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Manual Dexterity in the Cold

WARREN H. TEICHNER. *From the Psychology Branch, Environmental Protection Research Division, Quartermaster Research and Engineering Center, Natick, Massachusetts*

ABSTRACT

TEICHNER, WARREN H. *Manual dexterity in the cold.* J. Appl. Physiol. 11(3): 333–338. 1957.—The effects of the cold on manual dexterity were studied by relating performance time on the Minnesota Rate of Manipulation Test to air temperature and velocity, windchill, mean surface skin temperature, digital temperature of the working hand and rate of digital cooling using data from 530 subjects sorted into 14 different combinations of air temperature and wind for an exposure period of approximately 60 minutes. Air temperature and windchill were found to increase performance time significantly; wind velocity did not have a significant effect by itself; mean surface skin temperature was slightly, but significantly, inversely correlated with performance time only for nude men; digital cooling rate and digital temperature were not demonstrated to be related to performance time.

AS RECENTLY REVIEWED by Dusek (1), previous studies of manual dexterity in the cold have been limited to the effects of air temperature. Actually, loss of heat of the hand to air depends on the temperature differential, air movement and the configuration of the hand. Further, the combined action of air temperature and wind velocity or windchill (2, 3) may have effects not deducible from the independent effects of each. In addition, vascular responses of the hand add a new, complex variable to the otherwise relatively simple heat exchange. Thus, conclusions about manual dexterity in the cold must be held in abeyance until the physical parameters and resultant physiological phenomena have been related to performance. It was the purpose of the present study to explore both of these sets of relationships.

Two previous studies are of particular interest. McCleary (4) studied the ability of men to complete a complex brush assembly task in five 'still' air temperatures between 32° and −40°F. Temperature of the forefinger of the working hand was recorded under conditions comparable to the working conditions, but not during the actual performance. McCleary found that, relative to control conditions, the percentage decrement in total assembly time was a positively accelerated increasing function of the ambient temperature; the data also suggested that assembly time was inversely related to digital temperature. However, digital temperature should be recorded in direct temporal relation to performance before wide generalizations are proposed.

LeBlanc (5) recently studied the relationship of digital, knuckle and hand temperatures to finger flexion and found that all three were related. In this experiment the hand was cooled in water and flexion subsequently measured in air. LeBlanc points out the relationship between flexion, dexterity and decreased viscosity of the synovial fluid resulting from lowered temperature. However, no demonstration was actually made of the relation of either flexion or any of the temperature phenomena of the hand to skilled hand function, i.e. to dexterity. In view of the difficulties usually found in overcoming practice effects in manual tasks, such demonstrations cannot be assumed too easily.

METHOD

The subjects were 580 infantrymen from Ft. Devens. Twenty-man groups were used one per day until the total number was exhausted.

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On arrival at the laboratory the 20 subjects were randomly sorted into five-man subgroups two of which were tested before the noon meal and two after it. Of the original 580 subjects, 20 were eliminated prior to testing for medical reasons or history of frostbite.

In the climatic chamber the five subjects sat side by side about 3 feet apart in front of a long table and faced sideways to the direction of air coming through the wind tunnel. For the first 25 minutes they sat quietly and cooled. Detailed instructions were given at this time and procedures demonstrated. Following this they stood and completed 15 trials (approximately 20 min.) on the manual dexterity test. After this, they were seated for 7–10 minutes during which visual reaction times were obtained. Then they ran in place slowly for 3 minutes (mild exercise) following which they completed five more trials on the manual dexterity test.

The test used was the one-handed turning task of the Minnesota Rate of Manipulation Test. This is a commercially available dexterity test which consists essentially of 60 circular wooden discs, 1½ inches in diameter fitted into holes recessed in a rectangular board so that the discs protrude ⅟₁₆ inch above the surface of the board. To complete one trial, a subject was required to lift, turn and replace all 60 discs using his right hand. He was instructed to do this as quickly as possible. Performance time per trial was measured to .01 second with Standard Electric timers. This test was used because of its known high reliability (6) and because it represents the two most important components of manual dexterity, finger dexterity and gross hand dexterity, as determined by factor analysis (7). Thus, results obtained with this test should allow reliable generalizations to a wide variety of skilled hand performances.

TABLE 1. EXPERIMENTAL CONDITIONS

Ambient Temp. °F	Wind Speed mph	Windchill Cal/m²/hr.	No. Subjects Start	No. Subjects Finish	Clothing Conditions
60	5		59	59	Fatigues
60	5		118	118	Nude
30	5	780	40	40	Arctic
0	5	1166	40	40	Arctic
−15	5	1359	39	38	Arctic
−15	10	1609	40	40	Arctic
−15	15	1765	38	38	Arctic
−15	20	1873	40	28	Arctic
−15	30	2018	18	9	Arctic
−25	5	1488	17	17	Arctic
−35	5	1617	20	19	Arctic
−35	10	1914	19	19	Arctic
−35	15	2100	37	31	Arctic
−35	20	2228	35	33	Arctic

The experimental plan called for a 2 × 5 factorial of temperature and air velocity (wind speed), a number of temperatures at constant wind speed and two groups of subjects at 60°F, 5 mph wind, one lightly clothed (army fatigues) and one essentially nude (shorts and socks). Other than the latter two groups, all men wore a complete standard army arctic uniform. All subjects who wore the arctic clothing removed the heavy outer gauntlet-type mitten of the arctic glove just before performing on the manual dexterity test and redonned it immediately after each trial. While performing, these men wore the trigger-finger wool-knit inner glove. The two groups at 60°F wore no hand covering at all except for the manual dexterity test period during which they wore the wool-knit inner glove only and continuously. The experimental conditions are summarized in table 1.

Ten 30-gauge copper-constantan thermocouples were taped to different areas of the body of each subject. The output of each thermocouple was recorded by a Leeds and Northrup recording potentiometer; they were also automatically weighted according to the percentage of total body surface area each represented, integrated electronically and recorded as a measure of mean weighted surface skin temperature. The thermocouple placements and their percentage weighting factors were as follows: instep (.050), calf (.150), lateral thigh (.125), medial thigh (.125), back (.125), chest (.125), upper arm (.070), lower arm (.070), hand (.060), cheek (.100). The output of the thermocouples was recorded in sequence at a rate which provided a complete description of each individual's skin temperature every 4 minutes. Subjects were removed from the experiment as soon as possible if an extremity, usually the working hand, dropped to 38°F.

In addition to the temperature measurements described, one man in each subgroup wore an additional thermocouple taped to the distal portion of the tip of the fifth digit (little

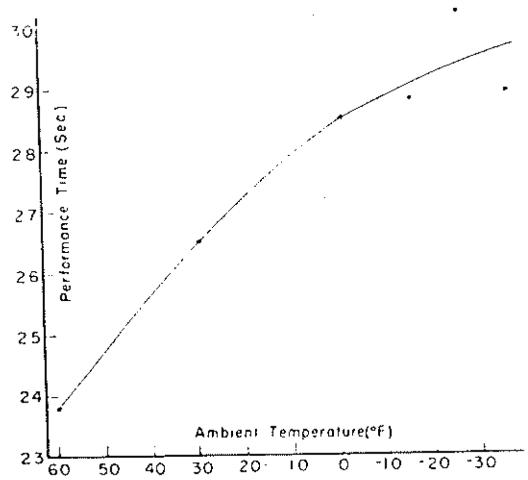

FIG. 1. Performance time as a function of ambient temperature.

finger) of the working hand. This thermocouple was recorded every 2 seconds on a separate Leeds and Northrup potentiometer. Since subjects were run in groups of five, it was necessary to insure that each one had some minimum time interval between trials. To achieve this, an interval of 40 seconds was timed from the moment that the last subject completed the test board to the signal to begin the next trial. Thus, the actual intertrial interval of each subject was equal to 40 seconds plus his trial performance time.

RESULTS

Data were used only from men who completed the experiment (table 1). In order to obtain a convenient, reliable measure of performance for between-group comparisons, the mean performance of each subject over trials 6–10, inclusive, was calculated and used as a basic datum. Choice of this trial period was based upon preliminary inspection of the learning curves and on previous results (6), both of which indicated that this period avoids the initial very rapid change in performance with practice and on the fact that an increased number of subjects had to be removed during the later trials. All comparisons exclude the group at −15°F, 30 mph, since the number of subjects available was considered too small for reliable between-group comparisons (table 1).

The effect of the intertrial intervals on the performance measures was investigated by obtaining Pearson correlations between mean performance and the mean calculated intertrial interval of each subject in *trials 6–10*. No significant relationship was found for men in fatigues or for all men combined; significant negative correlations were obtained for nude men (−.57) and for men in arctic clothing (−.40).

It is possible that the intertrial intervals provided rewarming periods for the hand, and thereby confounded the performance measures indirectly by raising the skin temperature of the hand. If so, then a correlation should be found between digital temperatures during actual performance trials and the length of the rewarming periods. To provide this test, the mean digital temperature of the 5-trial block was obtained for each available subject and correlated with the mean actual intertrial interval during these trials. No significant relationship between these two measures was found for any of the groups. Thus, it seems reasonable to suppose that the significant correlations obtained reflect individual differences in performance times rather than that the intervals had a rewarming effect which influenced the performance times.

Figure 1 presents the effects of ambient temperature at a constant wind speed of 5 mph on mean performance time. This figure, like all between-group comparisons to be presented, omits nude men unless otherwise noted. The curve drawn through the points was fitted by inspection. It may be seen that at a wind speed of 5 mph performance time was a negatively accelerated increasing function of ambient temperature. An analysis of variance of the data upon which Figure 2 was based provided an F-ratio of 14.64; with 5/214 *df* this is significant at less than the .01 level.

Figure 2 shows the effects of wind speed at −15°F and −35°F. Inspection of this figure indicates that the lower temperature produced a consistently longer performance time, a finding in agreement in Figure 1. Except for one inversion, −15°F, 15 mph, both temperature trends suggest increased performance loss with increased wind speed. An analysis of variance confirmed the significance of the temperature effect shown in Figure 2. It did not confirm the other suggested effects since neither wind nor the interaction was significant.

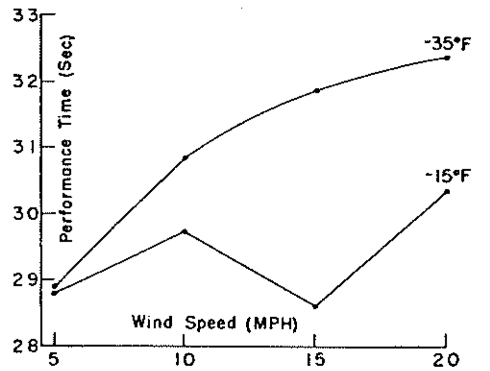

FIG. 2. Performance time as a function of wind speed.

Figure 3 shows the effect of windchill on performance time, on mean weighted skin temperature and on digital temperature. This figure also presents the results obtained with nude and clothed men at 60°F. Skin and digital temperature decreased systematically with increases in windchill. The nude subjects may be seen to have had the lowest mean skin temperatures. Digital temperatures at 60°F were equal for the two groups and relatively high compared with most other groups. Inspection of the upper half of figure 3 shows that performance time increased essentially as a linear function of windchill over the range studied. An analysis of variance of the data upon which these means were based yielded an F of 4.89 which with 10/344 df is significant at less than the .01 level.

The line drawn through the performance measures of figure 3 was fitted to the means by the method of least squares. It is interesting to note that the greatest deviations from this line occurs in the windchill range associated with the mean skin temperature inversions noted in the lower half of the figure. It may also be seen that there was a very small difference in performance time between the two groups at 60°F. This result is in accord with the differences observed between digital temperatures, but not in accord with the skin temperaatures.

To determine the relationship between mean skin temperature and performance time, Pearson correlations were calculated separately for each of the groups shown in table 1. Of these, only the correlation obtained with the nude men was significantly different from zero. This correlation, $-.33$, ($N = 118$) was of negligible magnitude.

Only those 89 subjects whose thermocouples were unaffected by donning and doffing the outer mitten were used to study the digital temperatures. Figure 4 presents the changes obtained during continued exposure using trials as the time base. For comparison, figure 4 also shows the mean performance times, mean digital temperature during the performance time (trial digital temperature), mean digital temperature within 2 seconds of of the start of the trial (initial digital temperature) and the rate of cooling of the digit during the trial.

The temperature curves of figure 4 are essentially parallel and indicate that digital temperature decreased in a negatively accelerated manner throughout the exposure period. The effects of exercise and prolonged hand rewarming which followed the 15th trial are clear cut; both temperatures recovered partially, then dropped steeply on resumption of performance although neither dropped to previous low levels. Rate of digital cooling followed essentially the same trend as the temperature curves, at least to *trial 9* where it shows a relatively greater inversion than the temperature curves and at *trials 13–15* where it shows an exaggerated increase as compared to the temperature curves. Following re-

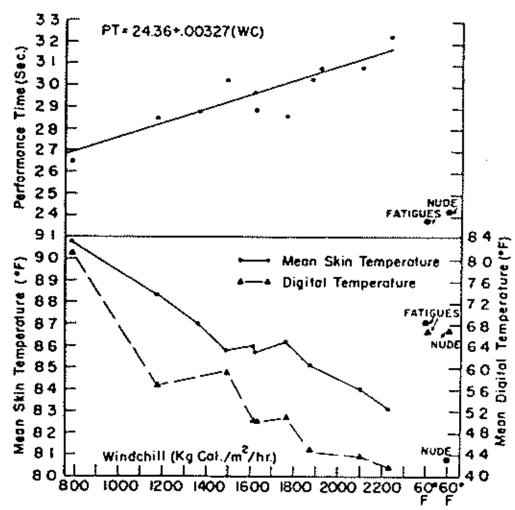

FIG. 3. Performance time, skin and digital temperature as a function of windchill.

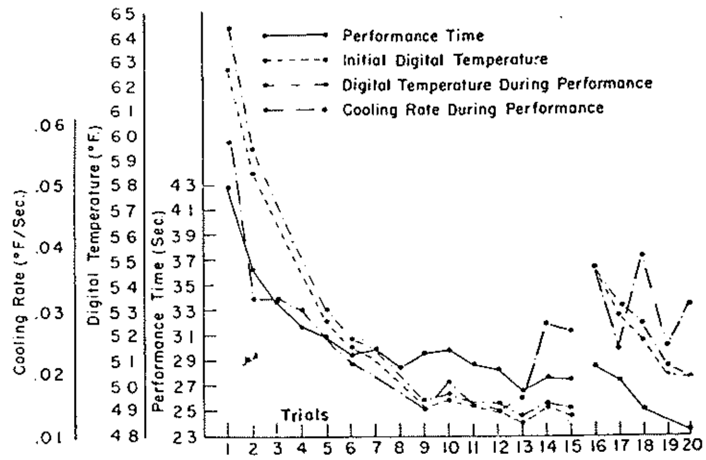

FIG. 4. Change in performance time and temperature phenomena with continued exposure.

warming, the rate curve appears quite variable and no longer consistent with the temperature curves.

The initial portion of the performance curve drops relatively rapidly; the middle five trials actually exhibit less acceleration than might be expected, a phenomenon suggestively coincident with similar changes in the other curves shown. On *trials 16* and *17* the curve shows a decrement as compared to the previous trend. This phenomenon is presumably a 'warm-up' decrement common to psychomotor tasks and previously demonstrated with this one (6). Following the initial decrement the curve drops steeply paralleling changes in digital temperatures.

The number of subjects available within each group on whom correlations between digital temperatures and performance times and the latter and digital cooling rates could be obtained was very small. No significant correlations were obtained. Since correlating within groups provided a restricted range of measures as well as reduced sample sizes, the lack of significant relationships obtained cannot be accepted with confidence. On the other hand, this result suggests that, if relationships existed, they were not strong ones.

DISCUSSION

Use of table 1 will show that an increasingly greater percentage of subjects were removed on grounds of approaching frostbite as the ambient conditions became more severe. Thus, the results were probably biased at the more severe conditions indicating performance times shorter than might be expected from unselected samples. This may account for the discrepancy between the negatively accelerated function of temperature obtained in the present study and the positively accelerated one obtained by McCleary (4).

The data are clear in showing that the ambient conditions had a systematic effect on both mean skin temperature and on digital temperature. The results of relating each of these to the performance measures is not so clear. The results of correlating within conditions suggest that mean skin temperature has a slight effect on performance, but only when subjects are nude. They also suggest that digital temperatures and digital cooling rates may not have a strong effect on performance, at least above the level of tissue damage.

No study has yet been performed in which manual skill and hand temperature have been directly related. The present results suggest that, even if such a relationship exists, performance may depend on other factors at least as strongly. In a recent study of reaction time in the cold (8), it was concluded that losses in reaction time are probably most dependent on the psychological effects of exposure to the cold, primarily what was called the 'distraction power' of the environment. The present results would appear to be amenable to explanation in terms of the same hypothesis. That is, if performance losses are not strongly dependent upon physiological states of the individual, which states also result from exposure to the cold, then it might be supposed that the losses observed are due largely to inability of the subject to maintain attention to the performance task. If this were so, then repeated exposure to cold environments should bring about adaptation, i.e. a learning to respond selectively to the relevant conditions of the task-environment situation, and a consequent recovery of normal performance levels. Some support for this hypothesis may be found in a previous study by Teichner and Kobrick (9) in which it was found that marked performance decrements, obtained during exposure to the cold, recovered gradually during prolonged exposure (approximately 2 weeks) in a manner characteristic of the learning curve for the task.

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