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Effect on Complex Manual Performance of Cooling the Body While Maintaining the Hands at Normal Temperatures

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ABSTRACT

Gaydos, Henry F. *Effect on complex manual performance of cooling the body while maintaining the hands at normal temperatures.* J. Appl. Physiol. 12(3): 373–376. 1958.—Subjects were tested on complex manual performance tasks under two different conditions. In one the body and hands were cooled simultaneously, and in the other the body was cooled to the same degree while the hands were kept warm. A significant decrement in manual proficiency was observed when hand skin temperature dropped to 50–55°F, but no decrement occurred when hand skin temperatures were maintained at 80°F or higher, despite body surface cooling to 78°F in both cases. It was concluded that hand temperature is a vital factor in fine manipulation, but the body can be cooled to a degree which is distinctly uncomfortable without affecting manual performance if the surface temperature of the hands is maintained at normal levels.

A previous study by Gaydos and Dusek (1) led the authors to conclude that the lowering of local hand and forearm temperatures was primarily responsible for the impairment of complex manual performance in subjects exposed to cold. The same amount of decrement in manipulative efficiency was found when hands were cooled to the same degree even though the ambient temperature surrounding the body was 70°–80°F under one condition and 15°F in the other. It appeared that ambient temperature, except as it influenced hand temperature, was unrelated to manual performance. There was, however, some question about the true effectiveness of the low ambient temperature since the subjects wore heavy clothing.

The present study was performed in order to determine whether impairment of performance could be prevented by maintaining the hands at normal temperatures even though the rest of the body was cooled to subnormal levels. Environmental variables attributable to clothing were eliminated by independently controling both the mean surface temperature of the body and the skin temperature of the hands.

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METHODS

Twelve white male enlisted men volunteered their services as subjects. A controlled temperature room was required for this experiment, and an electrically heated box was provided to enclose the subject's hands and forearms in a temperature environment that was independent of the temperature in the rest of the room. Skin temperatures from 10 points on the body were picked up by thermocouples and fed into a Leeds-Northrup multipoint recorder and automatic integrator system which recorded the mean weighted skin temperature for the body surface at 40-second intervals. One additional thermocouple was used to monitor the skin temperature of the fifth fingertip on the left hand.

Performance test apparatus and test procedures for this study were identical to those used earlier by Gaydos and Dusek.

Knot Tying. Three coils of ⅛ inch diameter braided cotton cord, each about 8-feet long, were suspended from pegs within easy reach of the subject. The subject grasped one end of the cord in his nonpreferred hand and, at a given signal, he proceeded to tie knots as rapidly as possible for a 30-second period. The knots tied were of the type known as 'overhand knot and bight.' Three trials were given at each session, with about 1 minute elapsing between trials.

Block Stringing. The blocks used were 1-inch cubes of wood with 3/16 inch holes drilled through the center of each face. The stringer consisted of a blunted 'needle,' 2½ inches long by 1/16 inch diameter, with a length of string passed through the eye. The subject held the stringer in his preferred hand, and at a given signal, he strung blocks as rapidly as possible for a 30-second period. Three trials were given at each session with about 1 minute elapsing between trials.

To eliminate the effects of practice, all subjects were required to perform both tasks on 5 successive days prior to the main testing sessions. All practice trials were carried out at an ambient temperature of approximately 75°F.

For the test sessions in both the experimental and the control conditions, the ambient room temperature was maintained at 45°F, and air movement was approximately 5 mph. Subjects were lightly clad in shorts, T-shirt, socks and shoes.

For the experimental condition, the temperature of the hand warming box was maintained at 90–100°F in order to keep the subject's hand temperature, as indicated by the thermocouple on the fifth fingertip, at 80°F or higher. The *knot tying* and *block stringing* tests were administered three times during the experimental session: *A*) when the subject first entered the room, *B*) when the subject's mean weighted skin temperature had dropped to between 81–82°F, and *C*) when the mean weighted skin temperature had dropped to between 78–79°F.

For the control condition, the heat source inside the hand warming box was turned off and the door to the box was left open so that the hands were exposed to the ambient room temperature of 45°F. This time the temperature of the fifth fingertip was the independent variable, and the *knot tying* and *block stringing* tests were administered *a*) when the subject first entered the room, *b*) when the fingertip temperature had dropped to between 60–65°F, and *c*) when the fingertip temperature had dropped to between 50–55°F.

All subjects performed under both conditions, but half the group was exposed first to the experimental condition, and the other half of the group was exposed first to the contro

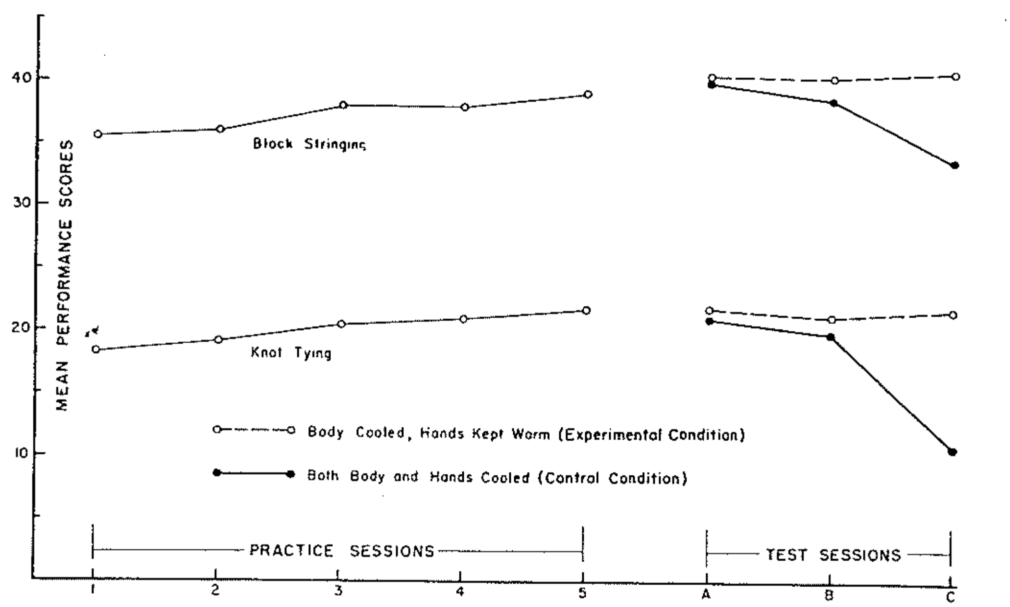

FIG. 1. Comparison of mean performance scores on a complex manual task. At points *A*, *B* and *C*, hand skin temperatures were above 80°F in the experimental condition, and above 80°, 60–65° and 50–55°F, respectively in the control condition. Mean body surface temperatures were 85°, 82° and 78°F, respectively in both conditions.

condition. Each subject had 1 day's rest between conditions.

RESULTS

Figure 1 shows the mean performance scores of the group plotted for 5 successive days of practice, and for test conditions *A*, *B* and *C*, representing mean weighted skin temperatures of approximately 85°, 82° and 78°F, respectively. Each trial was scored on the basis of the number of knots tied or number of blocks strung, according to the respective task, in the 30 seconds allowed. Points shown on the graph represent the sums of the scores of the three trials constituting each session.

It is evident in figure 1 that lowering the mean skin temperature of the body had no effect upon performance of the given task so long as normal hand temperature was maintained. However, when the temperature of the hands was lowered by exposing them to the same 45°F ambient condition surrounding the body, task performance deteriorated to an extent which seemed to depend upon the degree of hand cooling. Analysis of variance reveals a significant F-ratio attributable to the effects of differences in hand skin temperature, and this seems to have been the primary factor associated with decrement of performance.

There was a decline of manual proficiency as finger skin temperature dropped from a mean of about 75°F at point *A* to between 60° and 65°F at point *B*, but the difference in performance scores between these two points is not statistically significant for either task. On the other hand, the decline shown at point *C*, where finger temperatures ranged from about 50° to 55°F, is definitely significant for both tasks, using Duncan's (2) multiple range test at a 95% protection level. Thus, deterioration in performance appears to accelerate as finger skin temperature falls.

DISCUSSION

The results of the study by Gaydos and Dusek showed that a drop in hand skin temperature was apparently sufficient by itself to impair performance of a complex manual task, even though the rest of the body was exposed to a comfortable ambient temperature. The present study corroborates the consequent conclusions that local hand temperature is the main factor in performance decrement by showing that cooling of the body (within limits) has no effect upon complex manual performance so long as the hands are kept warm.

The 78°F mean weighted skin temperature at which the subjects had to perform is probably a more severe condition than is likely to be encountered in the field except under extraordinary circumstances. Horvath *et al.* (3) measured the mean skin temperatures of men sitting quietly in −40°F, while clothed in standard Arctic uniforms. On the average, it took nearly 2 hours for the men to cool to a mean skin temperature of 78°F. At an ambient temperature of −29°, 3 hours of exposure were still not enough to produce the same degree of cooling. Even though mean body surface temperatures are not likely to be lower than 78°F in practical field conditions, finger skin temperatures of men working in the cold may frequently fall to 55°F and lower. This can occur at ambient temperatures that are not much below freezing and even at temperatures above freezing if wet materials or materials having high thermal conductivity are handled.

It has been suggested that the encumbrance imposed by gloves on manual performance might be avoided by increasing the blood flow and hence the heat flow to the hands by application of heat to other body surfaces which would bring about vasodilatation in the extremities. Newton and Peacock (4) have reported a study in which they attempted to improve finger dexterity in the cold by applying auxiliary heat to the forearms. Some degree of improvement was observed, but the amount of auxiliary heat required to produce a significant change in performance was barely below the level of discomfort. They found no significant correlation between performance scores and skin temperature, which was taken from the back of the hand. In the present study however, the differences between back-of-hand temperatures and fifth fingertip temperatures varied from 5° to 20°F with no consistent relationship between them. It seems logical to infer that fingertip temperatures have more bearing on task performance, at least to the extent that feedback from the cutaneous receptors is required for such manipulation. Therefore, Newton and Peacock might have obtained a better correlation if they had measured fingertip temperatures.

However desirable it might be to warm the hands by inducing peripheral vasodilatation through auxiliary heat applied to the body, the concept may not be so easily applied in practical circumstances. Investigators dealing with this phenomenon, Ferris (5), Macht and Bader (6), Ames *et al.* (7), Bader and Mead (8), employed four subjects or fewer in their experiments, and while experiments based on so small a number of subjects may establish the existence of such a vascular response, they can hardly yield any quantitative data that can be generalized to a larger population. Nevertheless, the studies cited above generally agree that blood flow and skin temperature in vasoconstricted extremities tend to rise when the environment surrounding the body is changed from cold to warm. It seems also generally agreed that vasodilatation is greatly facilitated if the hands are warmed along with the body, although local warming of a vasoconstricted hand has little effect on its blood flow if the rest of the body remains cool. With the exception of the last study cited, in none of the above studies did the hand skin temperatures fall below 60°F before vasodilatation was induced by heating other parts of the body. It is evident that studies must be done with temperatures more nearly approaching those found under field conditions, and using larger numbers of subjects, before the practicality of this approach can be realistically evaluated.

Another question still unresolved is whether hand skin temperature and blood flow must both be maintained at or near normal levels to keep manipulative ability from being impaired. The investigators cited above all found that blood flow in the vasoconstricted hand remained minimal even though externally applied heat elevated the skin temperature. It is possible that normal hand skin temperature is itself a sufficient condition to prevent a decline in finger dexterity, whether or not vasoconstriction has occurred. In the present study no measurements were made of blood flow, but the ambient condition of 45°F could certainly have induced peripheral vasoconstriction. Whether or not such vasoconstriction actually occurred in the hands which were kept in the heated box is not known, but if it did occur, then it apparently had no adverse effect on manual performance. This possibility brings up an interesting speculation as to whether under some circumstances it might not be feasible to conserve body heat by maintaining a state of peripheral vasoconstriction, and at the same time to supply just enough local heat to keep the hands at their optimum operating capacity.

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