NAVAL SUBMARINE MEDICAL RESEARCH LABORATORY

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REPORT NUMBER 983

THE EFFECT OF THE THERMAL CONDITIONS OF TRAINING AND TESTING ON THE PERFORMANCE OF MOTOR TASKS MEASURING PRIMARY MANUAL ABILITIES

by

William H. ROGERS, Ernest M. NODDIN, and George MOELLER

Naval Medical Research and Development Command
Research Work Unit MR0410106A-0003

Released by:

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SUMMARY PAGE

THE PROBLEM

To assess and combat cold-induced decrements in performance of manual tasks measuring primary abilities.

FINDINGS

Performance on eight of nine tasks was inferior at 10° to 15°F relative to that at 40° to 50°F. The size of the decrement was dependent on the ability required, i.e., task performed, with the largest decrements occurring for those tasks requiring fine, precise dextrous abilities and the smallest decrements occurring for those tasks requiring gross speed abilities. Training on the tasks in the thermal conditions in which they were subsequently performed, found by a previous study to enhance performance, had no effect in this study. This negative finding is taken as tentative in light of methodological issues.

APPLICATION

This study shows that caution should be used when generalizing about the size of manual decrements in the cold, as these decrements are highly dependent on the abilities required by the tests used.

ADMINISTRATIVE INFORMATION

This investigation was conducted as part of Naval Submarine Medical Research Laboratory Independent Research Work Unit MR0000101-5086 - Potential mechanisms for improving manual performance in the cold. The present report was completed as part of Naval Medical Research and Development Command Work Unit MR0410106A-0003, Assessing and combating cold-induced decrements in primary manual abilities. It was submitted for review on 22 April 1982, approved for publication on 25 June 1982, and designated as NAVSUBMEDRSCHLAB Report No. 983.

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ABSTRACT

It has been well documented that manual performance deteriorates in the cold. However, motor tasks require many independent abilities from fine, precise finger dexterity to gross arm-hand speed, and it is likely that each of these abilities is affected differentially by the cold. To predict accurately the effects of cold on specific practical tasks, without direct test, the decrement to component skills must be known.

Two groups of U.S. Marines practiced a battery of nine motor tasks in a climatic chamber during a five-day cold exposure in which the Marines lived in the chamber 24 hours a day. Subjects practiced the tasks, each of which was known to load highly on a different psychomotor factor or manual ability, once a day for the first four days and were tested on the fifth day.

One group trained at 10° to 15°F, and the other group trained at 40° to 50°F. Both groups were then tested at both temperatures on the fifth day to test the hypothesis that subjects practiced in the cold should perform better on subsequent tests in the cold relative to subjects practiced in warmer temperatures, and those practiced in the warmer temperatures should perform better on subsequent tests in the warmer temperatures relative to subjects practiced in the cold. The hypothesis was not confirmed by the data, and methodological and theoretical problems in interpretation of that finding are discussed.

It was shown that performance of all but one of the tasks deteriorated at the cold temperature relative to performance at the warmer temperature on the test day. The degree of decrement varied with the task; tasks requiring fine, precise dextrous abilities deteriorated more than tasks requiring speed and reaction abilities.

THE EFFECT OF THE THERMAL CONDITIONS OF TRAINING AND TESTING ON THE PERFORMANCE OF MOTOR TASKS MEASURING PRIMARY MANUAL ABILITIES

Many studies (e.g., McCleary, 1953; Provins & Clark, 1960; Teichner, 1957; Springbett, 1951; Lockhart, 1968; LeBlanc, 1956) have shown decrements in the performance of motor tasks in the cold relative to performance of those tasks in warmer temperatures. The size of manual performance decrements have been attributed to many variables, including hand-skin temperature (HST) (Fox, 1967), prior cold exposure (Fox, 1967; LeBlanc, 1962; Mackworth, 1956), task demands (Fox, 1967), and the thermal conditions of training (Clark & Jones, 1962).

The manual tasks used to measure performance decrements in the cold differ in terms of gross versus fine dexterity requirements and, hence, their sensitivity to the effects of cold vary widely. Fleishman and his associates (e.g., Fleishman, 1967) through theoretical analyses and a long series of studies which applied factor analysis to the results of performance of various manual tasks, have identified many independent 'primary' manual abilities ranging from fine finger-dexterity to gross arm and hand speed. Since each of these abilities is independent, i.e., performance of tasks measuring them are not highly correlated, it is likely that tasks involving different abilities will be differentially affected by the cold.

In the past, the impetus for use of a particular experimental task has usually been its similarity to an applied task of interest. Thus, uniformity of tasks used and results obtained across studies was low, and findings could not be generalized to tasks other than those used. Some studies have assessed manual cold decrements with a task which measures a 'pure' or primary manual ability, the results of which then could be generalized to other tasks which involve the same ability. Most applied tasks, however, involve a combination of primary manual abilities; the abilities involved and the degree of importance of each vary from task to task. To obtain results on manual performance decrements in the cold which have wide generality, the magnitude of decrements on tasks designed to measure each of the primary manual abilities and the primary ability make-up of different classes of applied tasks should be determined. Then decrements on the applied tasks could be inferred from decrements on the tasks measuring primary abilities.

In this experiment, tasks found to measure primary manual abilities (Fleishman, 1967) were performed in cold and warm temperatures to assess the effect of cold on each primary manual ability. Experimental tasks measuring nine abilities which compose most practical motor tasks were used. Those abilities are: finger dexterity, manual dexterity, control precision, arm-hand steadiness, reaction time, response orientation, arm speed, wrist-finger speed, and aiming.

Attention has been focused on finding ways to reduce manual performance decrements, as well as on determining the magnitude of the decrements in the cold. One method has been based on the hypothesis that the thermal conditions under which a task has been practiced become part of the stimulus set for the task. That hypothesis predicts that performance of the tasks by individuals practiced in the test temperature would be superior to performance by individuals practiced in another thermal environment (Clark & Jones, 1962). In the experiment reported here, different groups of subjects practiced the tasks under different thermal conditions to determine the effect of the thermal conditions of practice on subsequent performance. If training temperature (cold or warm) influences performance at the test temperature (cold or warm), then the group that practiced in the warm conditions should perform better in the warm test conditions and the group that practiced in the cold conditions should perform better in the cold test conditions.

METHOD

Subjects

Thirty-two U.S. Marines stationed at Camp LeJeune, North Carolina, volunteered for this experiment. They ranged in age from 18 to 29 with a median age of 20. The experiment was run in two one-week replications, each with 15 enlisted men and one officer, all from the same battalion, serving in each replication. Five subjects did not complete the first replication, either de-volunteering or being medically disqualified. All subjects completed the second replication, resulting in a total of 27 men completing the experiment.

Apparatus

The experiment was conducted in the arctic chamber housed at the U.S. Army Research Institute of Environmental Medicine, Natick, MA. The chamber measured 15 feet (4.57 meters) by 65 feet (19.81 meters). The temperature could be varied between -70°F and +70°F (-56.6°C and 21°C), and the wind from 0 to 40 miles per hour. Subjects lived in the chamber for five days, with the daytime temperature averaging 0° to 5°F (-18°C to -15°C). The cooling generators were turned off about 3:30 p.m. each day, so by the time the tasks were administered at 4:30 p.m. the temperature in the main chamber was between 10° to 15°F, with no wind. An ante-chamber was used for administration of the tasks in the warm condition, and was between 40° to 50°F at the time of testing. The temperature and duration of the exposure was determined by the requirements of a water-balance study conducted by the Biochemistry Department of this Laboratory.

The reaction time apparatus consisted of a vertical partition with a center-mounted stimulus light containing two colored bulbs, and four keys on a horizontal board, two on each side of the vertical partition. The two keys on the subject's side of the vertical partition were 4 inches (10.2 cm) apart. The RTs were measured with a Lafayette clock counter, Model #54417.

The Rotary Pursuit, Minnesota Manual Dexterity Test, Steadiness Tester - Hole Type, Tapping Board, and O'Connor Finger Dexterity Test apparatus were all purchased from Lafayette Instrument Co. The Steadiness Tester and Rotary Pursuit apparatus were connected to Lafayette clock/counters and the Tapping Board was connected to a mechanical counter. Hand-held stopwatches were used to time all tests but the Simple and Choice Reaction Time and Rotary Pursuit tests.

Tasks

Each task was used to measure a different primary motor ability or psychomotor factor. The tasks and abilities measured were those described by Fleishman and his co-workers (e.g., Fleishman, 1967). Each test and the ability it measures will be described separately.

1) O'Connor Finger Dexterity Test - In this test the subject takes small metal rods from a well three at a time and places them in a small hole. The score is the number of holes completed in 60 seconds. This is a measure of the ability to make skillful, controlled movements, primarily of the fingers, to manipulate very small objects.

2) Minnesota Manual Dexterity Test - The two-handed turning subtask was used. Subjects pick up each block with one hand, transfer it to the other hand and replace it in its original hole with the opposite side up. This is done working from right to left on the top row, from left to right on the next row and so on. The score is the number of blocks turned over in a 30-second period. This task measures the ability to make skillful, well directed arm-hand movements to manipulate fairly large objects under speed conditions.

3) Rotary Pursuit Test - Subjects attempt to keep a stylus tip on a target circle near the edge of a turntable revolving at 45 rpm. The score is the cumulative time on the target for two 20-second trials. This test measures control precision, the ability to make fine, highly controlled, but not over controlled, muscular adjustments involving arm-hand movements which must be rapid but precise.

4) Steadiness Test - Subjects have to insert a stylus tip .16 cm in diameter into a .32 cm diameter hole and hold it as steadily as possible. Subjects sit and are not allowed to rest their hand or lower arm on any surface while performing the test. The score is the cumulative time the stylus is touching the edge of the hole during three 12-second trials. This test measures the steadiness with which precise arm-hand positioning movements not requiring speed or strength can be made.

5) Simple Reaction Time Test - Subjects keep the index finger of their preferred hand over a response key and press the key as quickly as possible when they see the stimulus light go on. The score is the cumulative reaction time over 20 trials, averaged for two sets of trials. This measures the speed with which one can respond to a stimulus when it appears.

6) Choice Reaction Time Test - Subjects keep the index finger of their preferred hand mid-way between the two response keys. The subject responds by hitting the left response key when the stimulus light is one color and the right key when the light is the other color. Each stimulus color is presented an equal number of times in random order in a trial set. The inter-stimulus interval for both reaction time tests is varied so that subjects cannot anticipate the stimulus onset. The score is the cumulative reaction time over 20 trials. This task measures the ability to make rapid discriminations of direction and orientation of movement patterns in response to visual discrimination under highly speeded conditions.

7) Tapping Test - Using a stylus, subjects alternately strike two metal plates separated by 30 cm. The score is the number of cumulative hits on the two plates over three 12-second trials. This task measures the speed at which one can make gross, discrete arm movements when accuracy is not a critical requirement.

8) Pencil & Paper Tapping Test - This is a printed test in which the subjects must place three pencil dots in a series of .5 inch (1.27 cm) diameter circles as fast as possible. The test sheet has 7 rows of circles, 10 circles to a row. The score is the total number of circles completed in 30 seconds. This is a measure of the speed at which pendular or rotary wrist movement can be made when accuracy is not a critical requirement.

9) Pencil & Paper Aiming Test - This is a printed test in which the subjects must place a single pencil dot in a series of .32 cm diameter circles as fast as possible. There are 100 circles and the distance between circles is variable. The score is the total number of circles completed in 30 seconds. This is a measure of the ability to make speeded and highly controlled muscular adjustments involving small muscle groups. Neither of the pencil and paper abilities (wrist-finger speed and aiming) have been found to extend to apparatus tests.

Procedure

Subjects of a replication were assigned at random to two experimental groups. Group A practiced the tasks for the first four days of the experiment at 40° to 50°F (4.4° to 10°C), and Group B practiced the tasks during those days at 10° to 15°F (-12.2°C to -9.4°C). Thirteen subjects assigned to Group A and 14 assigned to Group B completed the experiment.

All tests were performed bare-handed, but with full cold weather gear. Tests were administered at least once to each subject in an indoctrination and familiarization session prior to the cold exposure. For the first four days of the cold exposure (practice days), tests were administered to Group B in the main chamber (10° to 15°F) at about 4:30 p.m. and then to Group A in the ante-chamber (40° to 50°F) at about 6:30 p.m.[1]

Four test stations were set up: Station 1, consisting of the Pencil & Paper Tapping and Aiming Tests and the Minnesota Manual Dexterity Test; Station 2, consisting of the Simple and Choice Reaction Time Tests; Station 3, consisting of the Rotary Pursuit and Tapping Tests; and Station 4, consisting of the O'Connor Finger Dexterity Test and the Steadiness Test. Procedures for administering the tests to Groups A and B were identical. For each replication, subjects of Group A and B were divided into subgroups of four, resulting in Groups A1, A2, B1, and B2. Tests were administered to the subjects of a subgroup simultaneously, but the order in which the subgroups were tested alternated from day to day. Each subject started the first practice session at an assigned station. Subjects of Group A1 (B1) completed all tests at a given station and then took a break while each subject of Group A2 (B2) performed the tests at an assigned station. The order of tests at a station was reversed for each subject each day. Subjects not performing the tests were allowed to don their gloves to warm their hands. Subjects of a

Table 1

Correlations Among Nine Manual Tasks Performed in the Cold on Day 5 (N = 27)

	1 O'Connor Finger Dexterity	2 Minnesota Rate of Manipulation	3 Rotary Pursuit	4 Steadiness	5 Simple RT	6 Choice RT	7 Tapping	8 Pencil & Paper Tapping	9 Pencil & Paper Aiming
1		.44* (.45)	.41* (.24)	.42* (.11)	.36 (.26)	.44* (.32)	.24 (.28)	.04 (.29)	.25 (.34)
2			.30 (.36)	.07 (.16)	.25 (.28)	.35 (.37)	.03 (.44)	.25 (.36)	.03 (.41)
3				.31 (.19)	.41* (.22)	.39* (.28)	.26 (.33)	.05 (.30)	-.15 (.24)
4					.26 (.04)	.02 (.16)	.64** (.10)	.31 (.18)	.25 (.12)
5						.24 (.20)	.05 (.25)	-.06 (.24)	-.30 (.23)
6							.14 (.24)	.07 (.27)	.01 (.28)
7								.32 (.48)	.40* (.34)
8									.37 (.50)

Fleishman's (1954) correlations in parenthesis (N = 400)
All correlations are corrected for differences in scoring direction

*$p < .05$
**$p < .01$

subgroup rotated through the four stations in the order 1-2-3-4, alternating test and rest periods. On each subsequent day, subjects started testing at the last station visited on the preceding day.

On the test day (the fifth and last day of the cold exposure) the same procedures were followed except that the subgroups of four subjects cut across experimental groups so that two subjects from Group A and two from Group B performed the tasks simultaneously. Two subgroups alternated testing, as on practice days, and when they completed all testing at a given temperature, the other two subgroups alternated testing at that temperature. All subjects performed the tests in both temperatures (10^{o} to 15^{o}F and 40^{o} to 50^{o}F) on the test day, performing the tests in the colder temperature first.

RESULTS

A correlation matrix was computed to assess the relationship among performances of the nine tasks in the cold on the test day. The main concern was confirmation of Fleishman's claim that different abilities were evaluated by the several tests. This matrix, computed from the scores of 27 subjects, and the original correlations computed by Fleishman (1954) for 400 subjects, are presented in Table 1. Considering that the conditions of testing, sample size, subject population, and test scoring all varied between this experiment and Fleishman's (1954), the correlations are remarkably similar. In fact,

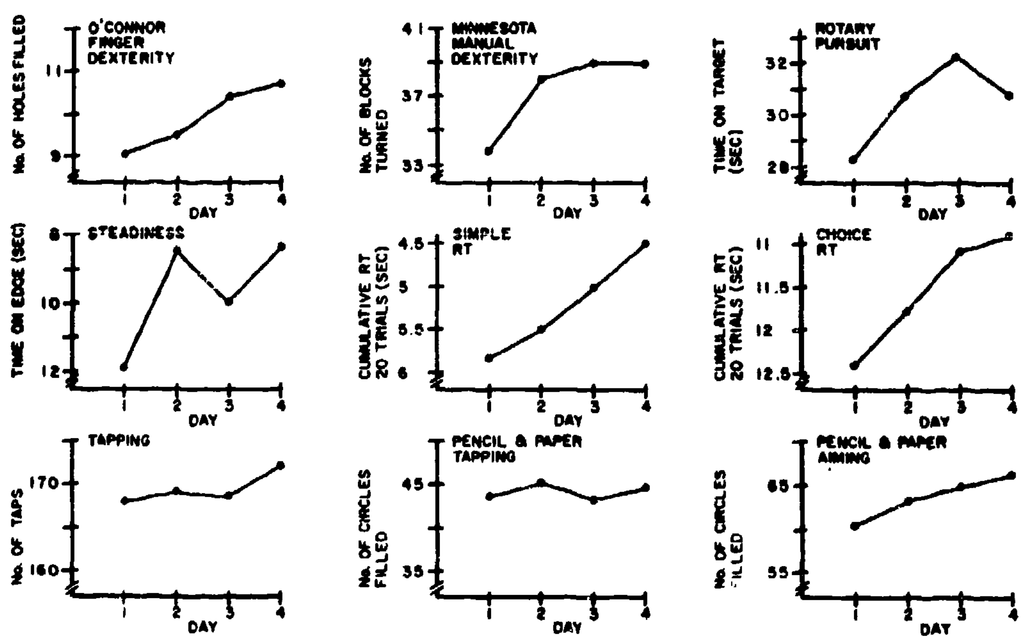

Figure 1. Practice effect (Days 1-4) for Nine Motor Tasks.

the correlations between the two matrices was r = .72. Only eight of the 36 possible correlations reached significance in our study; the small number of significant correlations is taken as support of the notion that independent abilities are evaluated by the nine tests.

Two mixed-design analyses of variance (ANOVA's)[2] were computed for each task, one for the practice days and one for the test day. The practice days ANOVA's were used to assess the effects of temperature during training (Group) and practice (Days) on performance of the tasks during training. The test day ANOVA's were used to assess the effects of temperature during training (Group) and test temperature on performance of the tasks on the test day. The first set of analyses showed: a significant Day effect for all tests but Tapping and Paper and Pencil Tapping, with performance tending to improve across days (Figure 1); a significant Group (temperature during training) effect for the O'Connor Finger Dexterity, Rotary Pursuit, and Simple Reaction Time tests, with Group A (training at 40° to 50°F) performing better than Group B (training at 10° to 15°F); and a significant Group x Day interaction for the Simple Reaction Time test, with Group B improving more across days than Group A (Figure 2).

Mean scores for each task in the warm and cold test conditions on the test day are presented in Table 2. The test day ANOVA's showed a significant test temperature effect for the O'Connor Finger Dexterity, Minnesota Manual Dexterity, Rotary Pursuit, and the Steadiness tests. No other

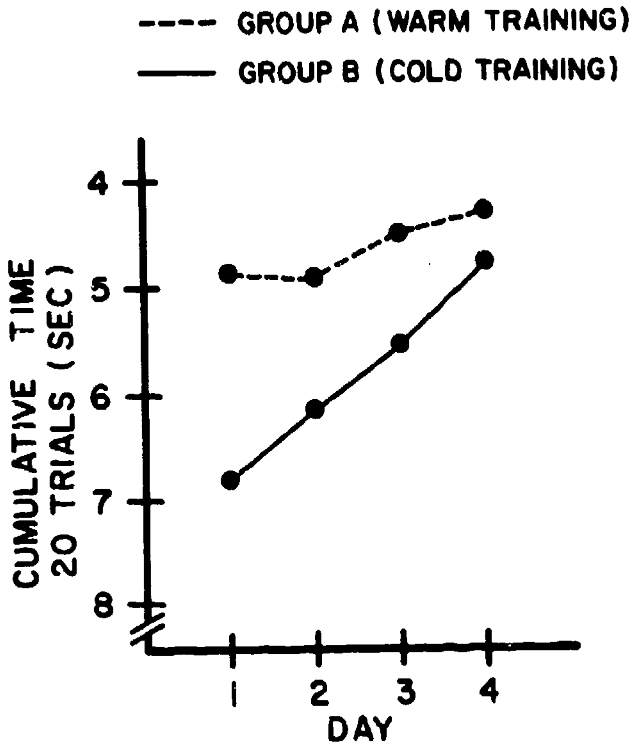

Figure 2. Simple Reaction Time Group x Day Interaction.

significant effects were found for the test day analyses. All significant results of both sets of ANOVA's are presented in Table 3.

Performance decrements of the cold training group (Group B) in relation to the warm training group (Group A) on the last practice day are shown in Figure 3. Performance decrements of all subjects in the cold temperature in relation to the warmer temperature on the test day are shown in Figure 4. These two profiles illustrate the importance of task requirements in determining the magnitude of performance decrements in the cold.

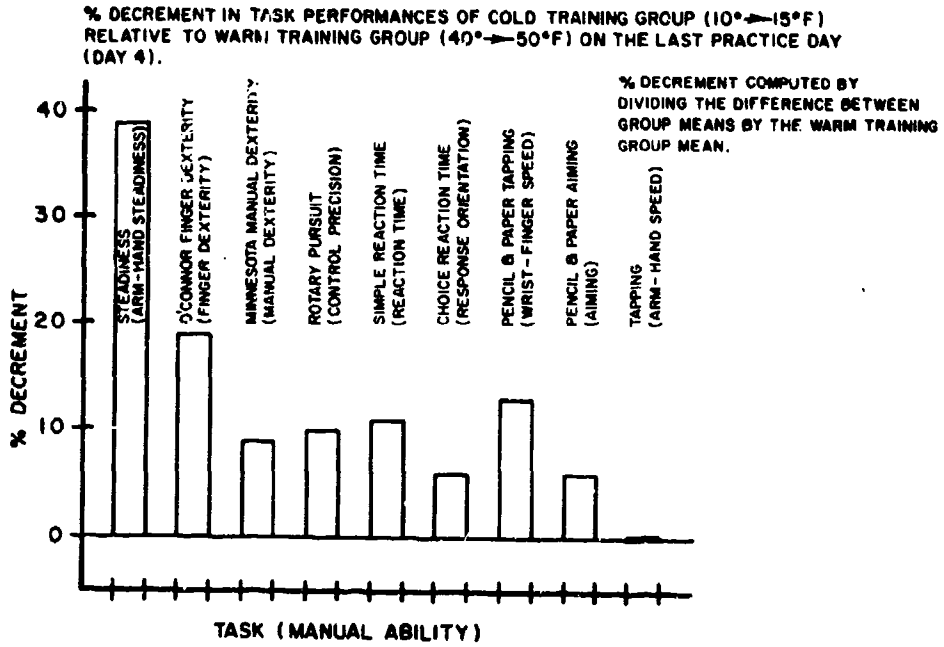

Figure 3. % Decrement in Task Performance of Cold Training Group (10° to 15°F) Relative to Warm Training Group (40° to 50°F) on the Last Practice Day (Day 4).

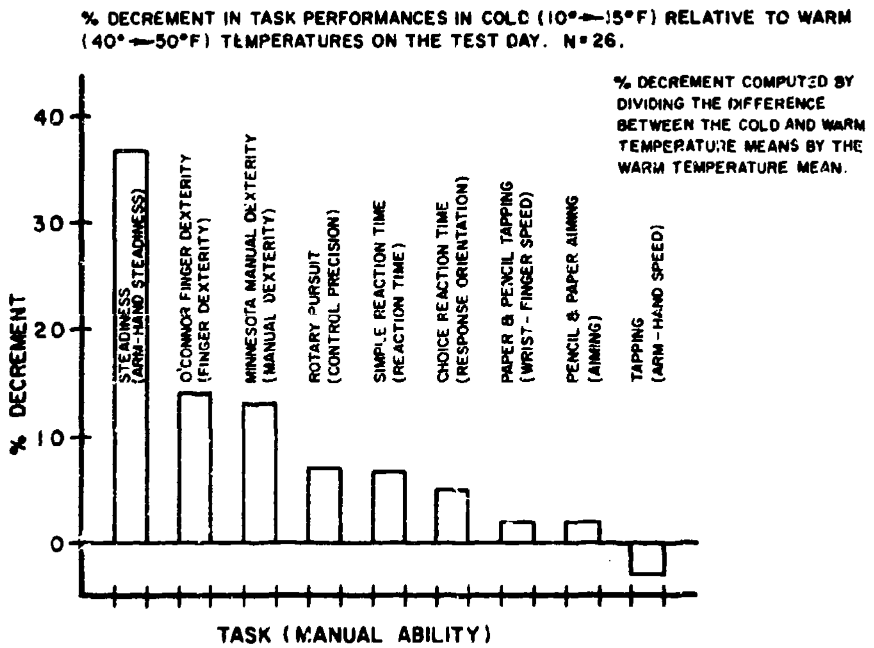

Figure 4. % Decrement in Task Performances in Cold (10° to 15°F) Relative to Warm (40° to 50°F) Temperatures on the Test Day. N = 26.

Table 2

Mean scores for nine tasks performed at 10° to 15° and 40° to 50°F on the test day (N = 26)

TEMP	O'Connor Finger Dexterity	Minnesota Manual Dexterity	Rotary Pursuit	Steadiness*	Simple* Reaction Time
10°→15°F	9.4	36.9	31.7	9.87	4.89
40°→50°F	10.9	42.6	34.0	7.19	4.58

TEMP	Choice* Reaction Time	Tapping	Pencil & Paper Tapping	Pencil & Paper Aiming
10°→15°F	11.51	167.6	48.2	69.3
40°→50°F	10.92	162.2	49.2	70.6

*Lower scores on these tests reflect better performance

DISCUSSION

Although task performance generally improved over days, there were several exceptions. Performance deteriorated on the Rotary Pursuit task between Days 3 and 4, and on the Steadiness Test between Days 2 and 3, and the reason for either drop is not apparent. The fact that no practice effect was shown for two tasks (Tapping and Pencil and Paper Tapping) seems reasonable, in retrospect, since gross speed abilities might be subject to less learning that precision abilities.

The Day x Group interaction for the Simple Reaction Time test (Figure 2) was due to the cold training group (Group B) starting out much slower than the warm training group (Group A) on Day 1 and improving at a faster rate over days, although Group B never equalled the performance of Group A. Subjects of Group B probably improved more rapidly because there was more room for improvement, but is is not clear why they initially performed so much slower than Group A subjects.

The lack of a Group x Test Temperature interaction for any task on the test day indicates that the thermal conditions of training is not an important variable in subsequent performance in the cold. This apparent contradiction of the Clark and Jones (1962) results concerning the importance of the thermal conditions of training is taken as tentative. Several methodological differences between the two studies could account for the different results. First, ambient temperature during training was the independent variable in the study reported here, whereas hand-skin temperature

Table 3

Analyses of Variance

Practice Days

TASK	SOURCE	df	F	p
O'Connor Finger Dexterity	Group	1,24	6.75	.025
	Days	3,72	7.45	.001
Minnesota Manual Dexterity	Days	3,72	15.93	.001
Rotary Pursuit	Group	1,24	8.53	.01
	Days	3,72	4.97	.005
Steadiness	Days	3,72	3.68	.025
Simple Reaction Time	Group	1,24	7.00	.025
	Days	3,72	17.74	.001
	Group x Days	3,72	4.97	.005
Choice Reaction Time	Days	3,72	5.48	.001
Pencil & Paper Aiming	Days	3,72	4.85	.005

Test Day

TASK	SOURCE	df	F	p
O'Connor Finger Dexterity	Test Temp	1,24	20.8	.001
Minnesota Manual Dexterity	Test Temp	1,24	45.1	.001
Rotary Pursuit	Test Temp	1,24	11.3	.001
Steadiness	Test Temp	1,24	8.3	.001

(HST) was the independent variable in the Clark and Jones study. Numerous factors could cause a wide variation in HST at any given ambient temperature, so the relationship between HST during training and test performance in this study is uncertain. Second, the Clark and Jones study used a cold box in which subjects exposed only their hands to the cold for a short time each day, whereas the subjects here lived and worked in the cold for five days. Third, Clark and Jones warm-training subjects were never exposed to the cold during training as were our warm-training subjects. This cold exposure allowed them the opportunity to perform practical manual tasks during the course of their daily activities in the cold. If, as we assume, Fleishman's battery does sample the range of motor abilities encountered in daily life, then the performance of routine tasks by the warm-training group in the cold gave them cold experience using the various motor abilities required to perform the test battery, accounting for the lack of a group difference on the test day.

Performance on several of the tasks deteriorated significantly in the colder temperatures, as indicated by the significant group differences on practice days and the test temperature differences on the test day. As expected, the degree of deterioration in the cold was dependent on the ability involved. The task-decrement profile derived from group differences on the last practice (Figure 3) is probably not as reliable as the task-decrement profile derived from group differences on the test day (Figure 4). The former set of contrasts involves a between-groups error term and the latter a within-groups (subjects) error term. The fact that, on the test day, the O'Connor Finger Dexterity, Minnesota Manual Dexterity, Rotary Pursuit, and Steadiness tests were considerably impaired by the cold and the other tests were slightly impaired by the cold, if at all, seems intuitively reasonable; the former tests require dexterity, steadiness, and precision abilities, i.e., those involving fine muscle control, and the latter require gross muscle control. It is not apparent why Pencil and Paper Aiming was only marginally affected by the cold, since it involves fine, precise motor control and was expected to deteriorate comparably to the other precision tasks under cold conditions.

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FOOTNOTES

[1] Subjects were allowed to warm up (about 15 minutes) before testing was started in the ante-room (40° to 50°F).

[2] All ANOVA's were computed on 26 subjects, 13 per experimental group. Subjects were receiving different quantities of water throughout the cold exposure as part of the previously mentioned water-balance study. Thus, one subject was dropped from our analyses in order to equate the two experimental groups on the water intake variable.

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It has been well documented that manual performance deteriorates in the cold. However, motor tasks require many independent abilities from fine, precise finger dexterity to gross arm-hand speed, and it is likely that each of these abilities is affected differentially by the cold. To predict accurately the effects of cold on specific practical tasks, without direct test, the decrement to component skills must be known.

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Two groups of U.S. Marines practiced a battery of nine motor tasks in a climatic chamber during a five-day cold exposure in which the Marines lived in the chamber 24 hours a day. The groups practiced the tasks, each of which was known to load highly on a different psychomotor factor or manual ability, once a day for the first four days. One group trained at 10° to 15°F, and the other group trained at 40° to 50°F. Both groups were tested at both temperatures on the fifth day, the test day.

The thermal conditions of training were varied to determine how these conditions affect subsequent performance in both thermal environments. The hypothesis was that subjects practicing in the cold should perform better on subsequent tests in the cold relative to those practicing in warmer temperatures, and those who practiced in the warmer temperatures should perform better on subsequent tests in the warmer temperatures relative to subjects practiced in the cold. The hypothesis was not confirmed by the data, and methodological and theoretical problems in interpretation of that finding are discussed.

It was shown that performance of all but one of the tasks deteriorated at the cold temperature relative to performance at the warmer temperature on the test day. The degree of decrement varied with the task; tasks requiring fine, precise dextrous abilities deteriorated more than tasks requiring speed and reaction abilities.