THE EFFECTS OF COLD ON HUMAN COGNITIVE PERFORMANCE - IMPLICATIONS FOR DESIGN

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Abstract

Many studies have looked at the physiological effects of sub-thermal temperatures and many conclusions are generally understood. However, there exists considerable debate as to whether cold environments affect human cognitive performance within the literature. The purpose of this study was to determine if cold environments affect human information processing. Twenty subjects (10 male and 10 female) participated in this study and were compensated. Subjects core body temperature (as measured tympanically) was dropped to 35.5°C and a Performance Assessment Battery (PAB) of tests was administered as well as a similar PAB at room temperature. This was a novel technique in the field of environmental ergonomics as all other research literature used time as a determinant of test administration. The PAB consisted of four tests (The Stroop Word-Colour test, a Working Memory test, a Signal Detection test and the Fitt's Task) that represented the four major stages of information processing (Perception, Working Memory, Response Selection and Response Execution). The results indicated that in fact, some stages of information processing were adversely affected when a reduced core body temperature was introduced however, caution should be advised when considering the latter two stages. Attention was allocated to the distracting effects of the cold environment during the more difficult tasks but could be argued that cold focused attention on the simpler tasks as only limited attention was required. The method introduced in the present study should be considered in further investigations as attempts to standardise variables in such testing conditions continues.

Introduction

For years human have had to endure a myriad of climatic changes that imposed different types of thermal stresses that are physically and mentally challenging (Enander 1990). The physiological responses to cold environments have been well documented (Kromer *et al.* 1997; McCardle *et al.* 1997; Rammsayer *et al.* 1995). With an increase in technology there is an increase in the ability to extract natural resources from increasingly adverse climates. In these working environments it is seldom that humans are stressed to physiological limits (Enander 1989; Enander and Hygge 1990). The fact that humans may not be maximally stressed physiologically, still leaves unanswered the question: do cold environments have an effect on cognitive performance and in particular, information processing?

Considering the plethora of occupations that expose man to such climates, little research has been done to address this issue (Enander and Hygge 1990; Ellis *et al.* 1985; Rammsayer *et al.* 1995). Within the existing research, many of the studies that have looked at cognitive capabilities during cold stress and have simulated this stress by cold water immersion (Baddeley *et al.* 1975; Banks 1979; Biersner 1976; Bowen 1968; Coleshaw *et al.* 1983; Lockhart 1968; Stang and Wiener 1970). Many of these early studies were conducted for military purposes and for those performing underwater work.

None of the previously researched studies have looked at the implications towards the design of end user products or persons exposed to such climates during vocational activities. Sanders and McCormick (1993) highlight human centred design guidelines (e.g. compatibility principles) but do little in the way of altering such guidelines when an operator is exposed to the cold ambient environment. Corlet & Clark (1995) outline control dimensions and standard efforts needed for operation but they too, failed to qualify the apparent lack of need to adjust such control and display characteristics. It is essential that an understanding be achieved as to how, if at all, mans' cognitive processes are altered while experiencing a drop in deep body temperature.

In general, the literature has yielded little information on the effects of cold environments on human cognitive performance. This may be caused by the difficulty in simulating such environments (i.e. not being able to produce similar wind-chill effects, Enander and Hygge 1990) or not having a reliable task to measure cognitive performance (Ellis 1985). What has been strikingly apparent throughout the literature has been the differences in methodology that are used in the various studies. With respect to cold air exposure Rammsayer *et al.* (1995) and Thomas *et al.* (1983) subjected their subjects to similar temperature but the protocols were drastically different. Likewise, in the cold water immersion studies, there are huge discrepancies with respect to water temperature and the duration that a subject is immersed.

All of the studies reviewed by the author have not considered individual differences with respect to individual's cooling rates. A person's cooling rate is dependent on many variables, and is extremely difficult to standardize across a sample of people (McCardle *et al.* 1997). Enander and Hygge (1990) state, "it has been proven considerably more difficult to establish relationships between indices of physiological measures of thermal stress and more complex cognitive and mental tasks." (pg. 44) Therefore, this study will attempt to minimize individual differences when examining the effects of cold environments on human cognitive performance, by lowering core body temperature to a predetermined level, regardless of the time to achieve this temperature. This technique of measurement and the consideration of individual differences among individuals have not been previously utilized in the published literature.

The purpose of this study is to examine how cold environments affect human cognitive performance and information processing in particular.

Methods
Subjects

The subjects (n=20) were recruited from within a university population. Subject data is presented in Table 1. There were an equal number of females and males that participated in this study. Male subjects were screen to fall within a range of 9-18% body fat while female subjects, who are predisposed to a higher percent body fat (McCardle, *et al.* 1997), fell into a 16-25% body fat range. These ranges have been declared as normal ranges for the respective sexes (Robbins *et al.* 1994). None of the subjects were colour blind. The subjects were compensated for their participation, as was noted in the signed consent form given before testing began (see Appendix A). Before participating in the study, all subjects completed a physical activity readiness questionnaire (PAR-Q) that was included with the consent form.

Table 1: Subject data (means and standard deviations) prior to testing.
Procedures

	Age (yrs)	Ht. (cm)	Wt. (kg)	% Body Fat	Resting Temp.(°C)
Mean	21.75	173.55	71.24	17.93	36.69
Stand Dev.	2.00	8.32	10.97	4.50	0.30

After the subjects entered the testing environment, they were randomly assigned, by a toss of a coin, into a control-experimental or experimental-control group. This was in attempt to control the order effect that has been previously shown to occur (Deese and Hulse 1967). Subjects core body temperature was measured with the *Braun Thermoscan*™ ten minutes after arrival and while seated. The use of the tympanic measurement has been used in previous studies that have looked cold and its effect on information processing (Rammsayer *et al.* 1995), memory registration and speed of reasoning (Coleshaw *et al.* 1983) and hormonal response to cognitive activity (Thomas *et al.* 1990). Likewise, various medical studies involving cardiac patients (Pujol *et al.* 1996), burn victims (Wilson *et al.* 1971) have identified this measure as the most reliable due to the tympanic membranes close proximity to the hypothalamus (Benzinger 1969), the thermoregulating center of body (Totora and Grabowski, 1995).

Once body temperature had been determined, the performance assessment battery (PAB) was administered. Subjects were instructed to wear shorts, t-shirt, socks and running shoes and not eat or exercise 2 hours prior to testing. These requirements are consistent with other moderate cold exposure studies (Thomas *et al.* 1983). In the control testing condition, room temperature was held constant at 18±2°C with a low relative humidity (RH) of 27%. The experimental condition took place in an environmental chamber that was held constant at 0±2°C with 32% RH. This type of exposure falls within the range of previous publications with -5°C considered extreme (Ellis *et al.* 1985) and +5°C considered moderately cold (Rammsayer *et al.* 1995; Thomas *et al.* 1983; Thomas *et al.* 1989).

After the subjects had finished the PAB they were immediately escorted into the environmental chamber. The experimental PAB was administered when the subjects core body temperature reached 35.5±0.1°C and was conducted in the chamber. This temperature has been noted as being a significant drop in core body temperature (Coleshaw *et al.* 1983; McCardle *et al.* 1997), but not at a level that would induce hypothermia (Thomas *et al.* 1989). Any subject who cooled to a level lower than 35.0°C or cooled to a body temperature lower than 35.5°C within the first 20 minutes was immediately excused from the study. One potential subject had to be excused due to the latter condition. Once the PAB had been completed, the subject was immediately excused from the chamber.

If the subject had been selected into the experimental-control group, exposure in the chamber started immediately following the measure of core body temperature. The PAB was administered with the same criteria as previously mentioned. Upon completion, subjects were removed and were then rewarmed by wearing a winter jacket and ski pants while sitting in a chair, that were provided by the investigator.

Performance Assessment Battery (PAB)
Stroop Word-Colour Test

Originally developed by Stroop (1935) to test perception, the Stroop Word-Colour test asks subjects to relay to the investigator the colour of the word that they are reading. Distracting variables are added by having all of the words read actual colour names that existed in the test. Subjects were given 60 seconds to relay as many colours as possible.

Working Memory Test
This test had been originally created by a North Atlantic Treaty Organization (NATO) group named Advisory Group For Aerospace Research & Development (AGARD) for the purposes of testing cognitive functioning for individuals working in stressful environments (e.g. divers and astronauts). It has been modified for the purposes of this study. Subjects were presented with a series of seven non-word random letters for one second and then were shown a single letter. This was accomplished by having both the random-letter series card and the target letter card displayed in a small binder. The investigator presented the non-word series for one second and then presented the randomly selected target letter. Subjects were then asked to indicate either "yes" the letter did exist in the previous series or "no" the letter did not exist in the previous series. This task lasted for 60 seconds.

Signal Detection Task

This test was originally created by Neissier (1967) and was modified for the purposes of this study. This test has been used in previous studies that looked cognitive functioning while subjects were under a thermal stress (Mallon 1997). Subjects were given a sheet of paper with four columns of series of letters (four) and instructed to note which of the series contain either or both of the predetermined target letters. Subjects were given 45 seconds to complete as many trials as possible.

Fitts' Task

The Fitts' Task (Fitts 1954) was originally created to look at the information capacity of the human motor system in controlling the amplitude of movement. This task asked subjects to alternated tap a pencil within two circles on either end of a standard A4 page. This task lasted 20 seconds.

Results
The data was collected and put through an analysis of variance (ANOVA) statistical package, CLR ANOVA 2.0. As mentioned previously, 21 subjects began the testing with data from only 20 subjects being analyzed. None of the subjects voluntarily dropped out of the study. The average drop in core body temperature was 1.2°C ± 0.31°C (mean ± standard deviation). Four subjects were tested after one hour even though their core body temperature had not reached 35.5°C. The physiological data did not yield conclusive evidence that suggested that the percentage of body fat had any correlation with cooling rate (r=0.07) or core temperature drop (r=0.03). Temperature drop and the time needed to experience such a drop was more closely correlated (r=0.30), but did not achieve significance. The average core body temperature when experimental testing took place was 35.5°C ± 0.24°C. The three performance measures used in the study were attempts/trial (A/T), correct responses/trial (CR/T) and accuracy (A).

Stroop Word-Colour Test
It was determined that subjects performed significantly better in the controlled environment than when exposed to the experimental condition (see Figure 1) when considering A/T ($F_{1,16}$ =36.41, p<0.001), CR/T ($F_{1,16}$ =46.21, p<0.001) and accuracy ($F_{1,16}$ =29.52, p<0.001). Female subjects significantly surpassed their males counterparts in both A/T ($F_{1,16}$ =5.13, p=0.038) and CR/T ($F_{1,16}$ =5.05, p=0.038). Similarly there were significant order-trial interaction effects for A/T ($F_{1,16}$ =15.73, p=0.001) and for CR/T ($F_{1,16}$ =12.29, p=0.003), independent of gender.

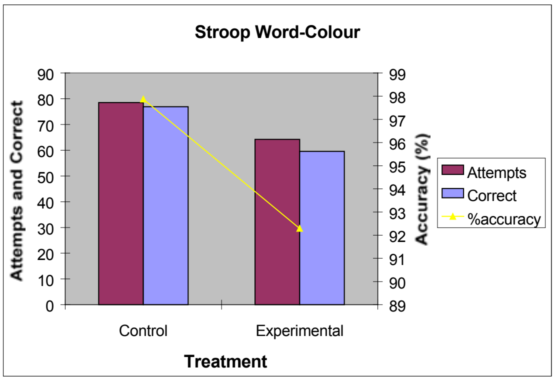

Figure 1. Stroop Work-Colour Test results (Attempts, Correct and % Accuracy) for experimental and control conditions

Working Memory
Unlike the results for the Stroop Word-Colour Test a significant gender effect was not present for any of the performance measures for the Working Memory task (see Figure 2). Subjects made significantly more attempts ($F_{1,16}$ =11.40, p=0.004) more correct responses ($F_{1,16}$ =23.34, p=0.0002) and were significantly more accurate ($F_{1,16}$ =6.98, p=0.018) while exposed to the control condition than the experimental conditional. There was a significant gender-order-trial effect ($F_{1,16}$ =4.62, p=0.047) for the number of attempts made per trial. The order-trial effect influenced the same performance measure, but did not reach significance ($F_{1,16}$ =3.78, p=0.07).

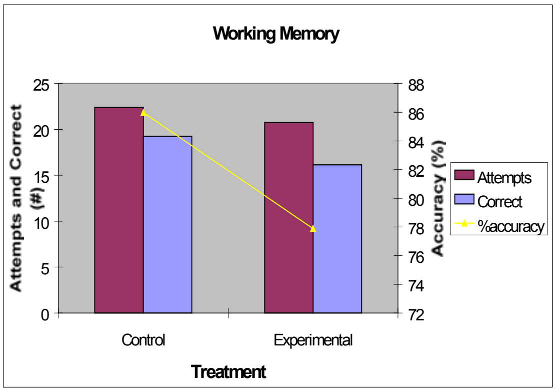

Figure 2: Working Memory results (Attempts, Correct and % Accuracy) for experimental and control conditions

Signal Detection

As depicted in Figure 3, Signal Detection task did not yield significant differences for any of the three performance measures. There was also no evidence that either gender or the order in which the tests were completed had any significant impact on cognitive performance while exposed to the cold environment.

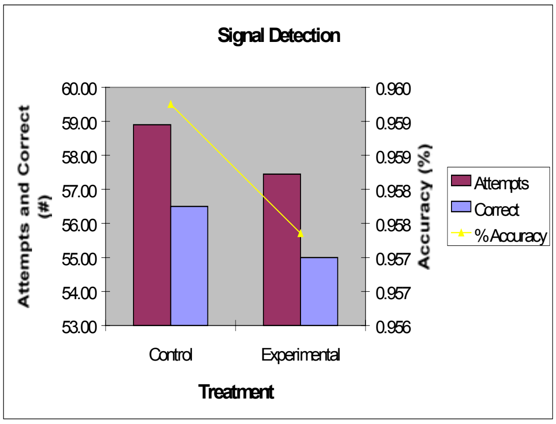

Figure 3: Signal Detection Task results (Attempts, Correct and % Accuracy) for experimental and control conditions

Fitts' Task
In the task that pits accuracy against speed of performance, subjects performance seemed to be impeded while exposed to the cold environment (see Figure 4). Significant differences were found for A/T ($F_{1,16}$ =5.96, p=0.027), CR/T ($F_{1,16}$ =6.18, p=0.021), and A ($F_{1,16}$ =10.24, p=0.006). A gender-trial effect influenced the results for CR/T but was found not be significant.

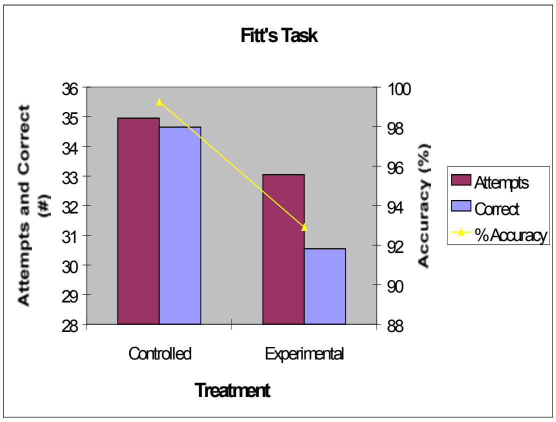

Figure 4: Fitts' Task results (Attempts, Correct and % Accuracy) for experimental and control conditions

Discussion
The purpose of the present study was to examine the effects of cold environments on human cognitive performance and in particular information processing capabilities. It was apparent from the physiological data that individual cooling rates are dependant on more than simply percent body fat. These results may have been less variable if the subjects were performing physical work that would induce thermogenesis and thus aid in regulating overall rates of

cooling among subjects. However, such activity is not seen in many vocational settings (Sanders and McCormick, 1993). Bowen (1968) found that divers performed physically demanding tasks more rapidly than in colder environments and attributed this finding to a need for heat production when exposed to cold environments.

The methodology used in this study was a novel investigative approach in the field of environmental ergonomics. Even with the large discrepancy in cooling times, dropping the subjects' core body temperatures to the desired level of 35.5°C was found to significantly hinder specific stages of information processing capabilities. This is important when considering future research in this field as this technique allows for one more variable to be standardized across subjects. Although the tympanic method of estimating deep body temperature had been used in previous studies (Rammsayer *et al.* 1995), the use of the *Braun Thermoscan*™ does not come highly recommended by other studies (Ducharme *et al.* 1994; Firm and Ducharme 1994). Recommendations for further studies in this area include the use of the same methodology however, better instrumentation may yield more precise results.

Perceptual encoding of information is often referred to as *Perception* in many information processing models (Wickens *et al.* 1997). The Stroop Word-Colour task was used to judge the first stage of information processing. Deep body cooling had a detrimental affect on performance for all subjects. Males were more affected than their female counterparts, this is not surprising considering that females have been noted to outperform males in similar verbal tasks (Morgan 1961). This was considered a complex task in relation to the other three tests in the PAB. Studies have concluded that more complex tasks are more adversely effected than are simple tasks (Giesbrecht *et al.* 1993; Thomas *et al.* 1989). This could help explain the vast differences in performance. The Stroop test has been used in one other study (Giesbrecht *et al.* 1993) and a similar drop off in performance was observed in their study.

It is important to note such results when considering designing of end user products. A decrease in perception was noted and this may indicate that operators may not gather the proper information from the working environment. Signals, displays and controls must be designed with these decrements in performance in mind. Understanding of the system with which the control room, cockpit etc. will exist is essential when designing to complement environmental characteristics.

The working memory test was considered the most difficult of the four tests in the PAB. Subjects showed a significant decrement in working memory performance when subjected to low thermal climates. All three performance measures were significantly affected. These results are similar with the findings from Coleshaw *et al.* (1983); Giesbrecht *et al.* (1993) and Bowen (1968), but do not support Bowen's (1968) conclusion that cold exposure has no effect on number of attempts per trials.

The results from the Signal Detection task do not lead one to believe that cold environments had a negative effect on this stage of information processing. Reverting back to the argument that simple tasks are less affected by thermal stressors than complex tasks, one can begin to account for the lack of difference between the two testing conditions. The Signal Detection task was the most simple task of the four. Even with the narrowing of attention that occurs (Endander and Hygge 1990) this simple task was not affected by the cold environment, therefore a more complex task may yield more conclusive results. These results are different from previous unpublished work when considering thermal stressors and this same Signal Detection task (Mallon, 1997). When subjects performed the Fitts' task there were observed decrements in all three of the performance measures. These results, however indicative of the obvious effect of the thermal stressor should be viewed with caution. Fitts (1954) used this task to monitor the speed - accuracy tradeoff that occurs in many athletic and vocational settings. He found an inverse relationship between speed and accuracy. As shown in the results of the Fitts' task (Figure 4), this was not the case in the present study. The expected speed - accuracy tradeoff did not occur. The high motor component of this task could have accounted for the decrease in all three performance measures. As subjects attempted to be more accurate, the possibility exists that a shivering component may have affected the results.

Practical applications for the present study include the design of panels and emergency signals that are used on oil platforms. Likewise, the working memory capacity of individuals should be considered with respect to previously learned information while exposed to adverse climates. Although motor tasks may be enhanced by technology (i.e. hydraulic levers etc.) it is important to consider the fluctuations in the cognitive capacity of the worker in the environmentally stressful environment

Future research in the area of cold environments and the effects on human cognitive performance should consider the present methodology when conducting research. Although it is unreasonable to surmise that a potential worker will be screened based on their cooling rate or percentage of body fat thickness, this method has a certain research utility. Assuming that physiological states are equal (as was the assumption during this study), one can begin to see what aspects of cognitive function are truly affected. Another intervention that would aid in this process would be the ability to isolate the temperature of certain segments of the body. This would help the researcher who could cool the core temperature but keep the extremities warm, thus aiding in the reduction of the effects of cold environments on motor performance.

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