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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 1.01°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 compared with the two unvarying, nonheating conditions. This was not a trade of speed for accuracy, since the thermal manipulation exerted no significant effect on error rate. The work suggests that processing rate 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., Colquhoun, 1971; Francois, 1927; Hancock, 1982). 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 Doktorsky, 1933; Kleitman and Jackson, 1950; Kleitman, Titelbaum, and Feiveson, 1938). More recently, Allan, 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 Nunneley, Reader, and Maldonado, 1982). They have suggested that whereas core and skin temperatures may differentially affect performance speed and comfort (Allnutt and Allan, 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 Brainard (1976) found that a 1.11°C increase in selective head temperature resulted in both faster choice reaction time and sequential visual

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scanning. However, Hancock and Dirkin (1982) reported that a consistent selective head temperature rise elicited slower but more accurate response to centrally and peripherally presented choice stimuli. The rationale behind the present work was to further understanding 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 three differing patterns of results concerning temperature elevation and performance. First, would the pattern of results reported by Hancock and Dirkin (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 Brainard (1976) be affirmed? 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 Lyman (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 equaled 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 a subject recognized that an error had occurred, the original mark was crossed and the correct circle indicated. An example of such a corrected addition is presented below:

	○	○	○	○	⊗	○	∅	○	○	○	○	○
42	6	4	8	7	9	3	5	2	4	3	7	5

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. There were 10 trials in each condition, each 2 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, 82 ± 27 kg; age 30.2 ± 10.1 years; mean ± range) and females (height, 164 ± 7.6 cm; weight 54 ± 9.5 kg; age 33.5 ± 8.9 years; mean ± range). All were in professed 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.

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 mitigate time-of-day effects previously noted (Kleitman, 1963). 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 indicated a significant main effect for the thermal condition on the mean of additions attempted, $F(2,16) = 6.47, p < 0.01$. Scheffé's post hoc test indicated that the mean number of additions attempted was significantly higher ($p < 0.05$) when head temperature was elevated, compared with the two nonheating conditions, which did not vary significantly. This trend toward increasing the number of additions attempted under the heat condition was observed in 11 of the 12 subjects tested. From a procedure given by Glass and Stanley (1970), power was calculated as 0.86 for this analysis. Beyond this main effect, there were no significant interactions between any of the factors, and no main effect for either of the between-subjects factors of sex or time of day.

This effect may have represented a trade of speed for accuracy of response, as was observed in a previous experiment on central and peripheral visual choice reaction time (Hancock and Dirkin, 1982). However, analysis of variance indicated no significant effect for thermal condition on the mean number of errors committed, $F(2,16) = 0.63, p > 0.05$. In addition, there were no alternate interactional or main effects for this measure. Subsequent analysis on the mean of the number of correct additions (i.e., total additions attempted minus errors committed) affirmed the pattern of improved performance in the heating condition, $F(2,16) = 4.76, p < 0.05$. Scheffé's post hoc test indicated that more correct additions were accomplished under the heating condition as compared with the placebo condition ($p < 0.05$), and although the comparison between heat and control conditions marginally failed to reach this level ($0.05 < p < 0.06$), the data indicate a differential effect for heat per se. This difference appears as a change in the mean of performance, since no main or interactional effects were observed for the standard deviation of any of the above measures.

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 insulational value of the helmet when 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

TABLE 1

Means and (Standard Deviations) for the Thermal Response and Addition Performance in the Three Experimental Conditions.

	Performance Conditions		
	Control	*Placebo*	*Heat*
Total additions Attempted per trial	12.53 (3.36)	12.30 (2.91)	13.08* (3.05)
Addition errors Committed per trial	0.83 (0.93)	0.83 (0.94)	0.93 (1.07)
Rise in temperature Deep auditory meatus site (°C)	0.16 (0.11)	0.33 (0.16)	1.01* (0.29)
Rise in temperature Head skin site (°C)	0.46* (0.35)	1.33* (0.76)	3.91* (1.26)

* 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; Nunneley, Troutman, 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; Nunneley 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 Dirkin (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 previous 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 (Bursill, 1958; Provins and Bell, 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 meatus, 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 (Cooper, Cranston, and Snell, 1964), this variation may help to account for differences in results.

Holt and Brainard (1976) reported facilitation in both choice reaction time and a visual search task when head temperature was elevated 1.11°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 lines 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 mental addition test. Items must be scanned sequentially in order that a terminal target be identified. However, while the Neisser (1964) 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 10 numbers in the current work, compared with the 24 required for difference 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 previous 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 (Halberg, 1960). 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, Hancock (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 condition. Extant data suggests that an elevation toward 1.0°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 (Hancock and Dirkin, 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 1.01°C increase (e.g., Hancock, 1983; Holt and Brainard, 1976). It is probable that optimal elevational values are again, 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 accrue over repeated performance to give substantial absolute benefit in practical tasks of greater temporal duration. If, as suggested, the optimal level for performance lies beyond the temperature range examined in the current study, then 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 precise fluctuations of temperature in the head core. Although Benzinger (1969) 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 observation is both difficult and potentially dangerous, and subject discomfort may interrupt performance. In the current work, temperature is measured in the auditory canal adjacent to the membrane, and Cooper et al., (1964) suggest that although the temperature gradient down the wall of the meatus devalues absolute measures, the site still reflects central temperature change. More recently, Greenleaf and Castle (1972) have questioned the use of the auditory canal site, and Nadel and Horvath (1970) have intimated 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 aural 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 (McCaffrey, Geis, Chung, and Wurster, 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 subsequent influence on cognitive and psychomotor task performance. Results from the present study suggest support for the position of Holt and Brainard (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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