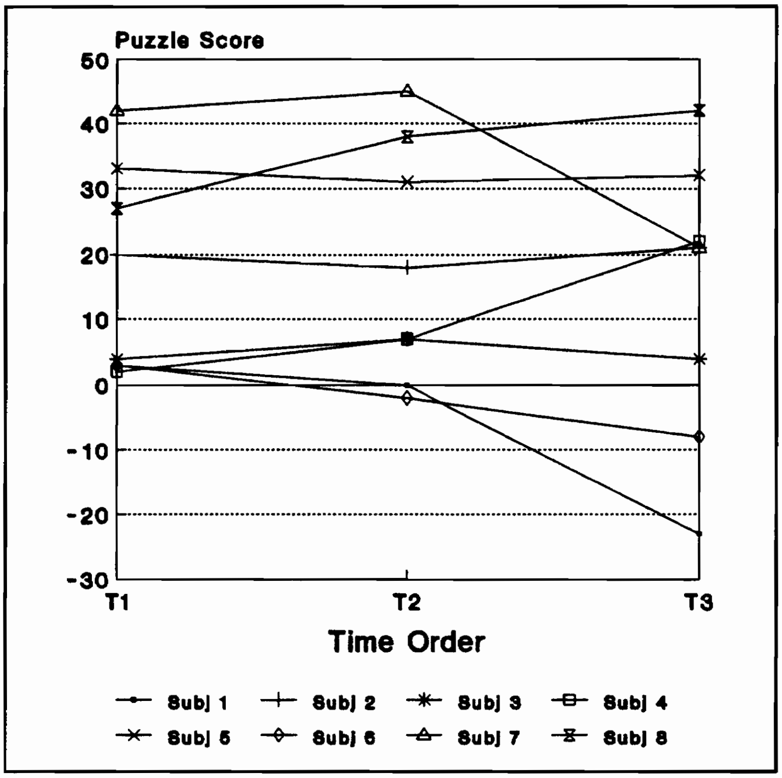

Figure 2: Puzzle scores (no puzzle 1)

Because of low F-values in the analyses, assumptions of the parametric statistical tests were performed, along with tests for outliers. In addition, all earlier presented analyses were performed on each task separately.

The experimenter first tested for a normal distribution in the data with the Kolmogorov-Smirnov test. This is a goodness of fit test concerned with the degree of agreement between the distribution of a set of observed scores and a specified theoretical distribution (Siegel, 1988). The point of the greatest difference between the observed data and the theoretical distribution is compared to a critical value. Tables 16 and 17 illustrate the results of the Kolmogorov-Smirnov tests for the automatic processing and controlled processing tasks respectively. No non-normal populations were found.

TABLE 16
Kolmogorov-Smirnov tests: Automatic processing

Treatment Combination	D_{max} Calculated	D_{crit} Tabled	Non-Normal Population?
Environment 1	.1662	.457	No
Environment 2	.1393	.457	No
Environment 3	.1293	.457	No
Environment 4	.1747	.457	No
Temperature 1	.1662	.457	No
Temperature 2	.0913	.270	No
Vapor Pressure 1	.1328	.328	No
Vapor Pressure 2	.1293	.457	No
Vapor Pressure 3	.1747	.457	No

TABLE 17
Kolmogorov-Smirnov tests: Controlled processing

Treatment Condition	D_{max} Calculated	D_{crit} Tabled	Non-Normal Population?
Environment 1	.266	.457	No
Environment 2	.209	.457	No
Environment 3	.252	.457	No
Environment 4	.216	.457	No
Temperature 1	.266	.457	No
Temperature 2	.136	.270	No
Vapor Pressure 1	.109	.328	No
Vapor Pressure 2	.252	.457	No
Vapor Pressure 3	.216	.457	No

The next assumption investigated was homogeneity of variance. According to Montgomery (1991), if this assumption is violated, the F-test is only slightly affected in balanced fixed effects models. However, in unbalanced designs or in cases where one variance is much larger than the others, the problem is more serious. The usual approach in dealing with nonconstant variance is to apply a variance-stabilizing transformation, and then run the analysis procedure on the transformed data (Montgomery, 1991). Conclusions however are limited to the transformed populations. The experimenter tested for equality of variance using the Bartlett's test. Bartlett's test has been widely used, and computes a statistic whose sampling distribution is closely approximated by the chi-square with (a-1) degrees of freedom, when the (a) random samples are from independent normal samples. Test statistics were computed to be 0.3849 (automatic processing) and 0.5477 (controlled processing), with a critical value of 7.81 in both cases. Therefore, for both types of processing, the null hypothesis that the variances were equal could not be rejected.

A visual check for normality can be made by plotting the residuals (Montgomery, 1991). It should look like a normal distribution, centered at zero, but considerable fluctuation can be expected because of the small samples. Therefore, the appearance of a moderate departure from normality does not necessarily imply a serious violation of the assumptions (Montgomery, 1991). Plotting residuals in time sequence helps detect correlation between residuals. A tendency to have runs of positive and negative residuals indicate positive correlation, which would imply that the independence assumption of errors is violated (Montgomery, 1991). Randomization of the experiment is important in obtaining independence. If residuals spread more at either the beginning or end of the experiment, the process drifted. A likely cause of the drift in the process is that the skill of the subject (or experimenter) changed over time. Figures 3 and 4 illustrate plots of residuals versus means for the automatic processing and the controlled processing tasks respectively. Figures 5 and 6 illustrate plots of residuals over time. If the model is correct, and the assumptions are satisfied, the residuals should be structureless. Plots do not indicate any structure of the residuals.

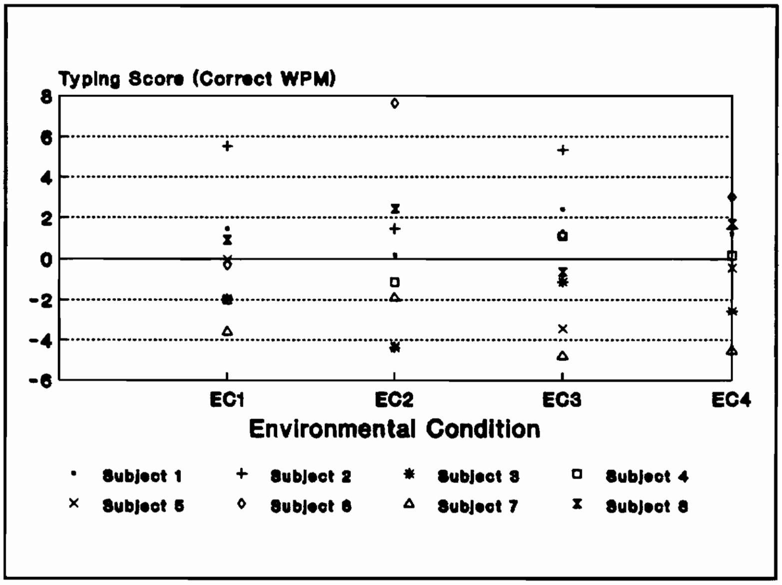

Figure 3: Plot of residuals vs means

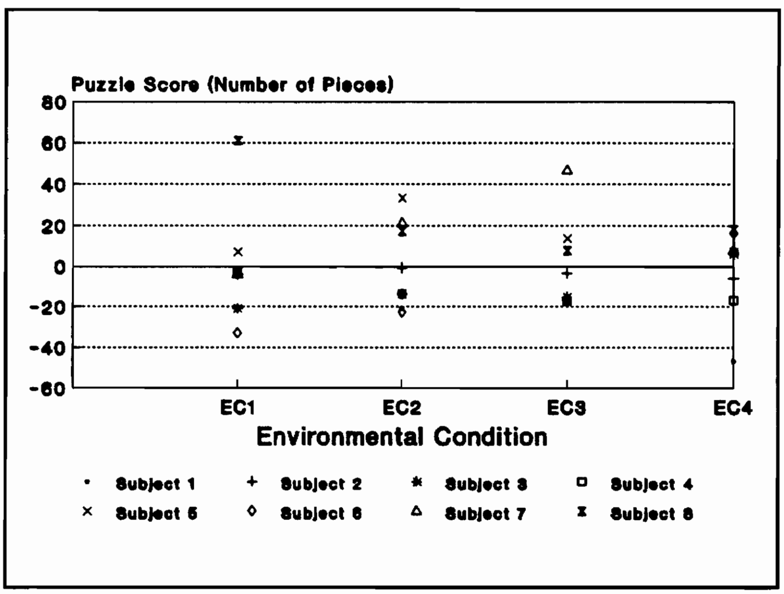

Figure 4: Plot of residuals vs means

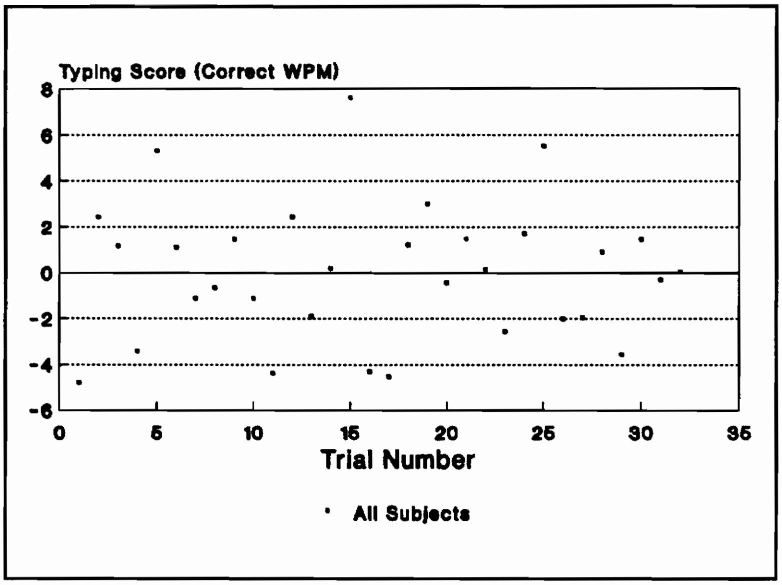

Figure 5: Plot of residuals vs time

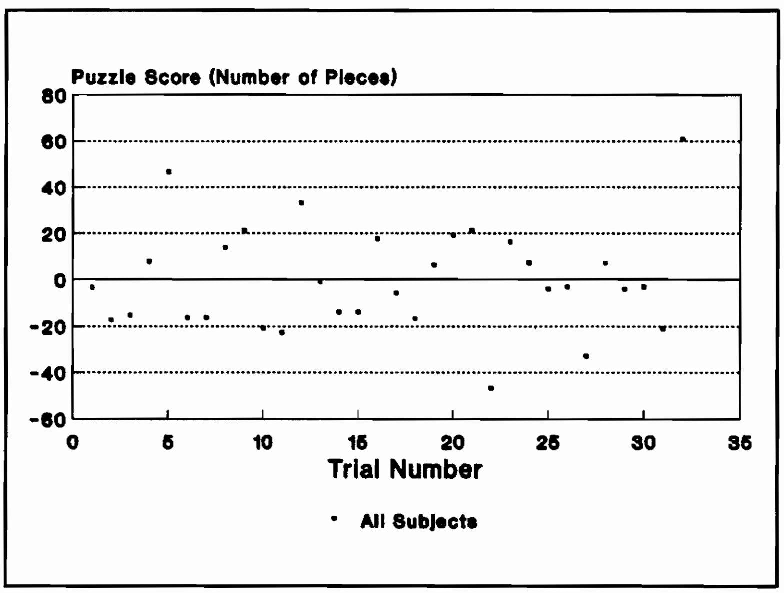

Figure 6: Plot of residuals vs time

The meaningfulness of the results of parametric tests depend on the validity of the assumptions (Siegel, 1988). Nonparametric statistical tests typically make fewer assumptions regarding the data (Siegel, 1988). Along with having a lower power-efficiency, non-parametric techniques are also systematic, and not always convenient to use (Siegel, 1988). Based on the lack of assumption violations, parametric statistics cannot be determined to be inappropriate.

The maximum normal residual (MNR) tests for outliers in data. This test is similar to other outlier tests in that it attempts to determine how rare an extreme observation would be if the data were normal and followed the assumed model (Snedecor and Cochran, 1989). This test uses the following formula for the MNR:

$$MNR = \max(X - X_{mean})/\text{sqrt}(\text{residual sum of squares})$$

For each type of processing, the most extreme value was tested to determine if it should be considered an outlier. If it could occur by chance with a probability of .05 or less, it was considered an outlier; if within-class variances are heterogeneous, a large residual may be tested by comparing it only with other residuals in the same class (Snedecor and Cochran, 1989). As determined earlier, variances were homogeneous. Extreme points were tested against all other points in the data set, including those in other classes. This provides a more powerful test than only testing extreme points against other points in the same class. The total number of subject trials for each type of processing was used to determine the critical value. The critical value for temperature, vapor pressure, and environmental conditions was 0.5294, with N=32 and alpha=0.05. Tables 18 and 19 summarize the results of the Maximum Normal Residual tests for the automatic processing and the controlled processing proportion scores respectively. Tables 20 and 21 summarize the same tests, with difference scores.

TABLE 18
MNR tests: Automatic processing proportion scores

Treatment Combination	Tested Data Point	MNR Calculated	MNR Tabled	Stat. Sign.? (alpha=.05)
Env. Condition	1.2425	.521	.5294	No
Temperature	1.2425	.551	.5294	Yes
Temperature (without outlier)	.8779	.307	.5352	No
Vapor Pressure	1.2425	.500	.5294	No

TABLE 19
MNR tests: Controlled processing proportion scores

Treatment Combination	Tested Data Point	MNR Calculated	MNR Tabled	Stat. Sign.? (alpha=.05)
Env. Condition	.4651	.425	.5294	No
Temperature	.4651	.411	.5294	No
Vapor Pressure	.4651	.424	.5294	No

TABLE 20
MNR tests: Automatic processing difference scores

Treatment Combination	Tested Data Point	MNR Calculated	MNR Tabled	Stat. Sign.? (alpha=.05)
Env. Condition	8.4	.454	.5294	No
Temperature	8.4	.486	.5294	No
Vapor Pressure	8.4	.433	.5294	No

TABLE 21
MNR tests: Controlled processing difference scores

Treatment Combination	Tested Data Point	MNR Calculated	MNR Tabled	Stat. Sign.? (alpha=.05)
Env. Condition	86	.487	.5294	No
Temperature	86	.486	.5294	No
Vapor Pressure	86	.503	.5294	No

Although no controlled processing scores were found to be outliers, one automatic processing score was an outlier. That outlier was subject 6 in environmental condition 2, but only in the proportion score analysis of temperature. Table 22 presents the analysis of variance without the outlier point.

TABLE 22
ANOVA of Proportion scores for temperature without outlier

Source	Degrees of Freedom	Sum of Squares	Mean Squares	F	Pr>F
Between					
S	7	1.11	0.16		
Within					
T	1	0.04	0.04	0.46	0.52
T x S	7	0.68	0.10		
P	1	2.43	2.43	13.15	0.01
P x S	7	1.29	0.18		
T x P	1	0.01	0.01	0.11	0.75
T x P x S	7	0.68	0.10		
Total	31	6.24			

where: T = temperature P = type of processing S = subjects

As seen in the above table, removing the one outlier point from the analysis did not markedly change F-values. Similar values were seen in the two analyses (with outlier and without outlier).

In all preceding analyses, the two types of processing were significantly different. Therefore, each task was analyzed separately, as difference scores and proportion scores. The same analyses were performed on the individual tasks as was performed on the combined data. Tables 23 through 25 present the results of the analyses of variance for the automatic processing task alone, using proportion scores. Tables 26 through 28 present the results of the analyses of variance for the automatic processing task alone, using difference scores.

TABLE 23
ANOVA of Automatic processing proportion scores for environmental condition

Source	Degrees of Freedom	Sum of Squares	Mean Squares	F	Pr>F
Between					
S	7	0.12	0.02		
Within					
E	3	0.01	0.003	1.09	0.38
E x S	21	0.07	0.003		
Total	31	0.20			

where: E = environmental condition P = type of processing S = subjects

TABLE 24
ANOVA of Automatic processing proportion scores for temperature

Source	Degrees of Freedom	Sum of Squares	Mean Squares	F	Pr>F
Between					
S	7	0.07	0.01		
Within					
T	1	0.01	0.01	2.07	0.19
T x S	7	0.02	0.003		
Total	15	0.10			

where: T = temperature P = type of processing S = subjects

TABLE 25
ANOVA of Automatic processing proportion scores for vapor pressure

Source	Degrees of Freedom	Sum of Squares	Mean Squares	F	Pr>F
Between					
S	7	0.11	0.02		
Within					
V	2	0.01	0.005	2.87	0.09
V x S	14	0.02	0.002		
Total	23	0.14			

where: V = vapor pressure P = type of processing S = subjects

TABLE 26
ANOVA of Automatic processing difference scores for environmental condition

Source	Degrees of Freedom	Sum of Squares	Mean Squares	F	Pr>F
Between					
S	7	189.31	27.04		
Within					
E	3	17.27	5.76	1.36	0.28
E x S	21	89.14	4.25		
Total	31	295.72			

where: E = environmental condition P = type of processing S = subjects

TABLE 27
ANOVA of Automatic processing difference scores for temperature

Source	Degrees of Freedom	Sum of Squares	Mean Squares	F	Pr>F
Between					
S	7	134.68	19.24		
Within					
T	1	10.12	10.12	2.52	0.16
T x S	7	28.16	4.02		
Total	15	172.96			

where: T = temperature P = type of processing S = subjects

TABLE 28
ANOVA of Automatic processing difference scores for vapor pressure

Source	Degrees of Freedom	Sum of Squares	Mean Squares	F	Pr>F
Between					
S	7	168.95	24.14		
Within					
V	2	15.51	7.76	3.21	0.07
V x S	14	33.78	2.41		
Total	23	218.24			

where: V = vapor pressure P = type of processing S = subjects

No significant differences were found. However, there was almost a significant difference found between the three levels of vapor pressure (Pr>F=0.07). Although no statistically significant differences were found, F-values were markedly higher than in the combined data analysis.

Tables 29 through 31 illustrate analyses of variance for the controlled processing task using proportion scores. Tables 32 through 34 present the same analyses using difference scores.

TABLE 29
ANOVA of Controlled processing proportion scores for environmental condition

Source	Degrees of Freedom	Sum of Squares	Mean Squares	F	Pr>F
Between					
S	7	3.12	0.45		
Within					
E	3	0.07	0.02	0.20	0.90
E x S	21	2.29	0.11		
Total	31	5.48			

where: E = environmental condition P = type of processing S = subjects

TABLE 30
ANOVA of Controlled processing proportion scores for temperature

Source	Degrees of Freedom	Sum of Squares	Mean Squares	F	Pr>F
Between					
S	7	2.34	0.33		
Within					
T	1	0.05	0.05	0.26	0.63
T x S	7	1.34	0.19		
Total	15	3.73			

where: T = temperature P = type of processing S = subjects

TABLE 31
ANOVA of Controlled processing proportion scores for vapor pressure

Source	Degrees of Freedom	Sum of Squares	Mean Squares	F	Pr>F
Between					
S	7	3.02	0.43		
Within					
V	2	0.03	0.02	0.14	0.87
V x S	14	1.62	0.12		
Total	23	4.67			

where: V = vapor pressure P = type of processing S = subjects

TABLE 32
ANOVA of Controlled processing difference scores for environmental condition

Source	Degrees of Freedom	Sum of Squares	Mean Squares	F	Pr>F
Between					
S	7	9299.88	1328.55		
Within					
E	3	168.38	56.13	0.18	0.91
E x S	21	6374.63	303.55		
Total	31	15842.89			

where: E = environmental condition P = type of processing S = subjects

TABLE 33
ANOVA of Controlled processing difference scores for temperature

Source	Degrees of Freedom	Sum of Squares	Mean Squares	F	Pr>F
Between					
S	7	8107.63	1158.23		
Within					
T	1	84.38	84.38	0.16	0.70
T x S	7	3784.63	540.66		
Total	15	11976.64			

where: T = temperature P = type of processing S = subjects

TABLE 34
ANOVA of Controlled processing difference scores for vapor pressure

Source	Degrees of Freedom	Sum of Squares	Mean Squares	F	Pr>F
Between					
S	7	8323.15	1189.02		
Within					
V	2	96.13	48.06	0.15	0.86
V x S	14	4454.88	318.21		
Total	23	12874.16			

where: V = vapor pressure P = type of processing S = subjects

No significant differences were found for the controlled processing task either. F-values were very low, indicating that variability dominated the experiment. Because the low F-values did not occur in the automatic processing task, the variability in the controlled processing task appears to be the cause of the low F-values in the combined data analyses.

DISCUSSION

As was seen in the Results section, a large amount of variability existed in the data, especially in the controlled processing task. This was evidenced by very low F-values. Because of this variability, analyses did not provide the results expected. In the original analyses, F-values of all factors (excluding the main effect of type of processing) and interactions were below 0.5. An F-value of one indicates that the treatment had no effect, and to the extent that it is below one, variability dominates the experiment. F-values in this experiment indicated severe variability.

Mean automatic processing scores increased as the environmental conditions became less severe. This may be explained by a slight, but statistically insignificant effect by heat stress. On the other hand, mean controlled processing scores increased in the order of presentation. Figure 1 suggested that this was not a result of a learning effect. Instead, the order appears to be the result of a few very high scores.

Puzzle one appears to be less difficult than the other three. Although this puzzle was presented to each subject exactly once and to each condition exactly twice, the fact that this puzzle was so much different than the other three adds variability to the task. In addition, because all mean controlled processing difference scores were positive (proportion scores greater than one), the pre-trial puzzle may have been more difficult than the four experimental trial puzzles. The five puzzles used in the experiment appeared to be of equal difficulty, based on pilot subject performance. Subjects could have been nervous about the experiment on their first visit to the chamber, resulting in a lower pre-trial score. If this were the case, they may have been affected more in the controlled processing task than in the automatic processing task. This would be supported by previous studies that have found that automatic processing tasks are less affected by various forms of stressors than controlled processing tasks.

Variability within subjects was also a problem. For example, subject number 8 correctly placed 145 pieces on puzzle number one, after averaging 94.7 pieces on the other three puzzles. Because this was not an isolated case, the point was not identified as an outlier.

No assumptions of parametric statistics were concluded to be violated. Therefore, there was no basis on which to go to a nonparametric statistical test. The only outlier score was the automatic processing score for subject 6 in environmental condition 2, in the temperature analysis. This outlier point did not substantially affect the results of the analyses.

The only statistically significant factor was the type of processing. Controlled processing proportion scores were significantly greater than automatic processing proportion scores. Subsequently, each task was analyzed separately. No statistical differences were found in the automatic processing task (although there was almost a statistical difference found between the three levels of vapor pressure). No statistical differences were found in the controlled processing task either. There was indication that the variability in the experiment primarily resulted from this task.

Too much variability existed in this experiment. Some of the possible explanations for this variability include (1) an inadequate controlled processing task, (2) a non-homogeneous group of subjects, (3) a lack of subject motivation, (4) too mild of environmental conditions, and (5) subject tolerance to heat.

The controlled processing task did not appear to be an adequate measure of subject performance. Any effect by heat stress was overshadowed by other factors, such as individual variability of the task score. One subject correctly placed over three times as many pieces in one trial as another. This type of performance was not common for all however, and resulted in too much variability to find significant differences. The experimenter believes that the controlled processing scores are not adequately related to task performance.

Subjects may have been from a non-homogeneous group. More consistent ability may have resulted in similar effects. As it existed, scores for the controlled processing task were spread over a very wide range. Some subjects may have become less motivated during the experiment. This would result in performance decrements at the end of the experiment. Because environmental condition 1 (the least severe) was the last trial seen by all subjects, a lack of subject motivation at the end of the experiment could have resulted in a masking of a temperature effect.

An effect may have been more pronounced in more severe environmental conditions. More severe environmental conditions may have also resulted in less variability, as all subjects may have been affected more consistently. As seen in

Appendix H, other studies have looked at more extreme environments.

Subjects participating in this experiment may have had more tolerance to heat than other people. Four of the eight subjects were from India and two others were from Indonesia. No subjects had been in the United States for less than two years before the experiment, so heat adaptation should not have been a problem. Acclimatization to the heat should disappear after two to three weeks of return to normal conditions (Kroemer, 1991). Although College Station, Texas generally experiences a warm climate, this experiment was conducted in February. For several months before and throughout the experiment, ambient temperatures were much cooler than the environmental conditions. At one point during the study, the outside temperature was well below 30°F. Considering the temperatures that were seen during the time of the experiment, the subjects should not have been acclimatized to the heat. As the experiment was conducted, too much variability was introduced into the scores to provide significant results.

FUTURE RESEARCH

IMPROVING THE EXISTING EXPERIMENT

Variability was a major problem in this study, especially for the controlled processing task. Two methods of addressing variability are (1) to reduce the variability and (2) to increase the sample size. Each method will be discussed with emphasis on future research.

Reducing the Variability

In future studies, the controlled processing task should be improved or replaced with one that will not introduce as much variability into the study. Although the automatic processing task did not introduce as much variability into the experiment as the controlled processing task, it too could be improved. The automatic processing task was more consistent than the controlled processing task. Although each task was tested prior to implementation into the study, more extensive testing may have indicated that the controlled processing task was inadequate. Therefore, future controlled processing tasks should be evaluated very carefully before implementation.

A better controlled processing task might be a typing task with novice typists. The difference in type of processing would result from differences between subject ability.

Task improvement may also result from stricter subject selection. Subjects of more similar ability would reduce variability. Variability may also be reduced with the introduction of an incentive to motivate subjects to work at their full capacity.

More extreme temperatures may result in a temperature effect, while magnifying a vapor pressure effect. In addition, more extreme environmental conditions may reduce variability by affecting subjects more consistently. For example, an 85°F room may seem warm to some people and comfortable to others. On the other hand, a room that is 130°F would probably be perceived as uncomfortably hot to everyone. ANSI/ASHRAE Standard 55-1992 specifies the combinations of indoor space environment and personal factors that will produce thermal environmental conditions acceptable to 80% or more of the occupants within a space (ASHRAE, 1992). This standard recognizes that not all people are comfortable or uncomfortable in the same environment. Several subjects indicated that the environmental conditions were not very uncomfortable, while others felt that the most severe environmental condition was at least moderately uncomfortable. The experimenter recommends careful choice of environmental conditions in future research.

Increasing the Sample Size

Increasing the sample size decreases the impact of variability in the study. Sometimes practical limitations prohibit increasing the sample size enough to provide significantly more power. In that case, the marginal gain of increasing the sample size by several subjects may not be worth the cost of doing so. However, if the sample size is not large enough, variability within the experiment may not allow significant differences to be found.

A power analysis was performed to determine the necessary number of subjects to find a significant difference between levels of the independent variables, given the observed means and standard deviations (Cohen, 1969). Sample sizes, determined by the power analyses, are indicated in Tables 35 through 37.

TABLE 35
Necessary sample size: Automatic processing

Treatment Combination	Necessary N Power=.9	Necessary N Power=.8	Necessary N Power=.7	Necessary N Power=.5
Environmental Condition	298	228	183	118
Temperature	159	119	94	59
Vapor Pressure	84	64	52	33

TABLE 36
Necessary sample size: Controlled processing

Treatment Combination	Necessary N Power=.9	Necessary N Power=.8	Necessary N Power=.7	Necessary N Power=.5
Environmental Condition	1637	1252	1001	645
Temperature	1020	763	600	374
Vapor Pressure	712	545	436	281

TABLE 37
Necessary sample size: Proportion scores for combined data

Treatment Combination	Necessary N Power=.9	Necessary N Power=.8	Necessary N Power=.7	Necessary N Power=.5
Environmental Condition	2868	2193	1753	1129
Temperature	1015	759	597	372
Vapor Pressure	1282	980	784	505

The number of subjects used in this experiment was not sufficient to find a significant difference between factors. The controlled processing tasks had so much variability that hundreds, and in some cases even thousands of additional subjects would be needed to find a statistically significant difference with the observed means and standard deviations. The use of that many subjects would be impractical, and thus the variability in the experiment must be reduced in future research. Although the three levels of vapor pressure were almost found to be significantly different ($Pr>F=0.07$) with only eight subjects, an additional 25 subjects would be necessary to achieve significance with 50% power. Power in the experiment was very low.

This research indicates several areas of improvement for the future. First, the controlled processing task must be improved or replaced. Second, the sample size should be determined based on charts relating the desired power and sample size to a hypothesized effect. Thus sample size would be chosen based on known parameters. If the automatic processing task is used in future research, the observed means and standard deviations can be used to determine the necessary sample size. In addition, stricter subject selection would also reduce variability, allowing significant differences to be more easily found. Future efforts can still be concentrated on trying to isolate an effect of vapor pressure as variability in this experiment prohibited such a finding.

COLLECTING ADDITIONAL DATA

Future researchers should consider recording heart rate and core temperature data. This data would indicate the physiological strain induced on the subject in the various thermal environmental conditions. The data could also be studied to determine the change in physiological strain throughout experimental trials. In addition, the physiological strain could be compared to task performance. Recording such data in this experiment could have indicated whether or not the environmental conditions had any physiological affect on the subjects.

CONCLUSIONS

Environmental conditions did not significantly affect either the automatic processing task or the controlled processing task. The only statistical difference identified was between the two types of processing which indicates that subjects performed differently on the automatic processing task and the controlled processing task. Controlled processing proportion scores were significantly greater, but more variable, than automatic processing proportion scores. This means that for the controlled processing task, subjects scored higher trial scores relative to pre-trial scores than on the automatic processing task. However, the controlled processing task was dominated by variability. Therefore, although the automatic processing task appeared to be adequate, the controlled processing task did not adequately test the subjects' controlled processing ability.

Recommended improvements for future research efforts include (1) improving or replacing the controlled processing task, (2) using more subjects, (3) choosing a more homogeneous group of subjects, (4) providing an incentive to the subjects to provide a constant level of effort, and (5) using more extreme environmental conditions.

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APPENDIX A

Some Heat Stress Indices

Effective Temperature

The Effective Temperature Scale was developed in 1923 by Houghton and Yaglou as a sensory scale of warmth (Kerslake, 1972). It is based on instantaneous impressions of subjects moving back and forth from one conditioned room to another (Kerslake, 1972). If two environments are sensed as the same by subjects, the Effective Temperature will be the same, even though the various environmental conditions may not be. Houghton and Yaglou (1923) stated that the lines on the Effective Temperature chart represented lines of equal comfort or effective temperature. They felt that this chart indicated a true index of one's feeling of warmth. Poulton (1970) indicated that the Effective Temperature scale is based upon the heating or cooling effects of the atmosphere upon the skin of people who wandered from one room to another, and therefore should be applied to the same type of situations. This is not the case in situations where people do heavy work.

Operative Temperature

The Operative Temperature scale was developed in 1937 by Winslow, Herrington, and Gagge. The operative temperature represents a value properly derived to correspond to the known physical effects of radiation and convection (Winslow, Herrington, and Gagge, 1937). It does not however take into account the effects of humidity and air flow (Sanders and McCormick, 1987).

Corrected Effective Temperature (CET)

The Corrected Effective Temperature Scale was developed in 1946 by Bedford. As the name implies there is a correction factor applied to the original Effective Temperature Scale (Kerslake, 1972). This scale makes allowances for radiation. In practice, the Corrected Effective Temperature is obtained by entering the Effective Temperature nomogram with the observed values of globe and wet bulb temperatures (Kerslake, 1972).

Predicted 4-hour sweat rate (P4SR)

The Predicted 4-hour sweat rate was developed in 1947 by McArdle, Dunham, Holling, Ladell, Scott, Thomson, and Weiner to predict the amount of sweat that would be produced in the course of four hours. Known factors include air movement, dry temperature, wet temperature, and globe temperature in the case of radiant heat (Rodahl and Guthe, 1988). In addition, work load and clothing must be taken into account.

Heat Stress Index

The Heat Stress Index was developed by Belding and Hatch (1956), and is based on the analysis of heat exchange between the body and the environment. The rate of evaporative heat loss required for heat balance and the maximum evaporative capacity are each estimated (Kerslake, 1972). All calculations are based on a skin temperature of 35.0°C and a body surface area of 1.86 m^2. In addition, respiratory heat exchange is neglected. These assumptions allow the two estimated quantities to be found through the use of simple nomograms (Kerslake, 1972).

Wet Bulb Globe Temperature (WBGT)

The Wet Bulb Globe Temperature was developed in 1957 by Yaglou and Minard as an improvement to the Effective Temperature Scale. It takes into account radiant heat, which the Effective Temperature Scale did not (Kerslake, 1972). The index weights different temperatures according to the following formulas:

$$WBGT = 0.7\ T_{nw} + 0.2\ T_g + 0.1\ T_a \qquad \text{(radiant energy)}$$

$$WBGT = 0.7\ T_{nw} + 0.3\ T_g \qquad \text{(no radiant energy)}$$

T_{nw} = natural wet bulb temperature

T_g = globe temperature

T_a = dry bulb temperature

Wet Globe Temperature (WGT)

The Wet Globe Temperature scale was developed in 1971 by Botsford, and is comparable to the Wet Bulb Globe Temperature. It provides one number for heat stress, and uses a copper sphere covered by a wetted black cloth (Goldman, 1988). Botsford (1971) describes the wet globe thermometer as a simple instrument which combines air temperature, velocity, humidity, and thermal radiation into a single reading that is related to human responses in a meaningful way. He also states that the wet globe temperature correlates well with established methods of evaluating the thermal environment.

Standard Effective Temperature

The Standard Effective Temperature scale was developed in 1971 by Gagge, Stolwijk, and Nishi. It is a numerical index, and is defined in terms of dry bulb temperature and normal humidity (Gagge et al, 1971). It is comparable to temperatures of natural environments, which one generally experiences in temperate climates (Gagge et al, 1971). Of primary interest for this scale are normally clothed sedentary subjects in a uniformly heated and normally ventilated environment (Gagge et al, 1971).

APPENDIX B

Criteria for selection as an expert keyboardist

All potential subjects were given two separate timed tests, in which it was determined if their keyboarding skill level met the minimum standards for participation in the experiment. To pass the testing criteria, the subject had to type at least 40 gross words a minute (GWAM), with five or less errors in each of the two passages of text. A gross word is simply a standard 5-stroke word (Wanous, 1967).

If a subject passed the pretest, he then typed two different ten-minute writings to simulate the future automatic processing trials. The two writings were separated by a three-minute break during which the experimenter saved the work on a disk. The performance for the two ten-minute writings was measured by calculating the total number of correct gross words per minute. The measuring scale needed to be something to account for both speed and accuracy. Although West (1969) stated that on any given testing occasion, a pair of different five minute timings provides a highly reliable measure of stroking speed, a pair of ten minute timed writings was used because the ten-minute writings will increase the total exposure time for the subjects in the environmental chamber. In addition, although West (1969) indicated that speed and accuracy should be separated, it was decided that the performance measure for the keyboarding task would be the number of gross words correctly entered per minute (GWCEPM), relative to the number entered during the testing period. This was decided because it is much easier to correct mistakes on a keyboard than a typewriter, and it was simpler to work with a single value for a performance measure. The score from this initial pair of ten-minute writings was then used as a pre-trial score for the subject. The score was used as a comparison for the performance of the later automatic tasks. For example, if a subject's score was 52 GWCEPM on the pretest, and 36 GWCEPM on an experimental trial, the score for that trial would have been -16.

APPENDIX C

Explanation of the Study

This study looks at the effect of heat stress on the performance of certain types of tasks. The study involves experimentation for the purpose of determining the effect of heat stress on certain types of tasks.

The first thing that will be done in each experimental trial is determining your estimated core temperature. This will be done by taking your oral temperature and then using this sensor to convert it to an estimated core temperature. Throughout the experiment, your estimated core temperature and heart rate will be monitored to be sure that you do not reach the preset limits for removal. These preset limits are below the critical levels, but to be sure that you are protected, you will be removed if you hear either of the two alarms.

The experiment will consist of eight trials, each of which is expected to last approximately one hour. These trials will consist of either entering passages of text or working a computerized jigsaw puzzle. The order in which you are placed into the different environmental conditions and perform the tasks will be different for every subject. In addition, you will perform each of the two tasks today to be used as a comparison to later trials.

APPENDIX D

Informed Consent Form

Industrial Engineering Department
The Effect of Heat on Cognitive Performance
(Hughes/Koppa Fall 1993)

Subject #_____

I. PURPOSE OF THE EXPERIMENT

You are invited to participate in a study about the effect of different environmental conditions on the performance of certain tasks. The study involves experimentation for the purpose of evaluating the effect of heat on cognitive tasks, and will be performed in the Steed Research and Conditioning Laboratory at Texas A&M. This study, which will consist of eight, one hour experimental sessions per subject, involves eight subjects in addition to myself, the experimenter.

II. PROCEDURES

The procedures to be used in this research are typing several passages of text and working jigsaw puzzles, each on a computer. Each of the tasks will be performed under varying environmental conditions.

The possible risks to you as a participant are those that are typically associated with exposure to heat. They can be grouped into four clinical syndromes. These syndromes are heat cramps, heat exhaustion, exertional heat injury, and heat stroke.

Heat cramps are the least dangerous of all of the syndromes. Cramps are characterized by painful spasms of the voluntary muscles and usually follow strenuous exercise. It usually occurs in individuals in good physical condition, following a period of excessive sweating.

The second syndrome is heat exhaustion, which is probably the most common. This is when the cardiovascular responses fail as a result of high temperatures, and is particularly common in elderly individuals receiving diuretics (drugs or substances that promote the formation and excretion of urine). Preceding collapse there are a variety of symptoms including weakness, vertigo (similar to dizziness), headache, anorexia (lack or loss of appetite), nausea, vomiting, the urge to defecate, and faintness. Heat collapse can occur in both physically active as well as sedentary individuals. The onset of collapse is often rapid, and the duration of collapse brief.

The third syndrome is exertional heat injury, which occurs in individuals who are exerting themselves in hot ambient temperatures with a high relative humidity. It is particularly common in runners who enter races when they are not properly conditioned or fully prepared for the race. There are a variety of symptoms of exertional heat injury, including headache, piloerection (gooseflesh) on the chest and upper arms, chills, overbreathing, nausea, vomiting, muscle cramps, ataxia (impaired ability to coordinate movement), unsteady gait, incoherent speech, and in some cases a loss of consciousness.

The final syndrome, heat stroke, is most common in elderly individuals with preexisting chronic disease. Among these are arteriosclerosis (thickening, loss of elasticity, and calcification of arterial walls) and congestive heart failure, particularly when the patients receive diuretics (drugs or substances that promote the formation and excretion of urine). There are also a variety of other medical conditions which can make a person more susceptible to heat stroke. Among the symptoms of heat stroke are a loss of consciousness, headache, vertigo (similar to dizziness), faintness, abdominal distress, confusion, hyperpnea (deep, rapid, or labored respiration), and possibly delirium. Patients with heat stroke may die within a few hours or weeks following the episode.

Safeguards that will be used to minimize your risk are the monitoring of your estimated deep body temperature and the tracking of your heart rate. If either of these reach a predetermined limit, you will be removed from the environmental chamber. These limits have been determined as acceptable by the Student Health Center. Your medical records and the health questionnaire that you will fill out, will be reviewed by Donald freeman, M.D., Student Health Center, Texas A&M University. There has also been a contingency plan developed in the event that you show symptoms of heat illness. If any medical treatment would be necessary, you (or your insurance company) would be required to pay all costs.

III. BENEFITS OF THIS PROJECT

Your participation in the project will provide information regarding the effect of heat stress on cognitive processes. No guarantee of benefits has been made to encourage you to participate.

You may receive a summary of this research when completed. Please leave a self-addressed envelope (or appropriate means).

IV. EXTENT OF ANONYMITY AND CONFIDENTIALITY

Your individual results will be kept strictly confidential. At no time will the researchers release your individual results in the study to anyone other than the individuals working on the project, without your written consent. The information you provide will have your name removed and only a subject number will identify you during analyses and any written reports of the research. The results of the study will however be submitted for publication, but no individual subject results will be identifiable.

As was mentioned earlier, your medical records will be reviewed by Donald Freeman, M.D., Student Health Center. This will be done to be sure that nothing in your medical history indicates a susceptibility to heat illness. The information provided on the health questionnaire and your medical records will not be released, whether you participate in this study or not.

V. COMPENSATION

For participation in the project you will receive $5 for each hour completed, plus an additional bonus of $10 for completing the study. This will result in a total of approximately $55.

VI. FREEDOM TO WITHDRAW

You are free to withdraw from this study at any time without penalty. If you choose to withdraw, you will be compensated for the portion of the study that you completed.

There may be circumstances under which the investigator determines that you should not continue as a subject of this project. These circumstances are if you do not meet the criteria of the study, Donald Freeman, M.D. indicates that you are susceptible to heat illness and feels that you should not participate, if during the conduct of the study your heart rate reaches 140 beats per minute, or if during the conduct of the study your estimated core temperature reaches 38.2°C (101°F). You will however be compensated for the portion for the project completed. If during the course of a trial you are withdrawn, you will be allowed to continue with the experiment at a later date as long as the rescue squad did not need to be called and you had not been withdrawn earlier.

VII. APPROVAL OF RESEARCH

This research project has been reviewed and approved by the Institutional Review Board - Human Subjects in Research, Texas A&M University. For research related problems or questions regarding subjects' rights, the Institutional Review board may be contacted through Dr. Richard E. Miller, IRB Coordinator, Office of University Research, (409) 845 - 1811.

VIII. SUBJECT'S RESPONSIBILITIES

Please confirm your understanding of the following statements before signing the informed consent form.

I will answer all questions on the health questionnaire as accurately as possible,
I will wear the specified clothing ensemble during the experimental trials,
I will not consume alcohol or take casual drugs for 24 hours before any experimental trial,
I will not participate in vigorous exercise for 4 hours before any experimental trial (i.e. running up the stairs to the experiment),
I will not eat or drink anything for 30 minutes prior to any experimental trial,
I will notify the experimenter of any illness or medical condition that occurs during the experiment,
I will notify the experimenter if I take any medication during the experiment,
I have read and understand the above description of the study and possible risks,
I have had the opportunity to ask questions and have had all of them answered,
I hereby acknowledge the above and give my voluntary consent for participation in this study,
I understand that if I choose to participate in the study, I may withdraw at any time without penalty, and
I understand that should I have any questions about this research and its conduct, I should contact the following.

Principal Investigator:	Dr. Rodger Koppa Industrial Engineering Zachry Hall	845-3540
	Mr. Raymond Hughes TTI, Safety Division Building 7751, 128K	845-9928

I have read and understand the explanation provided to me and voluntarily agree to participate in this study.

Subject's Signature:_______________ Date:____

Subject's ID Number:_______________

SUBJECT COPY OF PERMISSION AND RESPONSIBILITIES

You, the subject, have the following responsibilities and rights.

I will answer all questions on the health questionnaire as accurately as possible,
I will wear the specified clothing ensemble during the experimental trials,
I will not consume alcohol or take casual drugs for 24 hours before any experimental trial,
I will not participate in vigorous exercise for 4 hours before any experimental trial (i.e. running up the stairs to the experiment),
I will not eat or drink anything for 30 minutes prior to any experimental trial,
I will notify the experimenter of any illness or medical condition that occurs during the experiment,
I will notify the experimenter if I take any medication during the experiment,
I have read and understand the above description of the study and possible risks,
I have had the opportunity to ask questions and have had all of them answered,
I hereby acknowledge the above and give my voluntary consent for participation in this study,
I understand that if I choose to participate in the study, I may withdraw at any time without penalty, and
I understand that should I have any questions about this research and its conduct, I should contact the following.

Principal Investigator:	Dr. Rodger Koppa Industrial Engineering Zachry Hall	845-3540
	Mr. Raymond Hughes TTI, Safety Division Building 7751, 128K	845-9928

APPENDIX E
Screening Health Questionnaire

Signing this form signifies your granting of permission to the Department of Industrial and Systems Engineering to obtain the review of the questionnaire and health records by Donald Freeman, M.D., Student Health Center, Texas A&M University. This will be done to determine if there is any reason that you should not participate in this research.

Name: ______________________

SSN: ______________________

Age: ______________________

Weight: ______________________

Height: ______________________

Please answer each question either yes or no, and explain any yes response.

1. Have you ever had heat cramps, heat exhaustion, heat stroke, or passing out as a result of heat or exercise?

2. Have you ever experienced any muscle related problems as a result of heat or exercise?

3. Have you ever experienced chest pain or shortness of breath as a result of heat or exercise?

4. Do you have a history of heart disease?

5. Do you have a history of kidney disease?

6. Do you have a history of high or low blood pressure?

7. Do you have a history of diabetes?

8. Do you have a history of asthma or lung disease?

9. Do you have a history of stroke or seizure disorder?

10. Do you have a history of thyroid disease?

11. Do you have a history of problems with your central nervous system?

12. Have you had a problem with sweat production?

13. Have you had any recent infections?

14. Do you have any other current or chronic medical conditions?

15. Do you smoke? (If so how much)

16. Have you ever been treated for alcoholism or drug use?

17. Do you drink alcohol? (If so how much per week)

18. Do you take recreational drugs? (If so what kind and how much)

19. Are you on any medications at this time? (including over the counter medications)

20. Is there any additional information that you feel may be important concerning your medical history that you can include?

Note: A subject will be excluded from this study if he has a history of diabetes, heart disease, heat response disease (such as malignant hyperthermia), or any other indication that he will be susceptible to heat illness.

Signature: ________________

Date: ___________________

APPENDIX F

Instructions for Initial Visit

Please read the explanation of the study, and ask any questions that you may have. When you finish reading the explanation of the study, you may choose to read and sign the informed consent form as well as the screening health questionnaire. Please ask any questions that you may have, and be sure to note that your medical records and the questionnaire will be reviewed by Student Health Services if you sign the questionnaire.

When you feel that you have had all of your questions answered, you will be tested to be sure that you match our criteria as an expert keyboardist. You will enter two separate passages of text into the computer. Please enter the passages of text as you would if it was being done in a working environment.

If your pretest meets subject criteria, you will then perform each of the tasks that will be done in future trials. To begin, you will again enter two passages of text, but this time each will last ten minutes. Between passages, you will be given a three-minute rest period. When the second writing is complete, you will work a computerized jigsaw puzzle for 15 minutes.

Your medical records and questionnaire will be reviewed by Student Health Services. If they find no reason to bar your participation in the study, you will be asked to participate in eight more hours of the experiment, one hour per day. Before each experimental trial, you are asked not to do the following things. Do not consume alcohol or casual drugs for 24 hours before each trial. Do not participate in vigorous exercise for four hours before each trial. For example, do not run up the stairs to the experiment. Do not eat or drink anything for 30 minutes prior to an experimental trial. It is important that you are dressed in the same type of outfit for all trials. Please wear men's briefs, calf length socks, shoes, short-sleeve knit sport shirt, and walking shorts. You may bring your clothes and change into them when you arrive at the laboratory. In addition, you may also leave them here between trials.

If you develop any health problems or begin taking medication before you complete the study, please notify one of the experimenters so that this new information can be provided to the Student Health Services.

APPENDIX G

Instructions for Experimental Trials

INSTRUCTIONS - KEYBOARDING TASK

General Instructions. Before you perform the task, a heart rate and tympanic temperature monitor will be connected to you. These monitors are for your protection. Your health records and the questionnaire have been reviewed, and Student Health Services has found no reason that you should not participate in the study. We will however monitor your heart rate and estimated core temperature to detect any changes that would be too drastic. Upper limits for each of the measurements have been determined and accepted by the Student Health Services. These limits have been developed such that you would be removed before you reach a dangerous level.

You will be instructed to drink a glass of water to replace some of the water that you may lose through sweating. You will also be allowed to drink water throughout the experiment, but you are asked to drink the water during the rest period if possible. Because we are measuring the performance of your work, we would prefer that you do not stop working to take a drink of water. If however you feel that you need a drink, please take a drink as quickly as possible.

You will be in the environmental chamber for approximately one hour. The first half of the experiment will consist of attaching and calibrating the monitoring equipment and sitting in the chair. You will then perform the task at the table located by the door.

Note that the keyboard is the only equipment located inside of the chamber. The actual computer and screen are located outside of the chamber, but you can see the monitor through the door.

Keyboarding Task Instructions. You will be given two separate passages of text to enter via the keyboard in front of you. You can view your work on the monitor just outside of the door, and can arrange the keyboard and paper in any way that you would like. You should attempt to enter these passages of text just as you would in a work environment. When you begin typing, you will be presented only the first passage of text. You should enter as much of this passage of text as possible during the ten minutes that you are given, and if you complete the entire passage of text, go back to the beginning and start over. At the conclusion of the ten-minute period, I will instruct you to stop typing. At this point you will be given a three-minute rest period while I save your work on disk, and prepare the second passage of text for you to enter. When the rest period is over, you will enter the second passage of text in the same manner as the first. Throughout the trial, you will have unrestricted access to water. If possible, we would prefer that you only drink water during your rest periods, because we are trying to get an accurate measurement of your keyboarding ability. If however, you feel as if you need a drink of water during the trial, please take a drink as quickly as possible.

INSTRUCTIONS - JIGSAW PUZZLE TASK

General Instructions. Before you perform the task, a heart rate and tympanic temperature monitor will be connected to you. These monitors are for your protection. Your health records and the questionnaire have been reviewed, and Student Health Services has found no reason that you should not participate in the study. We will however monitor your heart rate and estimated core temperature to detect any changes that would be too drastic. Upper limits for each of the measurements have been determined and accepted by the Student Health Services. These limits have been developed such that you would be removed before you reach a dangerous level.

You will be instructed to drink a glass of water to replace some of the water that you may lose through sweating. You will also be allowed to drink water throughout the experiment, but you are asked to drink the water during the rest period if possible. Because we are measuring the performance of your work, we would prefer that you do not stop working to take a drink of water. If however you feel that you need a drink, please take a drink as quickly as possible.

You will be in the environmental chamber for approximately one hour. The first half of the experiment will consist of attaching and calibrating the monitoring equipment and sitting in the chair. You will then perform the task at the table located by the door. Note that the mouse is the only equipment located inside of the chamber. The actual computer and screen are located outside of the chamber, but you can see the monitor through the door.

Jigsaw Puzzle Task. You will be given a computerized puzzle to attempt to put together using the mouse in front of you. To choose a piece, you must click the right button on that piece. Then move the piece to the location that you would like and click the right button again. The two pieces will change locations. You can view your work on the monitor just outside of the door, and can arrange the mouse pad and mouse in any way that you would like. You should attempt to work as much of the jigsaw puzzle as possible during the 15 minutes allowed. There are a few notes regarding the puzzle. You will be given an overall view of the puzzle before you begin working it. Whenever you have a piece located in the correct position on the screen, the outside dark border of the piece will disappear and the piece cannot be moved again. Remember that if several pieces of the puzzle fit together, but are not in the correct position, they will not have the border disappear, and the pieces are not considered being correctly located.

Throughout the trial, you will have unrestricted access to water. If possible, we would prefer that you only drink water during your rest periods, because we are trying to get an accurate measurement of your ability to work computerized puzzles. If however, you feel as if you need a drink of water during the trial, please take a drink as quickly as possible.

APPENDIX H

Professional Opinions

Byron Jones
(913) 532 - 5620

- Kansas State University Institute for Environmental Research
- member of the Subject's Review Board
- Engineer
- has not done the research himself
- they have nurses or doctors
- he said ours is not extreme so he would have a nurse
- he felt as if the nurse would give a feeling of professionalism; the nurse would run the study
- they monitor blood pressure, heart rate (180 bpm), and core temperature (2° rise)

Dr. Fred Rohles
(913) 537 - 2936

- Kansas State University (retired)
- he said they hire a nurse as a research assistant
- he felt that hiring a nurse is a good practice, but we probably don't need it (we have only moderate heat stress)
- he felt that the shower across the hall was okay to cool any subjects down
- he felt that 140 bpm was fine for the heart rate limit
- he felt that with a core temperature rise of 2°, the subject should be pulled out
- he said to remember that heat stress does away with individual differences - most subjects will react in the same manner under heat stress conditions
- he said that they have done a lot higher heat stress exposures
- he said that the relative humidity is very high, but because our temperature is only 92°F (below body temperature), he did not feel that it was a problem with only 1 hour exposure and low activity levels
- he felt that the core temperature may not rise enough to see significant effects on performance by having the subject in the chamber for only 15 - 30 minutes before the task is begun
- he felt as if we have thought through our study, and did not have a problem with it
- when I asked him how he would feel if the study were performed without medical personnel, he said that although he would prefer to have medical personnel present he did not have any major concerns
- Dr. Rohles is an expert, and has published

Dr. Richard Gonzalez
(508) 651 - 4848
(508) 651 - 5298 (FAX)

- U.S. Army Research Institute of Environmental Medicine (Natic, Mass.)
- physiologist
- he was recommended by Byron Jones because as he said Dr. Gonzalez probably has as much experience with human subjects in hot/humid environments as anyone
- he felt that monitoring is more important than medical personnel
- he felt that our study was mild
- our monitoring is okay
  heart rate = 140 bpm is okay
  core temperature should be 101°F
- he said that he has done a lot higher heat stress exposures
- CPR for me would be okay
- keep the subjects well hydrated - I said 300 ml before the study

Dr. Newton Ellis
(409) 845 - 8787

- Texas A&M University
- he said they do not have medical personnel present
- he said they emphasize screening and choosing subjects that will not have any tendencies toward problems with heat exposure

APPENDIX I

Raw Data

Subject	Env Cond	PreTrial Puzzle	Puzzle Number	Puzzle Score	PreTrial Typing	Typing Passages	Typing Score
1	1	43	1	65	31.9375	8 3	34.84
1	2	43	3	43	31.9375	6 1	32.93
1	3	43	4	46	31.9375	4 2	34.59
1	4	43	2	20	31.9375	5 7	32.60
2	1	34	3	55	61.35	1 5	68.34
2	2	34	2	54	61.35	7 2	63.59
2	3	34	1	50	61.35	8 4	66.91
2	4	34	4	52	61.35	3 6	62.28
3	1	38	2	42	31.59	6 8	31.10
3	2	38	4	45	31.59	4 3	28.02
3	3	38	3	42	31.59	2 7	30.68
3	4	38	1	68	31.59	1 5	28.50
4	1	43	2	65	31.36	5 2	30.82
4	2	43	1	50	31.36	3 4	31.03
4	3	43	4	45	31.36	7 8	32.67
4	4	43	3	50	31.36	6 1	30.98
5	1	55	3	87	29.86	2 4	31.28
5	2	55	1	109	29.86	1 8	26.36
5	3	55	2	88	29.86	5 6	26.65
5	4	55	4	86	29.86	7 3	28.89
6	1	81	4	73	34.64	3 6	35.80
6	2	81	3	79	34.64	5 7	43.04

6	3	81	2	84	34.64	1 2	36.00
6	4	81	1	121	34.64	4 8	37.12
7	1	49	4	70	41.45	7 1	39.34
7	2	49	2	91	41.45	8 5	40.36
7	3	49	1	115	41.45	6 3	36.885
7	4	49	3	94	41.45	2 4	36.39
8	1	59	1	145	39.89	4 6	42.25
8	2	59	4	97	39.89	5 7	43.14
8	3	59	3	86	39.89	3 1	39.47
8	4	59	2	101	39.89	8 2	41.05

APPENDIX J

Example Recruiting Sign

Subjects Needed

Earn $55 (approx.)

- must meet health requirements
- must type at least 40 wpm
- one hour per day for eight days

Call:	Call:	Call:	Call:
Ray	Ray	Ray	Ray
696-6005	696-6005	696-6005	696-6005

VITA

Raymond E. Hughes, Jr., was born in Baltimore, MD on September 19, 1969. In 1995, he received his Master of Science degree in Industrial & Systems Engineering with a concentration in Human Factors and Safety Engineering from Virginia Tech, Blacksburg, VA. His B.S., received in 1991, was also in Industrial & Systems Engineering from Virginia Tech.

Raymond's professional experience includes positions as an Agency Management Lead Analyst for the Virginia Department of Transportation, a Research Associate for the Texas Transportation Institute, and a contractor at the Aberdeen Proving Grounds. During his six summers as a contractor at the Aberdeen Proving Grounds, his primary responsibilities included project support and programming. He began working in the Human Factors Group of the Safety Division at the Texas Transportation Institute in September 1993 where he was involved in a variety of transportation research and evaluation projects. In November 1994, he began working in the Management Services Division of the Virginia Department of Transportation as an Agency Management Lead Analyst. While with the Virginia Department of Transportation, he has utilized a variety of classical industrial engineering techniques on various evaluation and productivity projects.

Raymond E Hughes Jr.