The Effect of an Induced Selective Increase in Head Temperature Upon Performance of a Simple Mental Task

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Subjects performed a simple mental addition task under three counter-balanced conditions of a head temperature manipulation. In the heating condition, a temperature-controlled helmet induced a 1.0°C rise in head temperature as measured in the deep auditory meatus. A placebo condition consisted of helmet application but not activation, and the control condition monitored performance in the absence of the helmet. Results indicated that significantly more additions were accomplished under the heating condition compared to the two unheated, nonheating conditions. This was not a wide of speed for accuracy, since the thermal manipulation exerted no significant effect on error rate. The work suggests that processing speed in a behavioral task is facilitated by the localized temperature increase.

INTRODUCTION

There has been and continues to be both practical and theoretical interest in the relationship between performance efficiency and fluctuations in operator body temperature (e.g., Colohan, 1971; Frances, 1927; Mehead, 1932). In early work, Kleitman reported that spontaneous or induced increases in body temperature, within the limits of the diurnal cycle, facilitated performance on a variety of cognitive and psychomotor tasks (cf. Kleitman and Yokotsuka, 1913; Kleitman and Jackson, 1950; Kleitman, Tin-foam, and Felstein, 1949). More recently, Allan and Gibson, and their colleagues have found that elevated body temperature above the normal range has the dual and opposing action of speeding performance while elevating error rate, resulting in a diminution of task capability (see also Nunnally, Reader, and Maidson, 1960). They have suggested that whereas core and skin temperatures may differentiate affect performance speed and comfort (Allan and Altan, 1973), the direction and rate of change of such temperatures are important determinants of overall efficiency (Allan and Gibson, 1979).

In contrast to studies using whole-body heating, in which performance level has been depressed, the selective heating of the head appears to offer a manipulation by which performance may be facilitated by temperature elevation above the level experienced in the normal diurnal cycle. Holt and Brinard (1976) found that a 1.1°C increase in selective head temperature resulted in both faster choice reaction time and sequential visual...
scanning. However, Hancock and Dickin (1982) reported that a consistent selective head temperature rise elicited slower and more accurate response to centrally and peripherally presented choice stimuli. The rationale behind the present work was to further understand concerning the relationship between selective head temperature variation and human performance. Specifically, in the current experiment, a simple mental performance task was used to distinguish between these differing patterns of results concerning temperature elevation and performance. First, would the pattern of results reported by Hancock and Dickin (1982) for a psychomotor task (i.e., slower but more accurate response) hold for a simple mental task? Second, would the observation of accelerated response with no increase in error rate as reported by Holt and Bradyard (1976) be confirmed? Or finally, would results show faster but less accurate response as documented in studies where whole-body temperature has been elevated by a comparable amount?

**METHOD**

**Experimental Task**

To test mental performance a simple arithmetic addition task was employed. The task was a modified version of a performance test previously validated and utilized by Blockley and Lynott (1950) and found to be sensitive to the effects of a thermal manipulation. A list of additions was presented in which a 2-digit number was followed by a series of 12 digits. The subject was required to add sequentially along the 12 digits until the cumulative total equalled that of the 2-digit number. At that point, the subject marked a line through a circle immediately above the digit that completed the addition and proceeded to the next problem. If the subject recognized that an error had occurred, the original mark was crossed out and the correct circle indicated. An example of such a corrected addition is presented below:

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   0 0 0 0 0 0 0 0 0 0 0 0
   4 2 6 4 8 7 9 1 3 5 2 4 3 7 5
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Thirty additions, in two columns of 15, were presented on a single trial sheet. They were matched such that in each column five additions had target numbers in the range 20 to 29, five in the range 30 to 39 and five in the range 40 to 49. Within these ranges, target numbers were randomly generated. The serial positions for correct responses were also matched, such that one occurred in serial positions 6 to 10 for each respective decade in each column. Subjects were unaware of this matching. The subjects were instructed to complete the additions in sequential order, down each sheet, as quickly and as accurately as possible. These were 10 trials in each condition, each 1 min in duration, with an intertrial interval of 10 s. The blocks of 10 trial sheets were also counterbalanced such that they were undertaken an equal number of times in each thermal condition, this manipulation being between subjects.

**Subjects**

A convenience sample of 12 subjects was drawn from the personnel of the research facility and the local student population. Six males and six females were randomly assigned, three to each of either a morning (9:00 a.m.) or evening (5:00 p.m.) group. Their physical characteristics were males (height 183 ± 10 cm; weight, 72 ± 27 kg; age 30.2 ± 16.1 years; mean ± range) and females (height, 164 ± 7.6 cm; weight 54 ± 9.5 kg; age 33.5 ± 3.9 years; mean ± range). All were in good health at the time of experimentation. None of the subjects had any direct familiarity with either the specific task or the heating manipulation utilized.
HEAD TEMPERATURES AND PERFORMANCE

Test Facility
The experiments were conducted in two adjoining experimental rooms. The subject was seated at a desk in one room and could be observed from a rear oblique position through a one-way mirror window while engaged in performance. Trial timing, temperature monitoring, and control equipment were under the supervision of the experimenters in the adjoining room.

Experimental Design
Each subject performed an initial practice period followed by three experimental conditions. These latter conditions, (i.e., heat, placebo, and control) were administered such that each of the six possible orders was undertaken by 2 of the 12 subjects. The design allowed additional counterbalancing across both sex and time of day. All experimental sessions for individual subjects commenced within a 15-min span of the same time of day. The latter condition was instituted to negate time-of-day effects previously noted (Kleiman, 1965). All subjects completed the experiment on four sequential days, and there was no weekend testing.

Thermal Conditions
Head skin and auditory canal temperature were monitored during both practice and experimental sessions. For the measurement of skin temperature, a skin thermistor was attached at a point 5 cm horizontally from the right eye, immediately adjacent to the right pinna. Deep auditory meatus temperature was measured by a commercial tympanic sensor. The disposable thermistor was inserted into the right meatus and slightly withdrawn from painful membrane contact. The sensor, with its attached cotton-wool insert was subsequently taped, and an insulating rubber helmet secured both auditory canal and head skin thermistors in the position. The above constituted the ensemble in the control condition. In the placebo condition a heating helmet was worn but not activated. In the heating condition, helmet temperature was elevated to induce a 1°C rise in temperature at the auditory canal site. This increase was directly comparable with that employed in the earlier study of Holt and Brainard (1976).

Procedure
The subject had temperature recording thermistors attached while seated in the experimental room. The addition task was explained and a single example given to the subject prior to the commencement of the practice session. Data from the latter were not included in the analysis. Trials began in the heat condition after subjects had stabilized at 1°C above the initially monitored resting value. An equivalent waiting period of approximately 6 min was imposed in the two nonheating conditions. Via an intercom, subjects were instructed to begin and were informed of the termination of a trial after 2 min had elapsed. The addition sheet that constituted the trial was turned over, and the subject prepared for the next start signal during the 10-s intertrial interval. Temperatures were recorded immediately after the start signal for each of the 10 trials, and performance was scored on the number of additions attempted and number of mistakes made per trial.

RESULTS
Performance Data
An analysis of variance was conducted using thermal condition, sex, and time of day as factors. There were three levels of the within-subject factor thermal condition (i.e., heat, placebo and control) whereas time of day was a between-subjects factor with two levels: morning and evening. The analysis in-

August, 1983—443
HUMAN FACTORS

Physiological data

Analysis of variance was also performed on the data elicited for the temperature measures. For initial values of auditory canal and head skin temperature, there was no effect for thermal condition. This observation assured that no significant temperature differences were present prior to the imposition of the selective head temperature manipulation. The main effect for the rise in auditory canal temperature was highly significant, $F(2,16) = 89.1, p < 0.001$, and Scheffé's post hoc procedure affirmed that the rise in temperature was significantly greater in the heat condition as compared with the two unvarying, nonheating conditions ($p < 0.05$). A similar main effect was found for the rise in skin temperature, $F(2,16) = 45.1, p < 0.001$. However, Scheffé's post hoc procedure significantly differentiated rise in head skin temperature under each of the experimental conditions ($p < 0.05$). The observation that rise in head skin temperature during heating exceeded that for placebo (which exceeded the value in the control condition) is taken as indicative of the insulative value of the helmet worn but not activated. A summary of the above performance and physiological data is given in Table 1.

There are two other observations on the physiological data that merit comment. First, there is a lack of difference between the baseline auditory canal temperature values for the morning versus the evening groups. This is most probably due to the comparison being made across differing subjects who exhibit distinctive individual diurnal temperature rhythms. Second, a main effect for sex was noted in baseline auditory canal temperature, $F(1,8) = 6.5, p < 0.05$, where the female subjects exhibited a significantly higher resting temperature than males. Five of the male subjects had baseline temperature

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HEAT TEMPERATURES AND PERFORMANCE

August, 1983—445

<table>
<thead>
<tr>
<th>TABLE I</th>
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<tr>
<td><strong>Means and (Standard Deviations) for the Thermal Response and Addition Performance in the Three Experimental Conditions.</strong></td>
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<tr>
<td><strong>Performance Conditions</strong></td>
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<tr>
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<tr>
<td>Total additions</td>
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<tr>
<td>(2.36)</td>
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<tr>
<td>Addition errors</td>
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<td>(0.03)</td>
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<td>Committed per trial</td>
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<td>(0.11)</td>
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<tr>
<td>Deep auditory reflex site (°C)</td>
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<tr>
<td>(0.20)</td>
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<tr>
<td>Rise in temperature</td>
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<tr>
<td>(0.20)</td>
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<tr>
<td>Head skin site (°C)</td>
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<td>(0.20)</td>
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*Significantly different from the other conditions, beyond p < 0.05 level.

values below those of all the female subjects, whereas one male subject exhibited a resting temperature value in excess of all but two of the female subjects.

**DISCUSSION**

There have been several previous investigations concerning the effects of an abnormal temperature difference between the head and the rest of the body. However, these have predominantly taken the form of physiological inquiries into the effectiveness of specific head cooling to alleviate whole-body heat stress during exposure to high ambient temperature (Brown and Williams, 1982; Huneley, Truttmann, and Webb, 1971). Such cooling has been shown to facilitate comfort (Brown and Williams, 1982; Williams and Shitzer, 1974) and aspects of cognitive performance (Konz and Gupta, 1969; Huneley et al., 1982). In contrast to the above studies, the present work imposes selective head heating while the subject occupies a neutral thermal environment. Results from the current study do not follow the pattern exhibited in a previous investigation, Hancock and Dirksen (1982) found that reactions to both central and peripherally presented stimuli were slower but more accurate under the heating condition. This disparity may be due to three factors. First, there are differences between the respective performance tasks. The previous study elicited psychomotor response to visual stimuli, whereas the present work required simple mental performance as measured by an addition task. Second, the present study required that both central and peripheral visual stimuli be monitored. In the present work the task is presented centrally and previous observations of attentional narrowing under heat stress may be implicated as a differential factor between the two studies (Burrill, 1956; Provis and Beil, 1970). Third, although the induced rise in temperature appeared high in the former study, the 3.9°C rise, measured at the termination of the heat exposure, reflects a considerably smaller change at a site adjacent to the tympanic membrane. Although the precise difference between rise in temperature can not be inferred directly (Kooper, Cranston, and Smell, 1964), this variate may help to account for differences in results.

Holt and Brainard (1975) reported facilitation in both choice reaction time and a vi-
usual search task when head temperature was elevated 1.1°C. In the search task, performance improvement with heating became manifest when the serial position of the target exceeded the 24th item. The individual heat and control regression times for search time against item position indicated that a 5-s facilitation in identification time was induced by the heat at the 200th item position. There are certain similarities between the search task and the manual addition test; items must be scanned sequentially in order that a terminal target be identified. However, while the Neisser (1966) search task requires scanning and rejection of nontarget items, the addition test demands sequential addition of each number to achieve correct response. This variation may account for improved performance when subjects monitored a maximum of only 17 numbers in the current work, compared with the 24 required for differences in the search task. The general conclusion of an increment in processing speed under selective head temperature increase appears common to both investigations.

The lack of interaction between the heating manipulation and time of day upon performance is apparently contradictory to prior observations concerning the diurnal variation in task performance ability. An alternate implication might be that there is some form of ceiling effect whereby selective increasing temperature no longer facilitates performance. These explanations cannot be drawn from the present results because the time of day manipulation was made between subjects, whose baseline temperatures were subject to individual difference. However, the interaction between the present manipulation and time of day on performance is deserving of more thorough investigation. Although selective head heating has been shown to be beneficial in the performance of different tasks, it may be possible that such augmented thermal support may be used to maintain operator temperature near the zenith of the circadian cycle (Wallberg, 1969). In consequence, it may provide a method by which diurnal fluctuation in performance efficiency may be palliated. This would be of particular interest to research concerned with the performance capabilities of operators during prescribed work periods and particularly relevant to those concerned with shift work.

To understand the practical significance of the present results concerning the head temperature manipulation, it is necessary to examine the relationship between the level of thermal elevation and the task undertaken. First, variations in the speed of operation at any discrete temperature change appear, in part, to be dependent upon the nature of the performance required. For example, in a study concerning the perception of brief temporal intervals under a comparable 1.1°C head temperature elevation, Honack (1983) found a 13.6% reduction in duration of estimation as compared with the 6.3% change in the present addition task. Second, as performance varies across tasks at a single elevational value, so speed of performance within a task also changes with differences in thermal conditions. Extant data suggest that an elevation toward 1.9°C appears to represent a threshold with respect to such performance. Below this value, latency increases but errors decrease, and a speed-accuracy trade-off is manifest (Honack and Dijk, 1982). However, beyond this value both error and latency are reduced so that a gain in capability is realized.

The degree to which such gain in performance continues with further temperature elevation has yet to be thoroughly determined. The data that are available suggest a perpetuation of this trend beyond the present 1.9°C increase (e.g., Honack, 1981; Holt and Brainard, 1976). It is probable that optimal
elevational values are given. In part, dependent upon the task undertaken, and although gain in the present work seems small (approximately one addition per 2-min trial), this should serve as an indication of the potential for absolute benefits in practical tasks of greater temporal duration. If, as suggested by optimal level for performance lies beyond the temperature range examined in the current study, both potential relative and absolute increase in performance on applied person-machine tasks may be possible through further exploration of the present manipulation.

The physiological effects of the present selective head-heating manipulation are far from clear. First, it is uncertain whether the temperature measured adjacent to the tympanic membrane reflects the temperature of the head core. Although Benzing's (1965) advocated the potency of tympanic membrane temperature as just such a measure, actual membrane contact is painful, and there is a possibility of tissue damage. Consequently, prolonged observations are both difficult and potentially dangerous, and subjects discontinue their participation. In the current work, temperature was measured in the auditory canal adjacent to the meatus and Cooper et al. (1964) suggest that although the temperature gradient down the wall of the meanus decreases absolute measures, the site still reflects central temperature changes. More recently, Greenleaf and Castle (1972) have questioned the use of the auditory canal site, and Nadel and Horn (1970) have indicated that the measure may be influenced by skin temperature. At the current time, however, this site represents the most suitable and acceptable measure of head temperature change.

In affirming the use of equal thermometry during selective head heating, Marcus (1973) draws attention to potential sources of measurement error when specific sites on the head and neck are heated or cooled. Although countercurrent heat exchange has been observed during selective head heating (McCullough, Gelt, Chiang, and Wetig, 1975), the precise physiological effects of the current thermal manipulation have yet to be fully elucidated.

Research is needed on both the physiological effects of the thermal manipulation and its consequence influence on cognitive and psychomotor tasks performance. Results from the present study suggest support for the position of Holm and Truax (1976), which indicates that selective head heating is instrumental in eliciting performance improvement in certain behavioral tasks. Consequently, the present work holds potential importance for those concerned with increasing operational efficiency in person-machine systems.

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