

VOLUNTARY INCREASES IN DIGITAL SKIN TEMPERATURE
DURING A MILD COLD EXPOSURE

by

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ABSTRACT

Two experiments were carried out in an attempt to train subjects to increase their digital skin temperatures in a cold room through biofeedback techniques, and to assess the effect of this increase on perceptions of comfort and temperature, in addition to the effect on performance of dexterity and reasoning tasks.

Experiment I failed to show any evidence for long-term increases in digital skin temperatures as a result of the training procedure. However, some correlational data based on sex differences in perception ratings suggested that subjects would feel more comfortable and perceive a room as warmer when their digital skin temperature was elevated, even though the ambient temperature in the room was constant. The data also suggested that the training procedure itself was interfering with task performance in male subjects.

Analysis of individual subjects' data from Experiment I suggested some procedural changes which might facilitate the elevation of digital skin temperature in the cold through biofeedback techniques. These changes were implemented in Experiment II. In this second study all subjects were able to elevate and maintain high digital skin temperatures throughout the feedback period, even though the same subjects showed expected cooling for a comparable period in a control session. As predicted, subjects rated their comfort and the room temperature higher during periods when their digital skin temperature was elevated. Only male subjects were run in Experiment II, and again, performance scores indicated that the effort and concentration required to voluntarily elevate digital skin

temperature interfered with task performance.

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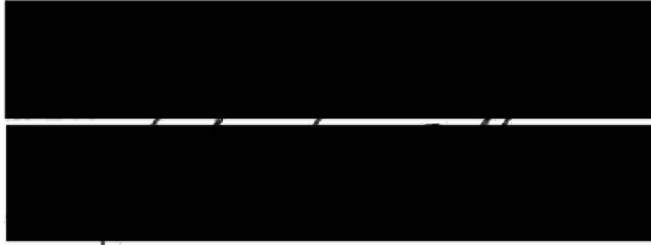


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Introduction

Upon a frosty winter night, those who think themselves capable of victoriously enduring the test are led to the shore of a river or lake. If all the streams are frozen in the region, a hole is made in the ice. A moonlight night, with a hard wind blowing, is chosen. Such nights are not rare in Tibet during the winter months.

The neophytes sit on the ground, cross-legged and naked. Sheets are dipped in the icy water. Each man wraps himself in one and must dry it on his body. As soon as the sheet has become dry, it is again dipped in the water and placed on the novice's body to be dried as before. The operation goes on in that way until daybreak. Then he who has dried the largest number of sheets is acknowledged the winner of the competition. (p. 158-159)

The above account from With Mystics and Magicians in Tibet (A. David-Neel, London, 1931) is cited by Evans-Wentz (1958). It describes a test of proficiency in Tūmmō (Kundalini Yoga in India), the yoga of psychic heat. Evans-Wentz also cited personal observations and "well-authenticated accounts" by Europeans in which followers of this doctrine had been observed to withstand arctic-like temperatures in the high Himalayas either nude or clad only in thin cotton robes. These people appear to have mastered a method for voluntarily controlling production of body heat, even under circumstances of extreme cold exposure.

Recent studies have shown that individuals can learn to increase finger temperatures in a normal thermal environment by use of biofeedback techniques (Wickramasekera, 1973; Sargent et al., 1973). No studies to date, however, have attempted to extend this technique to a cold environment. In view of the current concern with energy and associated suggestions to reduce the level of heating in schools, offices, and homes, the benefits of such a technique seem obvious even if effects can be shown under only mild cold stress.

The purpose of this study is to look at the possibility of voluntarily increasing digital temperatures under a mild cold stress and to look at what, if any, perceptual and performance changes are correlated with such increases.

Physiological Effects of Cold Exposure and Their Relation to Cold Perceptions

The human body's initial response to cold is one of heat conservation accomplished primarily through constriction of peripheral blood vessels, thereby decreasing blood flow and resultant heat loss through radiation. This means of thermoregulation is effective down to ambient temperatures (T_A) of about 60°F (16°C) (data for nude males, Gagge et al., 1967). Below this point, thermoregulation involves increased heat production by first shivering and then non-shivering thermogenesis (Bligh, 1973).

In addition to these physiological changes, cold exposure also brings about certain perceptual changes. Generally, a perception of cold and feelings of discomfort, and/or unpleasantness, occur which vary in degree with the type of exposure. The question of what stimuli trigger these perceptual changes has been a topic of debate for some time. Chatonnet and Cabanac (1965) reviewed earlier studies which found thermal comfort to be related to mean skin temperature (T_S), the average of several skin temperatures from both trunk and extremities. They referred to a report by Winslow and Herrington (1949) summarizing earlier studies (Winslow et al., 1937a,b) where a thermoneutral zone of T_S from about 84° to 95°F (29° to 33°C) is defined, with T_S outside of this range described as disagreeable. Hardy (1954) suggested that the zone about 91°F (33°C) was a preferred or set point temperature and that adjustments were

initiated by the cutaneous thermal receptors to maintain the T_S at this level. He was referring here mainly to behavioural means of thermoregulation such as increased clothing or external heat sources. He noted that strong, unpleasant thermal sensations were associated with T_S which deviated from this set point and that any return of T_S toward that point was found to be pleasant. He discussed the "affect" of thermal sensations as one of the most powerful drives for behavioral temperature regulation in conditions of external thermal stress.

Chatonnet and Cabanac's (1965) own data supported their hypothesis that T_S was not the primary cue for discomfort. Their work showed that in cold bath immersion, individuals complained of discomfort only when internal temperature (T_i) fell. This decline in T_i generally coincided with shivering and occurred at varying T_S . To explain their data they hypothesized that sensitivity to T_i is responsible for sensations of comfort, the role of T_S being purely incidental. They also suggested a possible input of feedback from central thermoregulatory responses (i.e. shivering) in determining comfort. They cited their own bath evidence as support for this, in addition to reports by several investigators that comfort was restored when shivering was suppressed by either natural (hypothermia, Fay and Smith (1941)) or artificial means (injections, Bortoluzzi and Montoli (1961); inhaling oxygen, MacCanon and Eitzman (1961)).

Gagge et al. (1967), in an often cited work which is accepted as the definitive study on thermal comfort, proposed a theory which to some degree accounted for the observed differences in the earlier studies. Based on ratings collected at the end of one hour's exposure to various T_A from 53.6° to 118.4° F (12° to 48° C), and from ratings throughout a two

hour exposure to 63.5°F (17.5°C), they concluded that feelings of discomfort increased as the average body temperature ($T_i + T_s$) deviated from its ideal level. In addition, they too proposed an input of thermoregulatory responses to cue changes in comfort and temperature sensations, but they saw this input as coming from more peripheral responses (i.e. vasomotion) than did Chatonnet and Cabanac (1965). Gagge et al. concluded that this response could override both T_i and T_s in determining comfort, especially in a return to neutral T_A . Their conclusions were based on their findings that as T_A decreased from 86°F (30°C) to approximately 60°F (16°C) comfort decreased linearly. Below T_A of 59°F (15°C), comfort decreased much more rapidly. Since vasoconstriction is considered to be an effective means of thermoregulation down to T_A of about 60°F (16°C), very little decrease in T_i would be expected after a one-hour exposure at T_A greater than 60°F (16°C). In fact, one might have expected an initial increase in T_i at the higher temperatures used here due to redistribution of heat as a result of vasoconstriction, yet comfort still showed a decrease. This expected increase in T_i was reported by Gagge et al. for the two-hour 63.5°F (17.5°C) exposure. Subjects in that study showed a large decrease in comfort ratings which corresponded with initial vasoconstriction and decreased T_s . T_i , however, showed an increase at the same time. Ratings remained fairly stable showing only a slight decrease through the rest of the two-hour session, even though T_s continued to drop and T_i had begun to fall by the end of the session. When subjects were transferred to a warm room at this time, comfort ratings returned to normal corresponding to initial vasodilation and increased T_s , even though T_i continued to fall for the next hour. This data by itself suggested that the strongest determinant of comfort is the periph-

eral thermoregulatory response. While this may be true for exposures where peripheral thermoregulation is effective, Gagge et al.'s inclusion of average body temperature provided a clearer explanation of not only their other data such as large increases in discomfort when T_i falls at low T_A , but data referred to earlier from other investigators (Chatonnet and Cabanac, 1965; Winslow et al., 1937a,b).

Gagge et al. also attempted to refine the comfort scale used by previous investigators by separating temperature sensations from comfort sensations. For ratings made at various T_A , they found ratings of cold to increase more rapidly than discomfort down to T_A of approximately 64°F (18°C); but from that point down, discomfort continued to increase while perception of cold levelled off. Comfort was found to correlate well with T_S , while small drops in T_S produced relatively large increases in cold perception. In data based on one continuous exposure (63.5°F (17.5°C)), they found both discomfort and cold perceptions to increase markedly upon initial exposure with very little further change through the two-hour period. When subjects were transferred to a warm room, comfort ratings returned to normal immediately, while temperature ratings showed an immediate large increase but took nearly 15 minutes to return to normal levels. This data suggested that while perceptions of comfort and temperature appeared to be similar, they might be discriminably different sensations, evidenced particularly by the divergence of the two rating scales at low T_A . More data would be useful to determine the nature of the differences in these two sensations, but on the basis of this data it appears useful not to risk confounding comfort ratings with ratings of temperature.

This confounding introduced by the words used to define a scale is

only one of the problems inherent in subjective scaling techniques which complicate direct comparisons of the studies discussed here. Different anchor and reference points for scales, equality of intervals within and across scales, implicit sets induced by the experimental setting, and the validity and reliability of stimulus ratings both within and across subjects are all old problems of psychophysical scaling techniques which may themselves alter results across studies (Stevens, 1951). For example, Chatonnet and Cabanac (1965) defined discomfort as the point at which the subjects complained of the cold. This approach in itself may have yielded quite different results than the category scales used by Winslow et al. (1937a,b) and Gagge et al. (1967) where subjects rated their discomfort at fixed intervals on a pre-labeled scale (see Stevens (1975) for a complete discussion). In addition to these problems, physical differences in the experimental settings such as dry cold exposure or cold water immersion, varying degrees of clothing used, and different levels of T_A used also hinder direct comparison of the studies.

Taking the above problems into consideration, it is still reasonable to expect, on the basis of the above studies, a correlation between comfort, T_S , and thermoregulatory vasoconstriction. Whether any of these factors has a causal relationship to the others is still an experimental question. If the conclusions of Gagge et al. (1967) are correct, a large increase in discomfort would be expected on initial exposure to low T_A corresponding to initial vasoconstriction. With extended exposure, discomfort should increase as T_S decreases, discomfort increasing even more sharply as T_i begins to decrease. If two of these variables are altered, a corresponding change in comfort should follow. This is indeed the case when vasodilation and increased T_S are induced by increasing T_A ,

even though T_i remains low (Gagge et al., 1967). The purpose of this study is to attempt to condition increased T_S via vasodilation under conditions of mild cold exposure while holding T_A constant, and observe the effect of these changes on comfort ratings.

(The vasodilation of interest here should be distinguished from cold-induced vasodilation occurring at T_S less than 50°F (10°C). This vasodilation appears to reflect the inability of smooth muscle fibers to contract at these temperatures (Keatinge, 1970) and is not a thermoregulatory response. This vasodilation is generally accompanied by shivering and pain (Carlson and Hsieh, 1965) and is considered to be qualitatively different from the vasodilation discussed here.)

Acclimatization to Cold

Since the present study involves modifying a strong homeostatic response, the question arises whether the implications of this modification may pose a danger for the organism. Although the levels of T_A to be used here are relatively mild, a lower T_A could be a logical extension for future research. The question then arises as to whether keeping large amounts of blood in the periphery during cold exposure may be a maladaptive response, for example by producing a dangerous lowering of T_i , or alternately by producing extreme increases in metabolism. Studies on acclimatization to cold offer some evidence that this need not be the case. In fact, they offer evidence that increased peripheral temperatures in the cold often result from adaptation.

Studies of acclimatization to cold room exposure and environmental exposure have failed to show a single consistent pattern of cold acclimatization. The available evidence offers support for at least three dis-

tinct patterns which may be referred to as metabolic, peripheral, and insulative adaptation. The first two of these patterns result in increased peripheral temperatures, although the physiological changes underlying the warmer extremities are different in each case.

Metabolic adaptation consists of elevations in basal metabolic rate (BMR) above the DuBois standards along with increased peripheral blood flow and increased temperatures of the extremities, often above levels displayed by non-acclimated white controls, even at warm T_A . Individuals showing this pattern of adaptation show a further increase in metabolism during cold exposure and are able to maintain warmer extremities than non-acclimated controls in the cold. This pattern has been reported in Eskimos (Adams and Covino, 1958; Hart et al., 1962), in a Nepalese Pilgrim (Pugh, 1963), and also in Caucasians exposed for six weeks to a natural cold environment (Scholander et al., 1958a). It has been suggested (e.g. Scholander et al., 1958a) that the increase in metabolism is responsible for the observed increase in blood flow and peripheral temperature. While this interpretation is consistent with the above results, metabolic increases in the cold do not appear to be necessary to produce increased peripheral blood flow or to maintain warmer extremities. This is evidenced by the reported cases of peripheral adaptation where warmer extremities have been observed in the cold with no associated rise in BMR, and a significantly lower metabolic response to cold than is seen in non-acclimated controls. In addition to these differences, this pattern is often accompanied by significantly lower rectal temperatures (T_R) during cold exposure than is found in controls. Peripheral adaptation has been reported for Lapps (Andersen et al., 1960), Andean Indians (Elsner, 1963), and Caucasians exposed to cold environments for two to four weeks (Balke

et al., 1944; Carlson et al., 1953; Rennie, 1958). To account for these observations, Carlson et al. (1953) proposed that cold-acclimatized men exhibit a different pattern of thermoregulation which involves changes in both metabolic and vascular response to cold whereby the extremity skin remains warmer, but cooling of peripheral subcutaneous tissues accounts for a greater proportion of heat loss than before acclimatization. (This concept is proposed as a hypothesis to be tested in future research rather than a theory supported by experimental evidence.)

It should be noted that a third pattern of acclimatization to cold differs markedly from both of the above patterns. In contrast to the warmer extremities which characterize both metabolic and peripheral adaptation patterns, considerable lowering of extremity temperatures has been noted in response to a cold environment in the Australian aborigines (Hammel, 1960; Scholander et al., 1958b; Hart et al., 1962). This insulative adaptation results in increasing the insulative properties of the skin by allowing it to cool, thereby increasing the thermal gradient from the body's core to the environment. The aborigines show no metabolic increase in response to cold exposure until skin temperatures at the extremities approach levels which would result in tissue damage. At this point a slight elevation in metabolism is seen which results in maintaining T_s just above the level of tissue damage (50°F (10°C)). BMR in the aborigines is not elevated above the DuBois standard. This unique pattern of physiological adaptation coincides with another unique characteristic of the aborigines' responses to a cold environment which should be noted. They are the only group reported here which has not responded to cold by behavioral means of thermoregulation such as clothing and shelter. The mean temperature of their environment is 41°F (5°C), yet they have never

worn clothing and their means of shelter consists only of short windbreaks used while sleeping. The aborigines are reported to sleep soundly through the night, even down to temperatures of 33°F (1°C), and show no obvious signs of discomfort. These findings suggest a cultural component of comfort which may influence patterns of cold acclimatization.

Manual Dexterity Decrements in the Cold

In addition to the physiological and subjective changes associated with cold exposure which have already been discussed, the deterioration of manual dexterity in the cold has also been the topic of much research. Many studies have tried to pinpoint the exact factors involved in the observed decrements in dexterity so that practical solutions might be developed which would enable people to work efficiently in cold environments. One such study (Mackworth, 1955) compared men in sub-Arctic regions who worked outdoors with men working indoors in the same regions. Mackworth found that the outdoor men in his study had seven times greater two-point tactile discrimination on their fingers in the cold than the indoor men, even though both groups were the same when tested in warm T_A . He also found that the outdoor men had higher digital temperatures than the indoor men both before and during exposure, and that the outdoor men were more resistant to numbing effects of the cold. He found a similar pattern of results were shown as a result of cold room exposure (5°F (-15°C)) for two hours a day, five days a week, for five weeks. His cold room subjects also reported less subjective discomfort to the cold.

Mackworth's findings suggested two factors which might be responsible for decrements in the cold: first, a distraction effect which was proposed by Teichner (1957), and second, lowered digital temperatures. Studies

by Gaydos (1958), Gaydos and Dusek (1958), and Lockhart (1966) which differentially cooled either the total body surface or hand surface showed that lowered digital temperature was the major component in performance decrements for tasks involving only wrist-finger speed and dexterity, such as knot tying. Slight decrements were observed when digital temperatures fell to 65°F (18.3°C), but significant decrements did not generally occur until digital temperatures fell below 60°F (16°C). The effect of distraction was ruled out in such tasks since no decrement in performance was observed even when the T_{S} was lowered to 69°F (20.5°C) as long as the hands were kept warm. However, cooling the body while maintaining hand temperature did produce a decrement in tasks which involved grosser forms of dexterity, such as forearm movements.

Clark and Cohen (1960) demonstrated that digital temperatures are not, however, the only factor involved in producing performance decrements on digital dexterity tasks in the cold, but that the rate of cooling was also an important factor. Their data showed that while significant decrements in performance were observed at digital temperatures of 45°F (7°C) regardless of cooling time, significantly greater decrements were seen in subjects whose hands reached this temperature over a period of 35 minutes than in subjects who reached this temperature in 15 minutes. This data suggests that Gaydos (1958), Gaydos and Dusek (1958), and Lockhart (1966) may have been too hasty in ruling out distraction effects as a factor influencing performance decrements in the cold. It is suggested that lowered digital temperatures are necessary and sufficient to produce digital dexterity performance decrements in the cold, but distraction effects resulting from increased exposure time may add to temperature effects and increase the magnitude of the decrement. Repeated exposure

to the cold tends to reduce feelings of discomfort as well as increase peripheral skin temperature, both of which seem to lead to the observed reduction in performance decrements seen in individuals acclimated to the cold (Mackworth, 1955; Clark and Jones, 1962).

The above data suggest that reduced dexterity decrements should be observed in individuals trained to increase peripheral blood flow in the cold, especially if increased peripheral temperatures result in an increase in comfort.

Biofeedback Techniques and Digital Skin Temperature

Irving (1972) reported a study in which he had compared finger and toe temperatures of two young men, belonging to a sect in Alaska which wore only light clothing and walked barefooted in winter snow, with the same measures from a young airman. The three subjects were tested in a room at about 32°F (0°C). The two members of the sect showed cyclical rewarming of the extremities, only two bouts of minor shivering, and were able to read in preparation for examinations during the session. In contrast, the airman's extremities became painful; he shivered so violently that the session had to be terminated; and he remarked that he "was completely unfitted for any use during the test". In addition,

Irving comments:

One of the students volunteered that a given toe was warming just as the cyclic recorder showed local warming of the skin by one degree, and repeated the remark of change when another location had cooled one degree. Thus we see that good endurance of cooling was attended by fine discrimination of consciously observed warmth in contrast to the useless numbness of the intolerant subject. (p. 185)

Irving's comment emphasized a very important aspect of the students' behavior: the students had become sensitive to a physiological process which most people are normally unaware of. They had learned to discrim-

inate small changes in peripheral temperatures. Developing such sensitivity and discrimination is a major emphasis of biofeedback training.

The technique of biofeedback is based on the principles of operant conditioning whereby the frequency of occurrence of a response can be increased by reinforcing the organism each time the desired response is emitted. This process requires that there be variability in the system of interest so that the response both occurs and can be discriminated from other responses. Biofeedback is a special case of operant conditioning which deals with reinforcing the occurrence of responses in physiological systems. The problem which arises when dealing with physiological systems is that most organisms are not sensitive to changes in ongoing physiological processes. While Irving's students had learned to discriminate small changes in finger and toe temperatures, most individuals find such small changes either difficult or impossible to notice. Biofeedback research has shown that individuals can learn to be sensitive to such changes and voluntarily control them under normal thermal conditions. Lisina (1965) reported that her subjects could learn to dilate blood vessels in the hand to turn off a painful shock. Later investigators have reported learned finger vasoconstriction (Snyder and Noble, 1971), learned dilation and constriction of cephalic blood vessels (Christie and Kotses, 1973), and learned control of peripheral skin temperature (Roberts et al., 1974). In addition, researchers are reporting success in treating migraine headaches by training patients to raise finger temperatures, and thereby presumably redistributing blood flow to the periphery (Wickramaskera, 1973; Sargent et al., 1973). These studies have used external means of monitoring physiological systems and providing feedback to the subjects regarding the state of the system at a given point in time. Once the

desired response has been learned with external feedback, subjects appear to be able to produce the same response without feedback (Wickramaskera, 1973; Sargent et al., 1973). In fact, Roberts et al. (1974) have reported that some subjects have actually shown better control of skin temperature in posttests without feedback. Christie and Kotses (1973) have reported the relative ease with which vasomotor responses can be learned based on data showing significant control of both cephalic vasodilation and vasoconstriction after three 25-minute sessions.

Hofeller et al. (1975) have raised an interesting methodological problem associated with biofeedback training. Their study was originally designed to test the relative merits of digital vs. analog feedback in hand temperature control. In addition, the experimenters wanted to include rigorous laboratory controls which they felt had been lacking in many previous studies since most had been done in clinical settings with high experimenter-subject interaction. They designed a study which limited experimenter-subject interaction by presenting instruction on tape and making all direct contact between experimenter and subject impersonal. The only significant temperature increases occurred in the first of three sessions in the analog group relative to the control group. The magnitude of increases shown by their subjects was much smaller than had been reported in the clinical studies. Analyzing responses to an open-ended, post-training interview revealed that many subjects resented the sterile atmosphere for what they considered a very personal experience, and resented hearing the "anonymous" voice on the tape. Some remarked they had been so irritated with listening to the tape they had tried not to follow the instruction on the recording. In addition, the experimenters reported that content analysis of the questionnaire had indicated two

performance sets in the subjects tested. They classified the first of these as task-oriented. These subjects reported believing that control would be best achieved through mental effort and concentration, appeared not to be worried about their progress, nor did they appear to lack confidence that they would eventually gain control of their hand temperature. The second performance set was classified as evaluation-oriented. Subjects with this set reported being concerned about their success or failure in training, reported lack of increases as a failure and reported becoming tense or upset when the feedback light did not come on. These subjects pressed the experimenters to find out how they were doing relative to the norms for raising hand temperatures and typically looked for some means of evaluating their performance relative to other subjects.

Reanalysis of the data in terms of performance sets showed that subjects with task-oriented sets showed successively larger temperature increases over the three sessions relative to both their own previous performance and the performance of subjects with evaluation-oriented sets. The authors concluded that one of the main functions of a warm, flexible experimenter-subject relationship was to mitigate against the negative influences of these evaluation-oriented sets which are counterproductive to biofeedback training.

Wickramaskera (1973) has suggested that observed increases in finger temperature in migraine headache subjects are the result of relaxation effects on the sympathetic system. If this is the case, it is easy to see why the tenseness reported by Hofeller et al.'s (1975) evaluation-oriented subjects would limit their ability to produce temperature increases. While Hofeller et al.'s conclusions have not been directly tested or replicated, the points they have raised bear consideration in

the design of studies using biofeedback techniques.

The present study was designed to use biofeedback techniques to experimentally increase digital temperature during mild cold exposure and to determine whether correlated changes in comfort and temperature sensations would result. A digital dexterity task and a mental reasoning task were also included to determine whether performance decrements would result from the cold exposure, and, if so, whether these decrements would be reduced in subjects who increased their digital temperatures.

EXPERIMENT I

Method

Subjects. Subjects were 9 male and 9 female volunteers from 22 to 33 years of age. All were personally acquainted with the experimenter. They were asked to participate in a study involving attempts to raise finger skin temperature by biofeedback techniques while in a cold room. Three males and three females were then assigned to each of two experimental groups and one control group. Three male subjects had requested they be assigned to a specific group. Since subject cooperation was an essential part of this study and the demands placed on the subjects were often unpleasant, these request were complied with. This resulted in one male in each group being placed in the group by request, and random assignment of all other subjects. Height and weight of all subjects are presented in Table 1.

Apparatus. A 6000 BTU room air conditioner with a cooling unit was used to cool an 8 x 10 ft room. Although the study had originally been designed to use a T_A of 59°F (15°C), limitations of the equipment made it necessary to use an average T_A of 64°F (17.8°C). Air circulated by the cooling unit oscillated from 61°F (16.1°C) to 67°F (19.4°C) in 10 minute cycles and resulted in a draft on the subject's back. Pilot tests done on subjects not used in the present experiment showed that no systematic effect on cooling was produced by the cycling of the air conditioner.

A relatively mild T_A was chosen for two reasons. First, Gagge et al. (1967) had shown that the range of temperature used here was sufficient to produce both cooling and discomfort and it seemed that the mildest stress sufficient to test the hypothesis might maximize the subjects' chances to increase their temperatures. Second, an effect shown for this

Table 1.

Height and Weight by Subject and Group.

(F = Feedback group; I = Instruction group; C = Control group.)

Subject	Height	Weight
MALES		
F1	5' 7"	145#
F2	5' 7"	130#
F3	5' 10"	145#
I1	6' 1"	160#
I2	5' 10"	165#
I3	5' 10"	140#
C1	5' 7"	155#
C2	6' 2"	165#
C3	5' 10"	140#
FEMALES		
F4	5' 9"	130#
F5	5' 3"	112#
F6	5' 3½"	120#
I4	5' 1"	116#
I5	5' 4"	125#
I6	5' 5½"	140#
C4	5' 5"	130#
C5	5' 4"	128#
C6	5' 4"	117#

temperature range would have practical implications for current proposals to lower heating levels of schools and public buildings. However, the T_A used here is higher than those used in any studies which reported decrements in dexterity task performance. Therefore, inclusion of performance tasks in the current study should be regarded as ancillary and exploratory in nature.

A thermistor from a Biofeedback Technology (BFT) 302 Feedback Thermometer was used to record finger skin temperature. This instrument is designed to provide accurate, immediate information on peripheral skin temperature changes and can detect changes in skin temperature as small as $.1^{\circ}\text{F}$ ($\sim .06^{\circ}\text{C}$) per mm. The unit provided auditory feedback via headphones in the form of a tone which decreased in frequency as finger temperature increased. The unit is equipped with a meter (range = $\pm 2.5^{\circ}\text{F}$ ($\sim 1.4^{\circ}\text{C}$)) on which the experimenter can continuously monitor subjects' temperatures, and was modified to drive an identical meter which was used to provide visual feedback to the subject. These meters were marked off in increments of $.1^{\circ}\text{F}$ ($\sim .06^{\circ}\text{C}$). Finger temperature was continuously recorded on an Esterline-Angus chart recorder (sensitivity = $.1^{\circ}\text{F}$ ($\sim .06^{\circ}\text{C}$)/mm).

An attempt was made to monitor tympanic and thoracic skin temperatures, but had to be discontinued due to equipment failure.

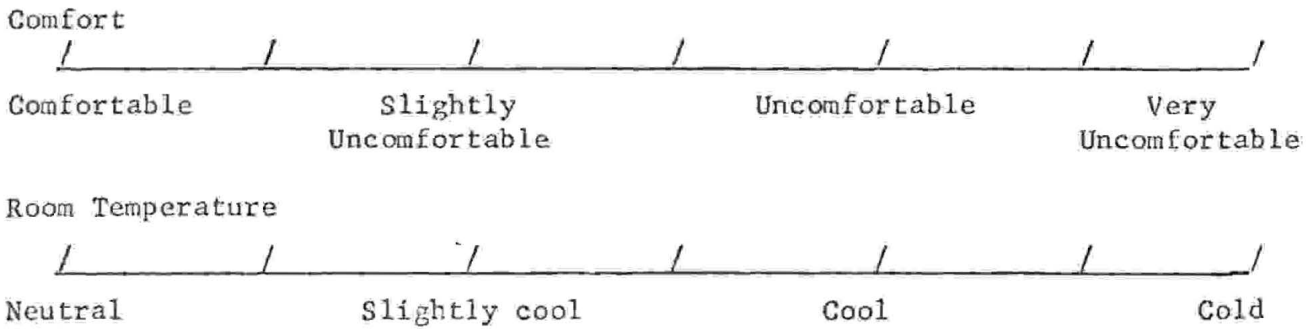
Procedure. Subjects were asked to change into bathing suits and shoes, no socks, in a small anteroom before entering the experimental room. They were seated in a chair centered approximately three feet in front of the cooling unit to equalize the effects of circulating air on all parts of the body. The experimenter was seated to the right and behind the subject. The thermistor was attached to the ventral surface of the second finger

of the subject's non-dominant hand. ("Dominance" here refers only to the hand used for writing.) Subjects were asked to sit quietly throughout the session with elbows resting on the arms of the chair and their hands either on the arms of the chair or on the table in front of them. Baseline temperatures were recorded for the first fifteen minutes of the session to establish a cooling rate for each subject. All subjects were asked to read material of their choosing during this period. Following baseline, subjects in the Feedback (FB) group were given access to visual and auditory feedback apparatus. Modes of feedback were explained and they were asked to try to increase their temperature or slow the rate of decrease by whatever means possible without movement. This period lasted for 30 minutes. A second experimental group (Instructions group (I)) was asked to concentrate on warming their hands for the equivalent 30-minute period but was given no external feedback. They were told they could see (and were shown) their results only at the end of the session. The Control (C) group continued to read throughout this period. Following this 30-minute conditioning period, another fifteen minutes of baseline were recorded for all subjects. Subjects again read during this period.

Subjects were asked to rate the room temperature and their thermal comfort in the room five times throughout the session:

- (1) immediately after entering the room,
- (2) at the end of the first baseline,
- (3) after the first 15 minutes of the conditioning period,
- (4) at the end of the conditioning period, and
- (5) at the end of the final baseline.

Scales used by Gagge et al. (1967) were used for this purpose. Scales were drawn on 15 cm continuums with intervals labeled as follows:



It was explained to the subjects that room temperature ratings referred to how they perceived the actual temperature of the room, and that comfort ratings referred to their thermal comfort in the room. Subjects were told they could mark anywhere on the scale and that if they felt the scale was not adequate in either direction they could mark beyond it, noting how far they felt the mark should be in intervals. Subjects were encouraged to ask questions on any points they did not fully understand. Each rating by the subject was made without seeing previous ratings. Ratings were scored by measuring the distance in cm from the left end of the scale.

Subjects were also given a digital dexterity task four times during the session:

- (1) at the beginning of the session,
- (2) at the end of the first baseline,
- (3) at the end of the conditioning period, and
- (4) at the end of the second baseline.

This task involved fitting key-shaped metal rods 3.5 cm long by .5 cm wide into keyhole slots of the same size. The slots are at different orientations forming a 5 x 5 grid on a 10 cm square box. Scores on the task are the number of rods fitted into slots in 30 sec. Although this task had not been used in previous cold studies, it had the advantage of showing no practice effect in pilot tests, and therefore required no previous training procedure. It could also be administered in a very brief period of time and therefore produce only minimal movement arti-

facts in cooling curves. Slight temperature increases were seen in some subjects during performance of the task, however, and for this reason the task was not given during the conditioning period.

In addition, subjects were asked to do a reasoning test (Baddeley, 1968) twice during the session:

- (1) at the beginning of the session, and
- (2) at the end of the conditioning period.

This test involved completing as many items as possible in 60 sec. Items were of the form "A follows B - AB" for which the subject decided if the phrase "A follows B" was true or false with respect to the letter pair "AB". Items ranged in difficulty from the one listed above through ones such as "A is not preceded by B - BA". The score on the test was the number of items correct. Baddeley reports the test to show no practice effect after the initial trial and to give highly reliable results over days ($r = .8$). The test was given at the two times stated above so that the three groups could be compared when their digital skin temperatures should have been most similar (at the beginning of the session) and when the maximum difference in temperatures was expected (at the end of the conditioning period). One-third of the items were randomly selected from the original test. Only one-third of the items were used so as to minimize movement artifacts and distraction or concentration effects which might result from taking the test and thus confound cooling curves during baseline periods. The test used here consisted of 22 items which subjects were given 60 seconds to complete.

The complete design is outlined in Table 2. This procedure was repeated at the same time on three consecutive days for each subject. Time of day was balanced across groups by running equal numbers of subjects from each group in the morning, afternoon, and evening. Subjects

Table 2. Design Outline for Experiment I.

<p>Feedback Group n = 6</p>	<p>R D M Read</p>	<p>R Try to raise finger temp. Visual and auditory feedback available</p>	<p>R D M Read</p>	R	D
<p>Instruction Group n = 6</p>	<p>R D M Read</p>	<p>R Concentrate on raising finger temperature No external feedback available</p>	<p>R D M Read</p>	R	D
<p>Control Group n = 6</p>	<p>R D M Read</p>	<p>R Read</p>	<p>R D M Read</p>	R	D
<p>Time in minutes</p>	<p>0</p>	<p>15</p>	<p>30</p>	45	60

R = Comfort and Temperature Ratings D = Digital Dexterity Task M = Mental Task

were asked not to eat for at least one and one-half hours prior to each session. (Forster et al. (1946) reported that eating lunch caused an increase in hand skin temperature at a T_A of 62.6°F (17°C) which took one and one-half hours to return to pre-eating levels.) Subjects who smoked were also asked not to smoke for an equivalent length of time to alleviate possible contaminating effects of nicotine on the circulatory system.

Results

Digital Skin Temperature

Temperatures were scored at the beginning of the session, and at the end of each 15-minute interval throughout the session. These scores represented temperatures at the start of each session, end of Baseline I, midway through conditioning, end of conditioning, and end of Baseline II. These points also corresponded to the times that comfort and temperature ratings were made. Data were analyzed in a 2(sex) x 3(condition) x 3(day) x 5(time) univariate analysis of variance with repeated measures on day and time. Treatment effects would thus be shown by a 2-way condition x time and/or a 3-way condition x time x day interaction. The F table from this analysis is presented in Table 3.

The analysis showed only a significant effect for time ($F_{4,48} = 68.396$, $p = .000000$) indicating that subjects cooled significantly over the session. It can be concluded from this analysis that the cooling rate did not change significantly over days, nor was it significantly affected by the experimental conditions or sex of the subject.

These results are represented graphically in Figure 1A. Although the sex difference in digital cooling was not significant ($F_{1,12} = 4.389$, $p = .058$), the low probability value and the parallels with other results presented below make it interesting to include a graph of the cooling curves for the two sexes for purposes of comparison (Figure 1B). The curves suggest a tendency for females to cool at a faster rate than males, but this time by sex interaction was far from significant ($F_{4,48} = 0.980$, $p = .428$).

Subjective Comfort Ratings

A 2(sex) x 3(condition) x 3(day) x 5(time) univariate analysis of

Table 3
F Table for Digital Skin Temperature Analysis

Source	DF	Mean Square	F-Ratio	Probability
Subjects	17			
Sex	1	554.70	4.389	0.0580
Condition	2	9.83	0.078	0.9256
Sex x Condition	2	43.03	0.340	0.7181
Error (Sex x Condition)	12	126.39		
Day	2	4.79	0.168	0.8464
Day x Sex	2	9.03	0.317	0.7314
Day x Condition	4	62.16	2.180	0.1018
Day x Sex x Condition	4	16.77	0.588	0.6744
Error (Day x Sex x Condition)	24	28.51		
Time	4	1187.57	68.396	0.0000*
Time x Sex	4	17.01	0.980	0.4275
Time x Condition	8	14.32	0.824	0.5852
Time x Sex x Condition	8	19.86	1.144	0.3523
Error (Time x Sex x Condition)	48	17.36		
Day x Time	8	8.06	1.388	0.2117
Day x Time x Sex	8	3.62	0.623	0.7570
Day x Time x Condition	16	7.82	1.346	0.1860
Day x Time x Sex x Condition	16	3.72	0.640	0.8440
Error (Day x Time x Sex x Condition)	96	5.81		

* significant

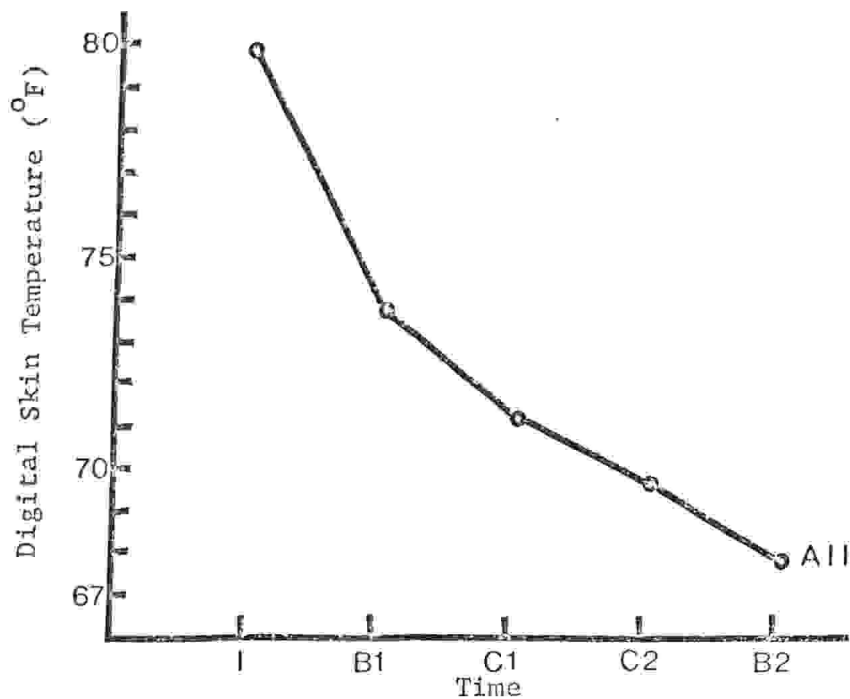


Figure 1A

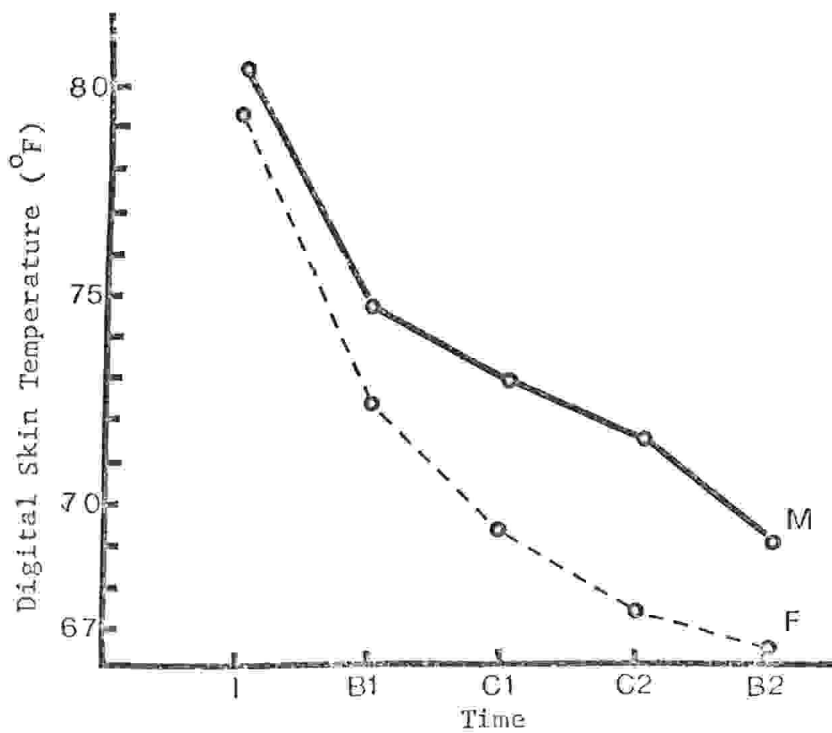


Figure 1B

Figure 1. Finger temperature decrement over time. Top graph (1A) shows temperature at beginning of session (I), end of first baseline (B1), midway in conditioning period (C1), end of conditioning period (C2), and end of second baseline (B2). Figure is average of all subjects on all days. Bottom graph (1B) shows same data for each sex.

variance with repeated measures on day and time was also run on the comfort ratings. The F table from this analysis is presented in Table 4. Again, no significant effects related to the experimental conditions were found. A significant decrease in comfort over time was found ($F_{4,48} = 46.601, p = .000000$). This effect is graphed in Figure 2A. In addition, a significant interaction between sex and time was found ($F_{4,48} = 6.254, p = .0004$). This interaction is graphed in Figure 2B and shows that comfort ratings decreased more rapidly over the session in females than in males. In addition, females showed a different pattern of response. Females showed their sharpest decrease in comfort over the first 15 minutes of the session and continued to show a steady decrease in comfort to the end of the session. Males, however, showed a slight decrease in comfort over the first 15 minutes, leveled off for the next 30 minutes, and showed their largest decrease in the last 15 minutes. The difference between the two groups by the end of the session is small and the steeper slope of the curve for males suggests that the groups might have converged in a longer session.

Room Temperature Ratings

Room temperature ratings were analyzed in the same way as comfort ratings. The F table from this analysis is presented in Table 5. The average of the room temperature ratings for each day was shown to increase significantly over days ($F_{2,24} = 7.513, p = .0029$). Figure 3 shows that the greatest increase in ratings came from Day 1 to Day 2 with a much smaller increase from Day 2 to Day 3. Within days, however, the same pattern of results is found for room temperature ratings as is found for comfort ratings (Figure 4). Subjects rated the room as significantly colder over time within a session ($F_{4,48} = 36.818, p = .000000$) (Figure

Table 4
F Table for Subjective Comfort Ratings Analysis

Source	DF	Mean Square	F-Ratio	Probability
Subjects	17			
Sex	1	396.03	0.058	0.8138
Condition	2	15780.05	2.311	0.1416
Sex x Condition	2	3041.81	0.445	0.6507
Error (Sex x Condition)	12	6828.95		
Day	2	510.45	0.486	0.6213
Day x Sex	2	2620.28	2.493	0.1039
Day x Condition	4	510.60	0.486	0.7461
Day x Sex x Condition	4	862.76	0.821	0.5248
Error (Day x Sex x Condition)	24	1051.24		
Time	4	29121.65	46.601	0.0000*
Time x Sex	4	3908.20	6.254	0.0004*
Time x Condition	8	1103.53	1.766	0.1075
Time x Sex x Condition	8	1004.28	1.607	0.1478
Error (Time x Sex x Condition)	48	624.91		
Day x Time	8	93.43	0.389	0.9142
Day x Time x Sex	8	306.72	1.276	0.2649
Day x Time x Condition	16	205.91	0.857	0.6192
Day x Time x Sex x Condition	16	136.48	0.568	0.9005
Error (Day x Time x Sex x Condition)	96	240.33		

* significant

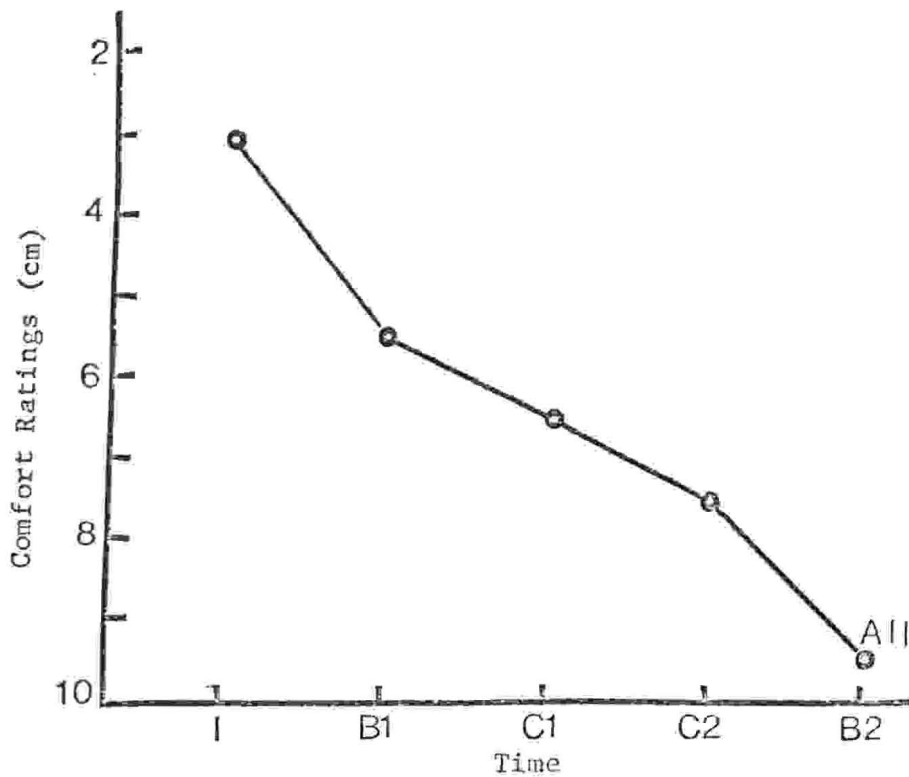


Figure 2A

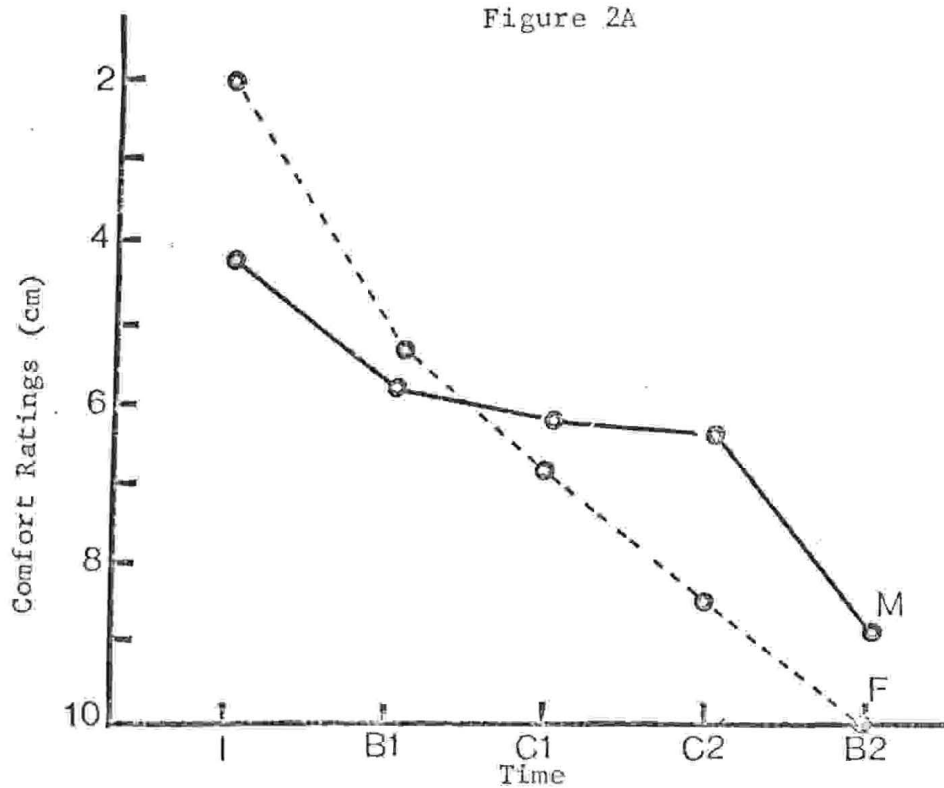


Figure 2B

Figure 2. Comfort ratings over time. (A) Top graph shows rating at beginning of session (I), end of Baseline I (B1), midway in conditioning period (C1), end of conditioning period (C2), and end of Baseline II (B2). Larger ratings reflect more discomfort. Figure is average for all subjects on all days. (B) Bottom graph shows same data plotted for each sex.

Table 5
F Table for Room Temperature Ratings Analysis

Source	DF	Mean Square	F-Ratio	Probability
Subjects	17			
Sex	1	9292.80	1.023	0.3317
Condition	2	8323.94	0.917	0.4261
Sex x Condition	2	5935.30	0.654	0.5377
Error (Sex x Condition)	12	9080.65		
Day	2	8353.13	7.513	0.0029*
Day x Sex	2	2582.58	2.323	0.1196
Day x Condition	4	1901.89	1.711	0.1805
Day x Sex x Condition	4	270.24	0.243	0.9110
Error (Day x Sex x Condition)	24	1111.85		
Time	4	17912.53	36.818	0.0000*
Time x Sex	4	2737.32	5.626	0.0008*
Time x Condition	8	769.82	1.582	0.1552
Time x Sex x Condition	8	636.74	1.309	0.2620
Error (Time x Sex x Condition)	48	486.52		
Day x Time	8	433.58	1.335	0.2354
Day x Time x Sex	8	286.97	0.884	0.5331
Day x Time x Condition	16	219.22	0.675	0.8116
Day x Time x Sex x Condition	16	281.51	0.867	0.6078
Error (Day x Time x Sex x Condition)	96	324.68		

* significant

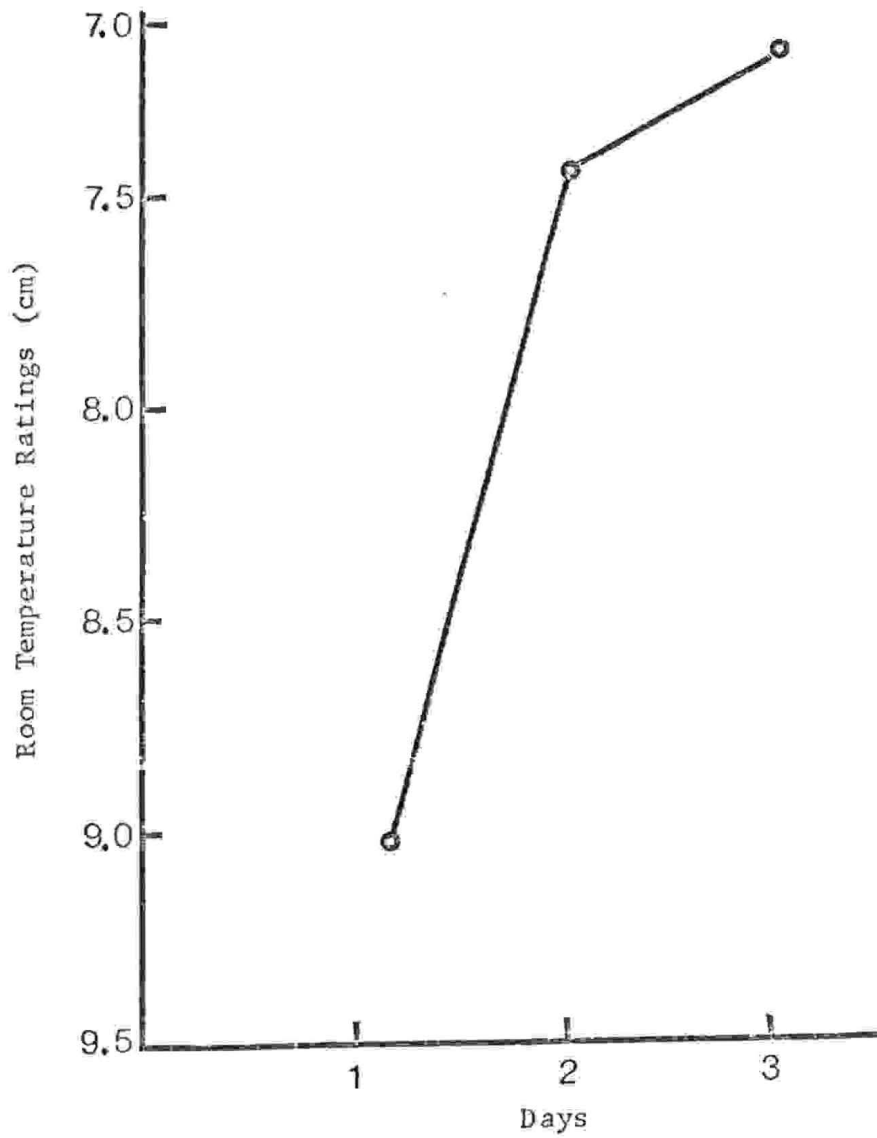


Figure 3. Average room temperature ratings for all subjects on their first, second, and third days. Larger numbers reflect colder ratings.

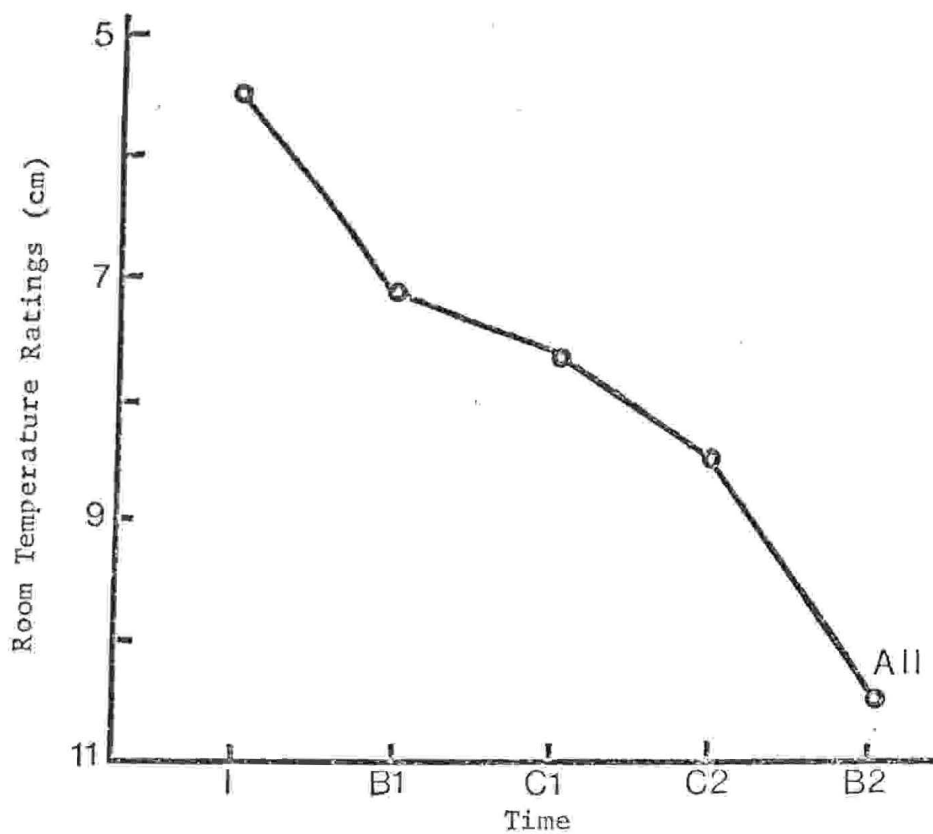


Figure 4A

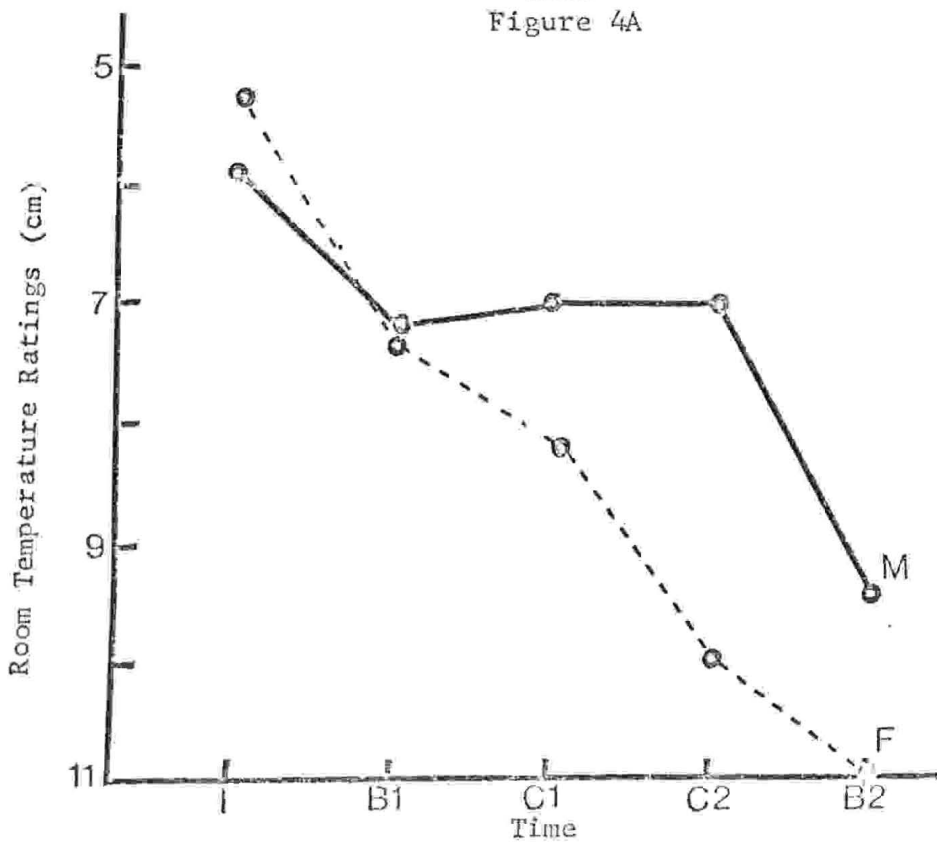


Figure 4B

Figure 4. Room temperature ratings over time. Top graph (A) shows rating at beginning of session (I), end of Baseline I (B1), midway in conditioning period (C1), end of conditioning period (C2), and end of Baseline II (B2). Larger ratings reflect colder perceptions. Figure is average for all subjects on all days. (B) Bottom graph shows same data plotted for each sex.

4A). As in comfort ratings, there was a significant time by sex interaction ($F_{4,48} = 5.626$, $p = .0008$) with males and females showing different patterns of ratings over time (Figure 4B). The patterns are very similar to those found in the case of the comfort ratings.

Digital Dexterity Task

The F table from a 2(sex) x 3(condition) x 3(day) x 4(time) repeated measures analysis of variance for scores on the dexterity task is presented in Table 6. A significant interaction of day, time, sex, and condition was found ($F_{12, 72} = 1.898$, $p = .0488$) and is plotted in Figure 5. From this graph, no consistent pattern which reflects group differences or changes over days is seen for females. Males, however, showed a consistent improvement over days. This improvement was greater for the Control and Instruction groups than for the Feedback group. In addition, the largest decrement in performance was seen in the male Feedback group, and, on two days (Day 1 and Day 3), coincided with the end of the conditioning period at C2.

The sex difference across days mentioned above is supported further by the significant day by sex interaction ($F_{2,24} = 3.431$, $p = .0489$). This interaction is plotted in Figure 6. Pooling the two sexes, the main effect for days was also significant ($F_{2,24} = 7.259$, $p = .0034$) and is plotted in Figure 7. A least significant difference (LSD) test showed that only the difference between Day 1 and Day 3 was significant ($p < .001$). Figure 6 shows that most of the improvement seen over days was due to the consistent improvement of the male subjects.

The main effect for time was also significant ($F_{3,36} = 4.932$, $p = .0057$). The graph of this time effect (Figure 8) shows a decrement in performance over the first three trials and a slight improvement on

Table 6
F Table for Digital Dexterity Task Analysis

Source	DF	Mean Square	F-Ratio	Probability
Subjects	17			
Sex	1	3.63	0.207	0.6570
Condition	2	9.04	0.516	0.6093
Sex x Condition	2	29.09	1.661	0.2307
Error (Sex x Condition)	12	17.51		
Day	2	15.29	7.259	0.0034*
Day x Sex	2	7.23	3.431	0.0489*
Day x Condition	4	1.15	0.544	0.7050
Day x Sex x Condition	4	1.79	0.849	0.5080
Error (Day x Sex x Condition)	24	2.11		
Time	3	6.50	4.932	0.0057*
Time x Sex	3	2.93	2.220	0.1026
Time x Condition	6	0.41	0.313	0.9262
Time x Sex x Condition	6	0.61	0.460	0.8329
Error (Time x Sex x Condition)	36	1.32		
Day x Time	6	0.38	0.570	0.7530
Day x Time x Sex	6	1.02	1.517	0.1848
Day x Time x Condition	12	1.19	1.768	0.0703
Day x Time x Sex x Condition	12	1.28	1.898	0.0488*
Error (Day x Time x Sex x Condition)	72	0.67		

* significant

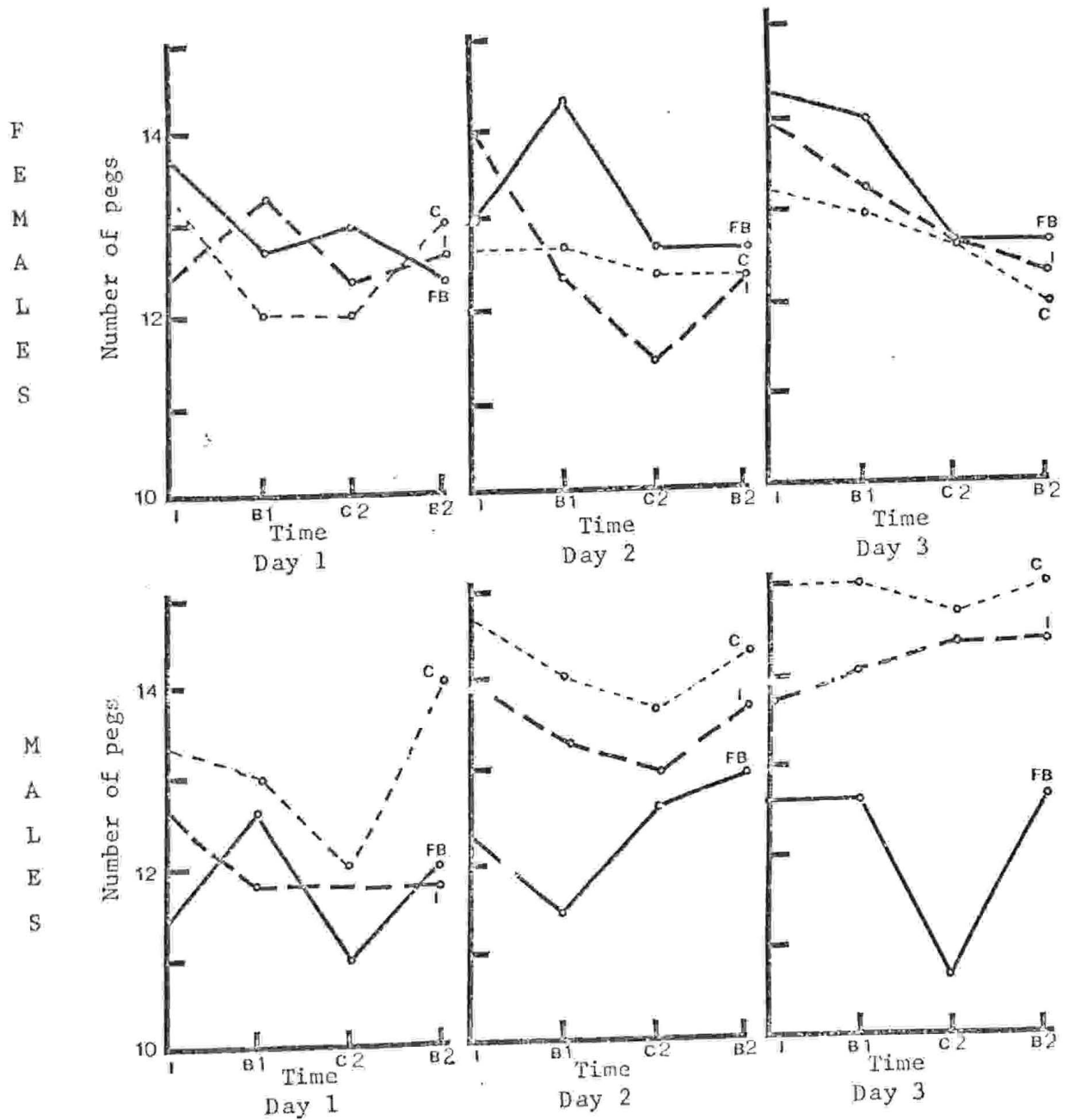


Figure 5. Scores on digital dexterity task plotted by sex and condition across time and days.

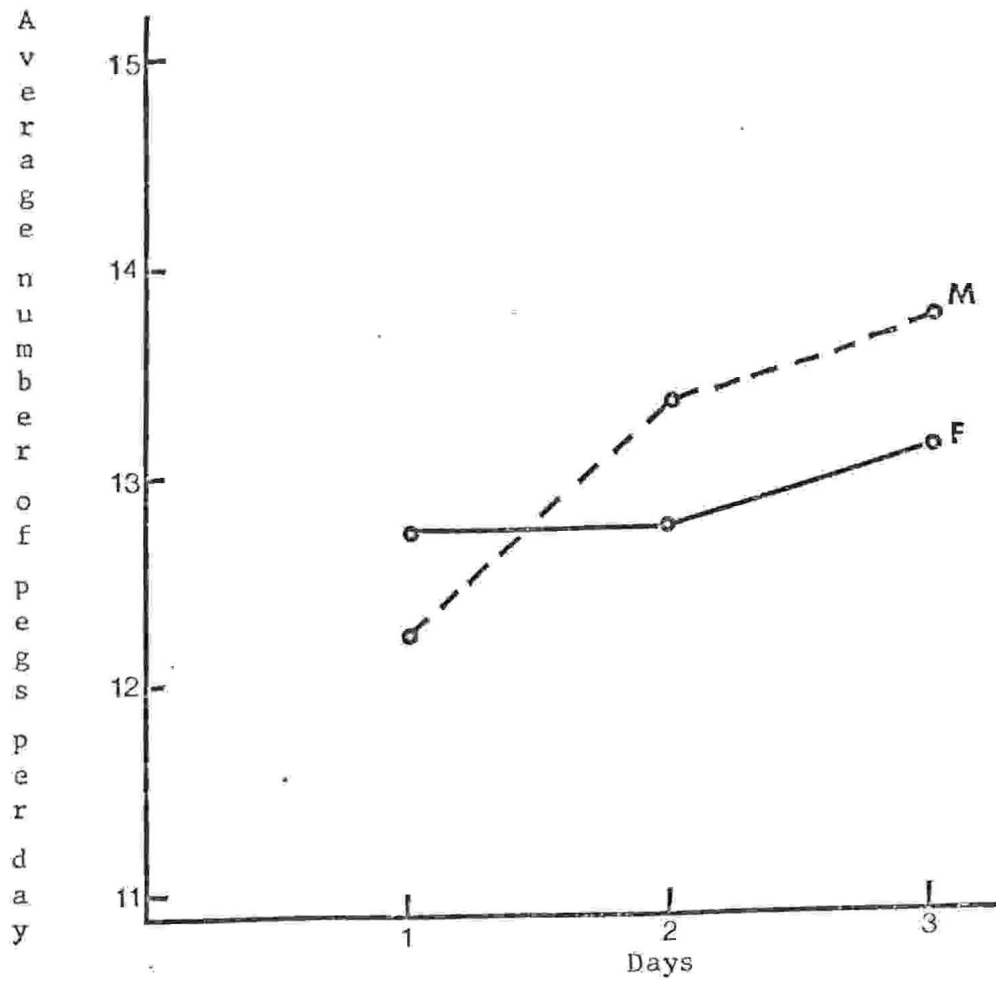


Figure 6. Improvement in performance on digital dexterity task over days plotted for each sex.

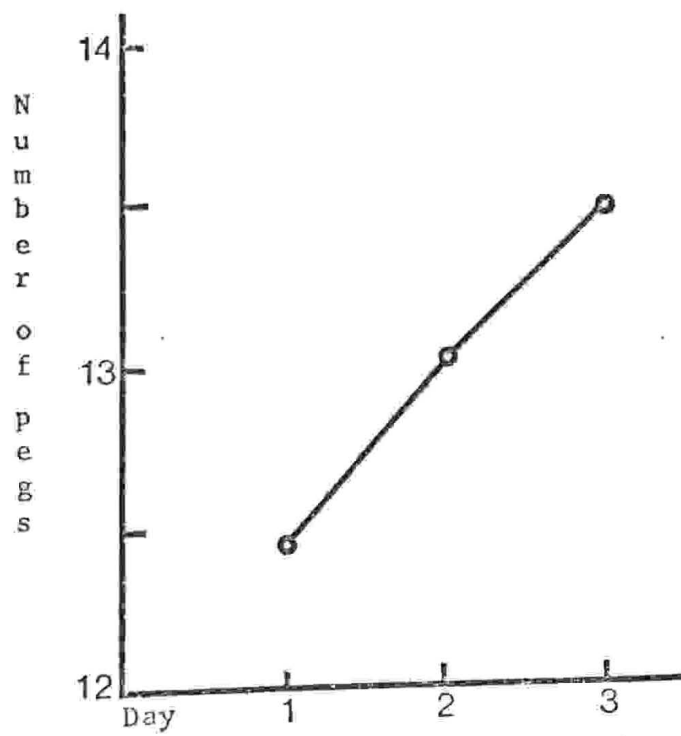


Figure 7. Improvement in digital dexterity task over days averaged over all subjects.

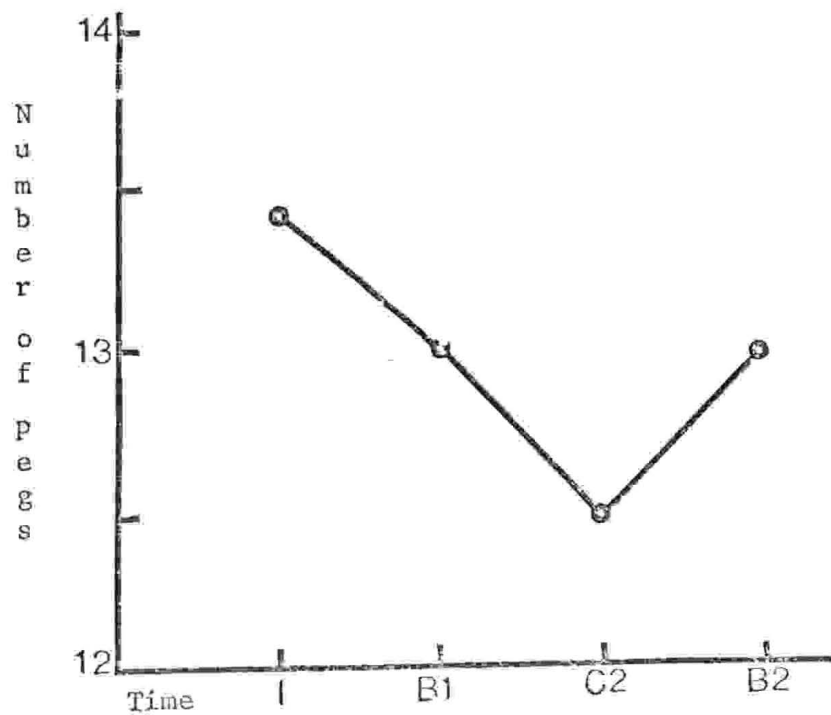


Figure 8. Performance decrement in digital dexterity task within sessions averaged over all subjects and days.

the final trial. LSD tests on these points showed that this final increase was not significant ($p > .05$), although significant decrements were seen from trial 1 to trial 3 ($p < .001$), and from trial 2 to trial 3 ($p < .025$). Again, from Figure 5, it should be noted that this decrement on trial 3 (C2) was most apparent in the Feedback males.

Reasoning Test

A 2(sex) x 3(condition) x 3(day) x 2(time) repeated measures univariate analysis of variance on the number of correct items for each trial showed no significant differences in performance within a session. The F table from this analysis is presented in Table 7. A significant improvement over days was found ($F_{2,24} = 4.649$, $p = .02$). This result is graphed in Figure 9. As in the dexterity task, the improvement from day to day was not significant ($p > .05$), but from Day 1 to Day 3, an LSD test was significant at the .01 level.

Table 7
F Table for Reasoning Test Analysis

Source	DF	Mean Square	F-Ratio	Probability
Subjects	17			
Sex	1	10.70	0.095	0.7635
Condition	2	15.08	0.133	0.8763
Sex x Condition	2	282.56	2.501	0.1237
Error (Sex x Condition)	12	113.00		
Day	2	106.86	4.649	0.0197*
Day x Sex	2	26.73	1.163	0.3296
Day x Condition	4	17.74	0.772	0.5544
Day x Sex x Condition	4	24.55	1.068	0.3939
Error (Day x Sex x Condition)	24	22.99		
Time	1	0.50	0.075	0.7887
Time x Sex	1	1.81	0.230	0.6401
Time x Condition	2	16.90	2.142	0.1601
Time x Sex x Condition	2	6.23	0.790	0.4761
Error (Time x Sex x Condition)	12	7.89		
Day x Time	2	2.79	0.220	0.039
Day x Time x Sex	2	3.73	0.295	0.7473
Day x Time x Condition	4	14.55	1.150	0.3573
Day x Time x Sex x Condition	4	4.94	0.390	0.8134
Error (Day x Time x Sex x Condition)	24	12.65		

* significant

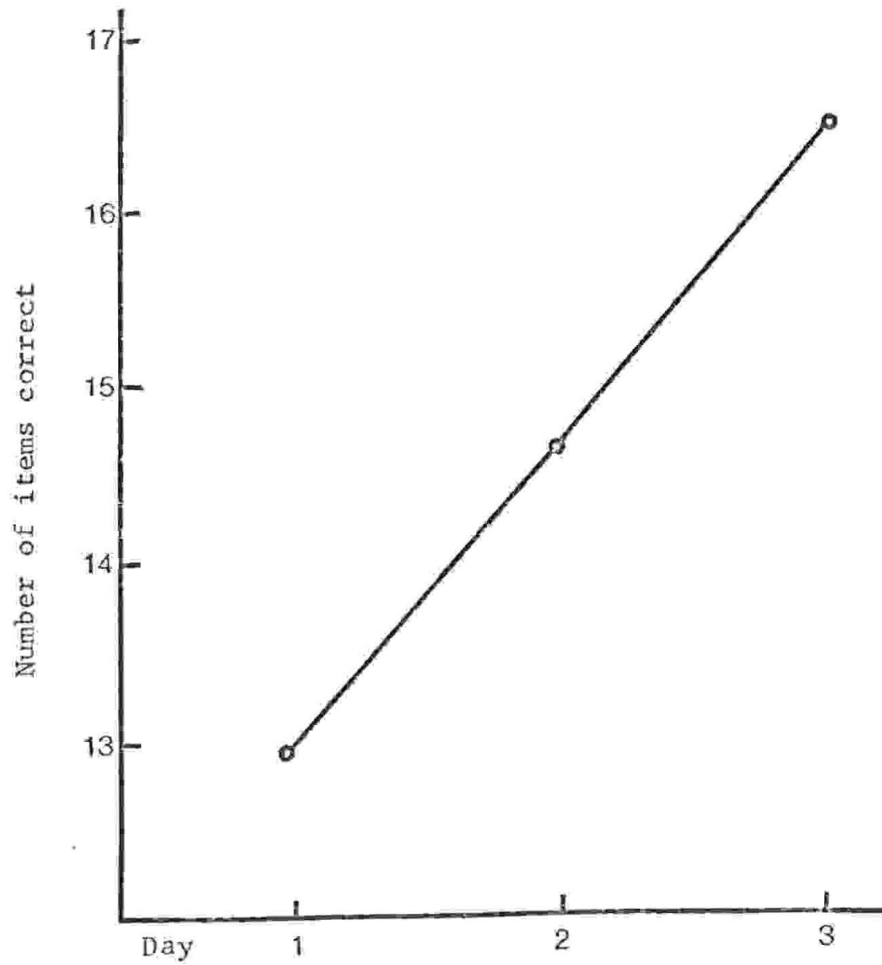


Figure 9. Performance on reasoning task. Graph shows average number of items correct for all subjects on each day.

Post hoc Analysis of Conditioning Effects

Although no significant differences in digital temperature were found across the three experimental groups, observation of the continuous temperature records suggested group differences in the number and magnitude of short-term increases which occurred during the conditioning period. These increases can be thought of as a measure of the variability in the steady downward cooling trend observed in the cold room. It is possible that the experimental groups showed more variability, but that the changes were too transitory to be reflected in an overall analysis of temperature.

It was further noted from analysis of the continuous records that most subjects reached a point of equilibrium before the end of the hour-long sessions. Rate of cooling from this point was greatly decelerated; small ($.1^{\circ}\text{F}$ ($\sim .06^{\circ}\text{C}$)) fluctuations were common; and in some cases rhythmical oscillations were noted. Such fluctuations may have been reflecting the synchrony of volleys of impulses in the sympathetic nervous system at equilibrium as has been discussed by Burton (1972, p. 201-207). Since these increases seemed to reflect spontaneous oscillations of the thermoregulatory system, it was decided to look only at increases occurring prior to equilibrium and determine if the groups were differentiated on the basis of these earlier increases.

Equilibrium was defined as the temperature 1°F higher than the final temperature for each session for each subject. The 5-minute block during which this temperature was reached was noted and only increases which occurred prior to that block and were greater than $.1^{\circ}\text{F}$ ($\sim .06^{\circ}\text{C}$) were included in the following analysis.

Tables 8 and 9 list these equilibrium and increase data for males

Table 8

Criterion Increases During Conditioning Period for Males

Subject	Day	Equilibrium Temperature	5-minute Block for Equilibrium	Magnitude of Criterion Increases	Starting Temperature Of Increase
FEEDBACK					
F1	1	69.6	B2 2	.3	70.1
	2	70.1	B2 1	none	
	3	68.3	C 5	none	
F2	1	70.8	B2 1	none	70.1
	2	70.0	B2 1	.2	
	3	70.4	B2 1	none	
F3	1	69.9	B2 1	.4	70.1
	2	none		.9	76.7
				.2	77.4
				.7	77.5
				.4	75.8
	3	71.0	B2 1	.8	72.0
INSTRUCTION					
I1	1	67.7	C 5	none	68.1
	2	71.7	C 2	none	
	3	68.0	C 6	.2	
I2	1	none		14.7	77.5
				.4	88.5
				2.3	88.2
				.7	90.0
				2.0	89.2
				2.3	72.2
	2	none		.8	73.8
				.6	74.0
				3.3	84.3
				4.4	87.6
				2.0	92.0
				.2	94.0
I3	1	67.8	C 5	none	70.2
	2	68.1	C 6	.2	
	3	68.6	B2 1	1.0	
CONTROL					
C1	1	70.6	C 2	none	83.5
	2	68.0	B2 2	1.0	
	3	68.3	B2 2	none	
C2	1	70.2	B1 2	none	
	2	68.6	C 3	none	
	3	67.4	C 5	none	
C3	1	68.3	C 6	none	
	2	70.4	C 6	none	
	3	69.7	C 2	none	

Table 9
Criterion Increases During Conditioning Period for Females

Subject	Day	Equilibrium Temperature	5-minute Block for Equilibrium	Magnitude of Criterion Increases	Starting Temperature Of Increase
FEEDBACK					
F4	1	69.1	C 3	none	
	2	68.7	B2 1	none	
	3	66.6	C 5	.3	67.9
				.3	67.0
F5	1	70.6	B2 1	4.9	70.8
	2	68.3	B2 2	4.9	71.2
	3	66.4	C 5	.2	66.7
F6	1	68.6	B2 2	.3	69.9
				.5	69.2
	2	69.6	B1 3	none	
	3	68.0	C 3	none	
INSTRUCTION					
I4	1	67.1	C 6	.3	71.2
	2	66.2	B2 1	.2	66.6
	3	65.1	B2 2	.2	67.7
			.3	66.6	
			.4	66.0	
I5	1	67.2	C 4	.2	67.4
	2	66.4	C 3	none	
	3	66.0	C 6	none	
I6	1	69.6	B2 1	none	
	2	67.5	C 6	.2	69.1
	3	67.2	C 6	none	
CONTROL					
C4	1	66.5	C 3	.3	68.4
	2	64.0	B2 1	none	
	3	64.9	C 6	none	
C5	1	67.5	C 6	none	
	2	66.4	C 5	none	
	3	68.9	B2 2	none	
C6	1	68.8	C 5	none	
	2	69.2	C 3	none	
	3	68.2	C 5	none	

and females respectively. This data is summarized in Table 10. It can be seen from Table 10 that all subjects in both the Feedback and Instruction groups showed criterion increases, while only one male and one female in the Control group showed these increases. T-tests between the groups showed a significant difference between the Feedback and Control groups in the number of criterion increases shown by each subject ($t_{(10)} = 2.7353, p < .05$). No significant differences were found between the Feedback and Instruction groups ($t_{(10)} = -.6016, p > .05$) or between the Instruction and Control groups ($t_{(10)} = 1.8574, p > .05$). Although it appears from Table 10 that the Instruction group had done better than the Feedback group in terms of criterion increases, one subject (I2) accounted for 12 of the 15 observed increases for males in the Instruction group. This disproportionate total for one subject probably accounted for the lack of significance in the Instruction group.

Subject I2 was the only subject who showed any clear and consistent evidence for an ability to raise his digital skin temperature and maintain it at a high level throughout the conditioning period. This subject showed a net increase in temperature over the conditioning period in all three sessions. However, continuous temperature records for this subject show that on Day 1 and Day 3, I2 did not show the steep cooling curves during the first baseline period that were shown by nearly all other subjects, but in fact showed increases in temperature during this baseline. On these two days he showed much larger net increases than he did on Day 2 when he did show cooling during the first baseline. These results raise the question of whether the increased temperature during the conditioning period for this subject was the result of voluntary control or merely a reflection of this subject's normal response to cold. Only one other

Table 10

Summary of Criterion Increases by Sex and Condition

Condition	MALES		FEMALES		TOTAL	
	# of criterion increases for group	# of subjects in group showing increases	# of criterion increases for group	# of subjects in group showing increases	# of criterion increases for group	# of subjects in group showing increases
FEEDBACK	8	3	7	3	15	6
INSTRUCTION	15	3	7	3	22	6
CONTROL	1	1	1	1	2	2

subject (C1) showed no steep cooling and actual increases during the first baseline. I2 and C1 had higher weights for their heights than any of the other subjects (Table 1), which would suggest that they had more tissue insulation than any other subjects. This extra insulation probably accounted for their temperatures being maintained at a high level for a longer period of time than other subjects. The digital skin temperatures for these two subjects over each session are plotted in Figure 10. While the pattern of cooling is similar for these two subjects during both initial and final baselines, it is very different during the conditioning period. In addition, the curves for I2 during the conditioning period are very different from the curves during the two baseline periods on each day. These differences support the idea that I2 was able to voluntarily increase and maintain his temperature for a specified period of time. It is interesting to compare I2's performance on the three days. On Day 1 there was very little cooling during the initial baseline period and some variability in the curve. A large conditioning increase occurred on this day. On Day 2, there was no variability in the initial baseline record and a large drop in temperature occurred before conditioning. While the subject still showed an increase for this day during conditioning, it was of much smaller magnitude than on Day 1. On Day 3, more variability in the initial baseline occurred than in Day 1 and the subject began the conditioning period at a much higher level. On this day he was able to maintain an even higher level throughout the conditioning period. These results suggest a relationship between the amount of variability in digital skin temperature, temperature at the beginning of conditioning, and the ability to increase and maintain one's finger temperature.

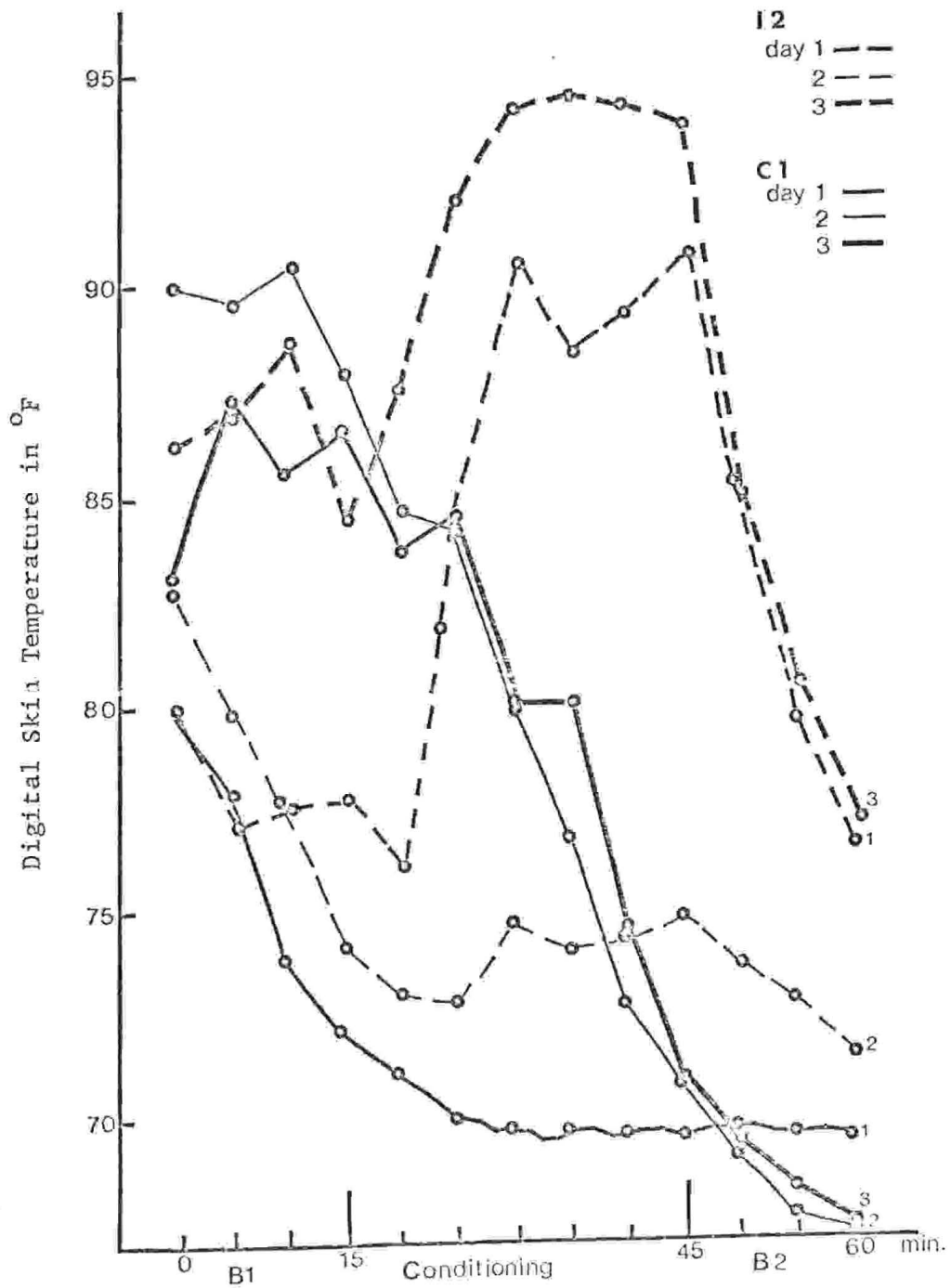


Figure 10. Finger temperatures for subjects I2 and C1 plotted over 5-minute intervals for each day. Heavy black lines at 15 and 45 minutes denote interval during which I2 was concentrating on increasing his temperature.

Discussion

Voluntary Control of Digital Skin Temperature

Although no significant differences in digital skin temperature were observed in this study as a result of attempts at voluntary control, the results suggest that it is possible for individuals to voluntarily increase the variability in digital skin temperature even though working against an ongoing environmental constraint. The data also suggest that external visual and auditory feedback aid and enhance an individual's efforts at voluntary control. While no significant differences in the number of increases occurred between the Feedback and Instruction group, the Feedback group had significantly more increases than the Control group while the Instruction group did not. In general, subjects with external feedback were able to show more temperature increases than subjects who only concentrated on warming their hands.

Even though all of the subjects in the Feedback group and Instruction group were able to show short-term increases in their digital skin temperature, they generally were not able to sustain these increases. In addition, many of the observed increases occurred late in the conditioning period when temperatures were very near to equilibrium levels. Since several investigators have reported that people can learn to voluntarily increase digital skin temperature in a thermoneutral environment (Wickramaskera, 1973; Sargent et al., 1973; and Roberts et al., 1974), it appears that the stress involved in cold exposure may be inhibiting long-term increases in temperature. The data of subject I2 suggests that this stress may be overcome if conditioning begins (a) while there is still variability in the cooling curve, and (b) while digital temperature is still relatively high. The variability in the cooling curve would insure

the occurrence of a response which could then be reinforced by the feedback. This factor alone, however, must not account for all the variance since subjects in the Feedback and Instruction groups were often able to increase the variability in the cooling curve, but still could not maintain a higher digital skin temperature. On both occasions when I2 was able to produce large increases and maintain them, his increases started from a higher temperature than was found for any other subjects in the Feedback and Instruction groups. On the one day when his temperature had dropped to a level comparable to other subjects in the experimental groups, he did not show as large a magnitude of increase, although he was able to maintain the increase until the end of the conditioning period. The day with initial cooling also occurred after a day on which he had been successful in producing a large increase and maintaining it over the entire period, which may have given him an additional advantage over subjects who had only shown transitory increases. While I2 had not received continuous external feedback, the possibility is not ruled out that he was receiving internal feedback such as feeling a finger pulse or a sensation of warmth from his hands. In addition, he was shown his results at the end of each session. This would result in reinforcing an overall pattern of response from the first session, and as such should have been a more powerful reinforcer than the reinforcement of isolated responses which other subjects would have received. Since I2 did report using the same strategy on Day 2 as he had on Day 1, the previously reinforced pattern of response could account for his ability to sustain an increase from a level which inhibited other subjects.

Relationship of Digital Skin Temperature to Comfort and Temperature Sensations

Since no significant differences in digital skin temperature as a result of experimental manipulation were observed, the basic hypotheses of this study could not be tested. Without a group who had increased their digital skin temperature in the cold, no statements can be made about the effect of increasing digital temperature in the cold on subjective comfort, temperature sensation, or performance of tasks. However, some of the correlational data from this study should be discussed in terms of support it offers for the original proposal that increasing digital skin temperature in the cold would result in increased ratings of comfort and temperature sensation. Gagge et al. (1967) reported a good correlation between comfort, temperature sensation, and mean skin temperature during cold exposure. By comparing the top graphs on Figures 1, 2, and 4, it can be seen that digital temperature alone also seems to be a good predictor of comfort and temperature sensation. Since no other temperature measures were taken in this study, no statements can be made about possible interactive effects of temperatures from other skin sites or internal temperatures on comfort and temperature sensation. But the predictive quality of digital skin temperature is further supported by noting the sex difference in the cooling curves in the bottom graph of Figure 1 and comparing this with the sex differences in comfort and temperature sensation ratings shown in the bottom graphs of Figures 2 and 4. Although this sex difference in cooling was not experimentally manipulated, the corresponding correlations in comfort and temperature ratings offer further support to the hypothesis that increasing digital skin temperature in the cold should lead to higher

comfort and temperature sensation ratings.

The sex differences in comfort and temperature sensations found in this study are of particular interest in and of themselves. Only one previous study of comfort and temperature sensations has looked at the effects of cooling on these variables in women. DuBois et al. (1952) found females to have a relatively wider neutral zone than men when relating mean skin temperature to comfort and temperature sensations. Comparing DuBois et al.'s data for women with similar data for men from Gagge et al. (1967), no apparent differences are seen either in width of the neutral zone or level of comfort and temperature sensations for a given T_g . Since DuBois et al.'s data were based on ratings made after $2\frac{1}{2}$ to $3\frac{1}{2}$ hours of exposure to different ambient temperatures, no direct comparisons can be made with the present study where ratings were made throughout exposure to a single ambient temperature. However, the data from this study do suggest similar relationships for the two sexes between comfort and temperature sensations and digital skin temperature. Figures 11 and 12 show digital temperatures plotted against temperature sensation ratings for females and males respectively. These scatter plots show similar relationships between temperature perceptions and digital skin temperature for the two sexes. Females gave a higher percentage of ratings above 10 (reflecting colder perceptions), but also showed lower digital skin temperatures at the time of the ratings. Due to the more rapid cooling in females than in males (Figure 1B), very few ratings were made by females at digital skin temperatures between 72°F (22.2°C) and 77°F (25°C), a temperature range which was quite common for males during ratings. This data suggests that the observed sex differences in perception of comfort and temperature are based in different physiologi-

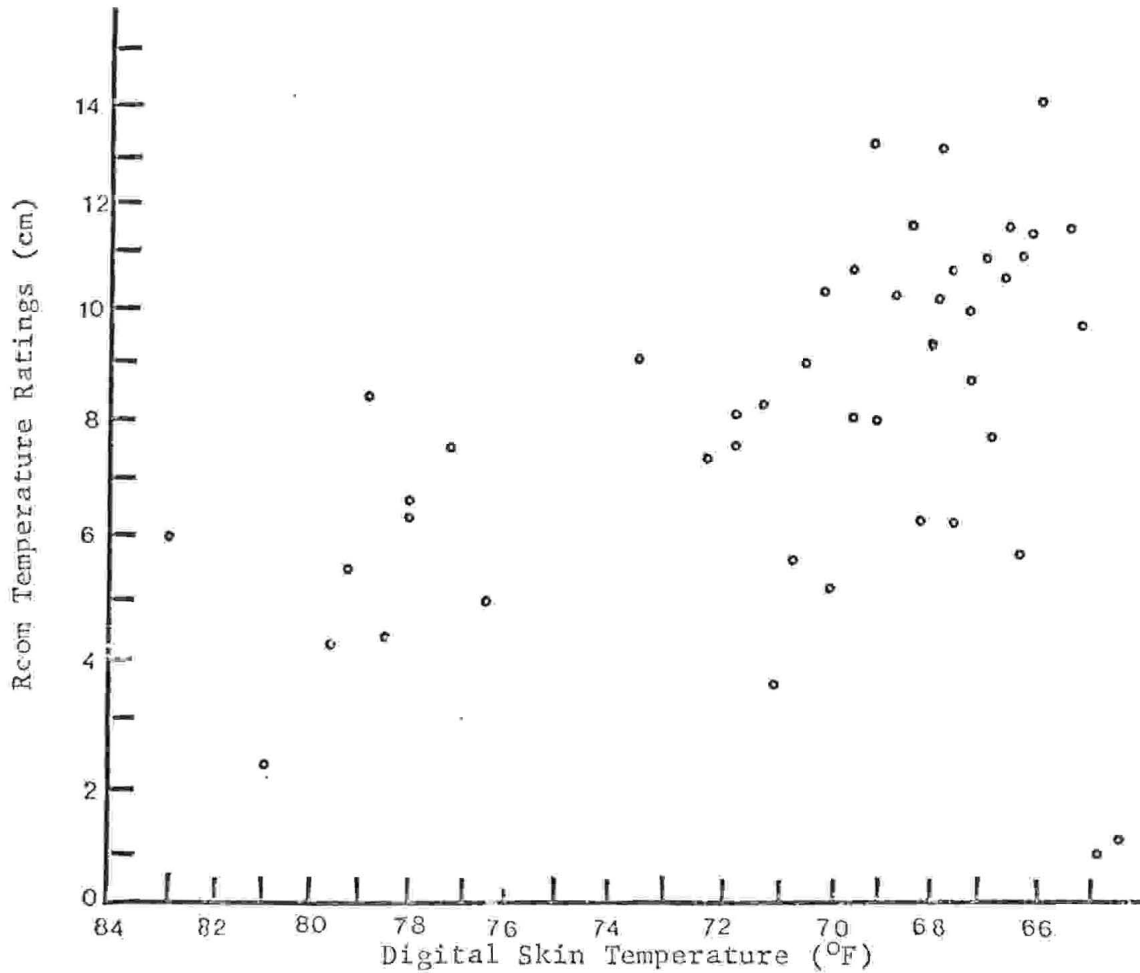


Figure 11. Room temperature ratings plotted against digital skin temperature at time of rating for females. Each point represents average for three subjects in same condition on same day at same rating time.

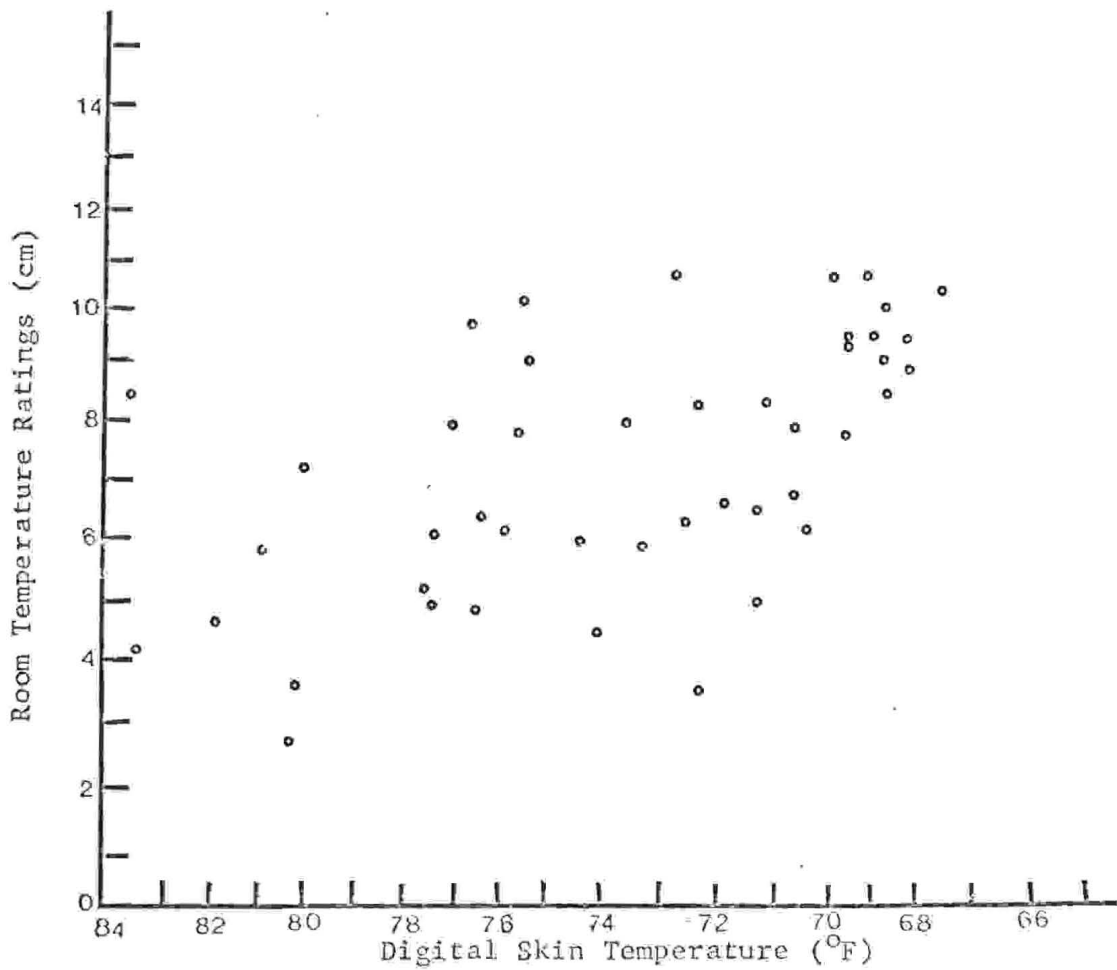


Figure 12. Room temperature ratings plotted against digital skin temperature at time of rating for males. Each point represents cell average for three subjects in same condition on same day at same rating time.

cal reactions to the same ambient temperature.

Digital Dexterity Task

As in comfort and temperature sensation ratings, the hypothesis that dexterity would improve if digital temperature was raised could not be tested. Although a significant practice effect was found over days, within a session the test was still sensitive to effects of cold exposure. However, since no significant decrement was seen until the end of the conditioning period, it seems that at least 45 minutes of cooling was necessary to show a decrement. The response of the males in the Feedback group is of particular interest. Even though males showed significantly more improvement across days than did females, the males in the Feedback group showed very little improvement across days. In addition, they showed the greatest decrement within a session. This decrement coincided with the end of the conditioning period and suggests that some aspect of the feedback training was actually interfering with performance of the task in these subjects.

Mental Reasoning Task Performance

The significant practice effect observed over days for the reasoning test was a surprising finding. The test is reported to have a "reasonably small" practice effect by Baddeley (1968). Baddeley, however, bases this assumption on data obtained from administering the test 5 times in a 1-hour period, while here the practice effect came out over days. Although he reports a reliability correlation of .8 between performance over days, this gives no information about a practice effect. This data is also reported for only 2 successive days. A significant improvement was not found between two successive days in the present

study, but the trend of higher scores on each successive day over the three day period did show significant practice effects from Day 1 to Day 3. Unfortunately, the ability to generalize from the present study to Baddeley's data is limited by the fact that only one-third of the original test was administered. The data do suggest, however, that performance on this test is not as stable as Baddeley implies.

The lack of a significant decrement as a result of cold exposure can not be adequately interpreted from this study. It is possible that the entire test is required to produce sensitivity to cold exposure, or the reliability reported by Baddeley. It is also possible that a practice effect within the session masked any decrement which might have occurred as a result of the cold. And, finally, the test itself may not be sensitive to effects of cold exposure. Further tests are necessary to determine the extent of the practice effect and whether or not the test is sensitive to effects of cold exposure.

EXPERIMENT II

Introduction

A brief follow-up study was designed in an attempt to clarify the results of Experiment I and test some of the implications of the conclusions drawn from that study. Changes in the original design were introduced in order to improve the experimental conditions and clarify some procedural and theoretical questions raised by the first study. A cold room was used which could maintain a constant low temperature and thereby eliminate the temperature oscillation and draft which occurred in Experiment I. A subjects-as-own-controls design was used to eliminate the problems encountered in Experiment I when comparing subjects who cooled at different rates in different groups or evaluating a subject's performance during conditioning against a baseline where no cooling had occurred. Only subjects who had participated in the first study were used in the second study so as to equalize previous cold exposure. In addition, the initial baseline period was shortened in an attempt to give feedback to subjects before they began to cool rapidly. This was done to allow for both more variability and higher digital temperatures at the beginning of the feedback period. Both of these variables were cited in Experiment I as being of possible importance for sustained temperature increases. The exploratory nature of this study, together with constraints imposed by scheduling demands on the cold room and the restriction of subjects to those run in Experiment I, meant that only a small number of subjects could be run over a minimal number of sessions. Accordingly, the design was further modified so as to include only feedback and control conditions.

Method

Subjects. Subjects were five males from Experiment I and one female (the experimenter). In Experiment I, three of the males in the present study had been in the Feedback group, one in the Control group and one in the Instruction group. The subject from the Instruction group was the subject who had shown temperature increases during conditioning periods on all three sessions of Experiment I. Two subjects had to be dropped from the analysis due to illness on the second day of running. Only the results from the remaining four subjects (all male, two from the original Feedback group, one from the Control group, and one from the Instruction group) will be reported here.

Apparatus. The experimental chamber for this study was a 6' x 10' cold room. Temperature was maintained at 53.6^oF (12^oC) with a gradual increase to 55.4^oF (13^oC) by the end of a session due to additional heat from subject and experimenter. This room eliminated the draft and rhythmical temperature fluctuations of Experiment I, but also necessitated lowering the experimental T_A due to limitations of the compressor. All other apparatus is the same as described in Experiment I.

Procedure. To compensate for the lower temperature, subjects were clothed in denim pants, a long-sleeved cotton shirt, a long-sleeved flannel shirt, shoes, and socks for this experiment (insulative value ~ 1 clo (Belding, 1968)). According to Belding, 3.21 clo would be required to maintain comfort at 53^oF (11.7^oC), while only 2.31 clo would be required to maintain comfort at 64^oF (17.8^oC) (T_A for Experiment I). The insulative value of clothing in Experiment I was ~ 0 clo, therefore subjects in both experiments were underclothed with respect to comfort by approximately

2 clo.

Before entering the cold room, subjects were asked to sit quietly in a warm anteroom for 15 minutes to equalize the effects of previous T_A for all subjects. During this time, a thermistor was attached in the same location as previously employed in Experiment I. The thermistor was insulated from room air by a piece of absorbent cotton. Subjects then completed the digital dexterity task and the reasoning task before entering the cold room. This was done so that performance in the cold could be compared with performance at normal temperature, and also so that the shortened baseline period in the cold room would be uncomplicated by confounding effects of performing the tasks.

Each subject was run for two sessions on consecutive days, one under Feedback conditions and one under Control conditions. The order of the conditions was counterbalanced for the six original subjects. Since the two subjects who were excluded from the analysis were run in the same order, their exclusion resulted in an incompletely counterbalanced design. Three of the remaining four subjects were run in the Feedback condition first, and only one in the Control condition first.

In the Feedback session, subjects were seated in the cold room and temperature recording was begun. Subjects were asked to complete the same rating scales for comfort and room temperature as in Experiment I. They then read for the remainder of a 5-minute baseline period. At the end of this period, another set of ratings was completed and a 30-minute conditioning period began. The same instructions and apparatus as in Experiment I were used. Another set of ratings were taken 15 minutes into this period and again at the end of this period. Subjects then

completed another dexterity task and another reasoning task and again read for the remainder of a 5-minute period while final baseline temperatures were recorded. At the end of the 40-minute session another set of ratings were made.

In the Control session, subjects followed the same procedure for tests and ratings, but continued to read during the 30-minute equivalent to the conditioning period. This gave baseline data over an equivalent length of time (40 minutes) to the Feedback session for each subject.

The complete design is outlined in Table 11.

Results

Figures 13, 15, and 17 present the results for digital temperature, subjective comfort ratings, and room temperature ratings respectively. These figures show the averaged data for all subjects on these measures. Figures 14, 16, and 18 present the corresponding data for individual subjects. It can be seen from these figures that by the end of the conditioning period there was no overlap for the two sessions on any of these variables. For this reason statistical analyses were not required for these variables. Results will be discussed with reference to graphs and performance of individual subjects. Given the small number of subjects, it is felt that graphic representations of each subject's data present a clearer picture than do summary statistics.

Digital Skin Temperature

Figure 13 presents the digital skin temperature results averaged across the four subjects in this study for each session. Scores are plotted in 5-minute intervals for each session, with the first score being the initial temperature (I), the second the temperature at the end of the first baseline (B1), the next six from the conditioning period (C), and the final score from the end of the last baseline (B2). Points at I, B1, C1, C2, and B2 correspond to the times when rating scales were completed during each period. Results for individual subjects are given in Figure 14. Heavy black dots denote readings at 5-minute intervals. Any inflection points in the temperature curves which occurred between these intervals are also noted.

Note in Figure 13 that not only were temperatures consistently higher and more stable during conditioning for the Feedback session, but

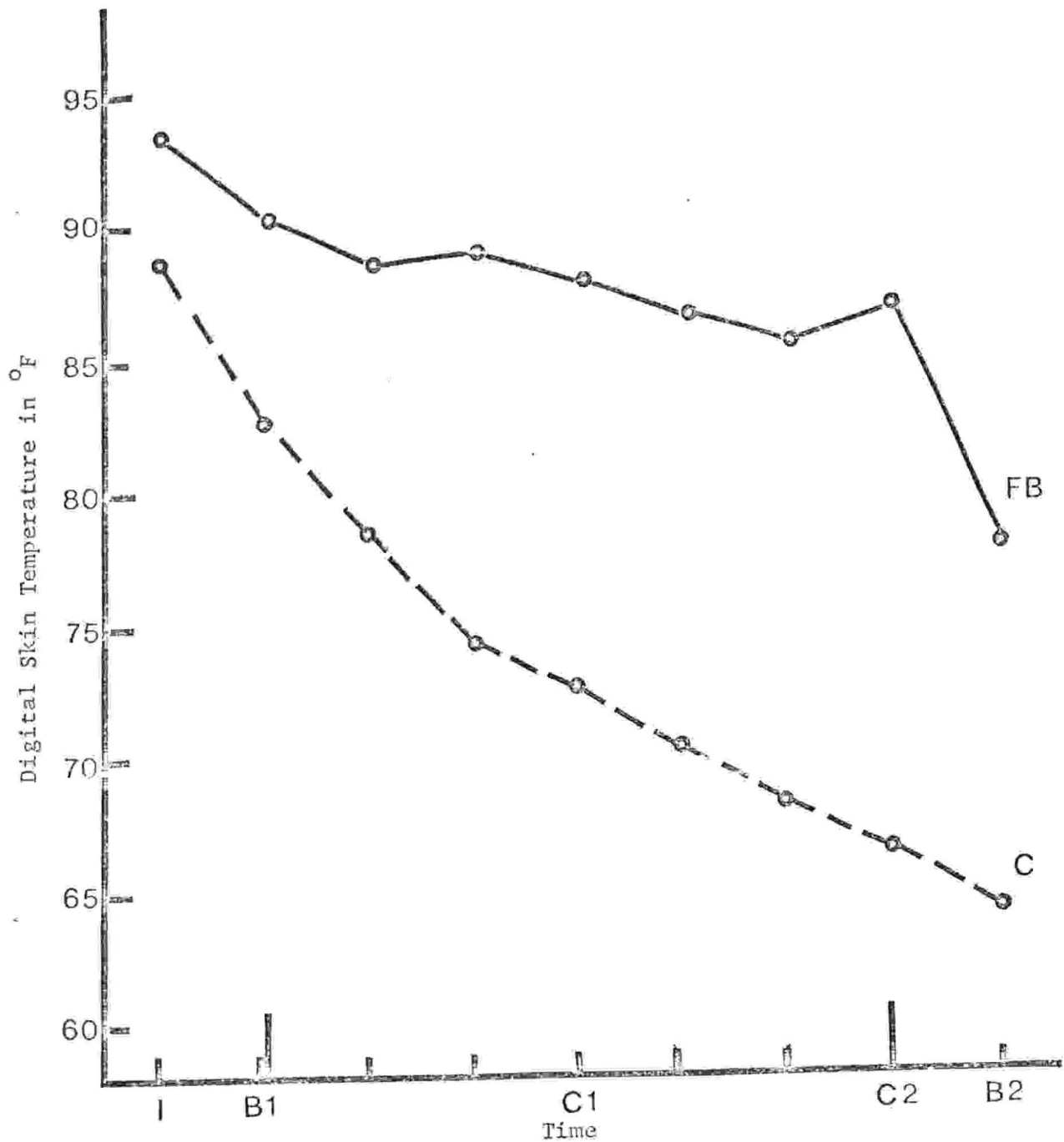


Figure 13. Average of all subjects digital skin temperatures at 5-minute intervals on each day. Solid line is Feedback day. Dashed line is Control day. Heavy black lines after B1 and at C2 denote interval during which feedback was available on Feedback day.

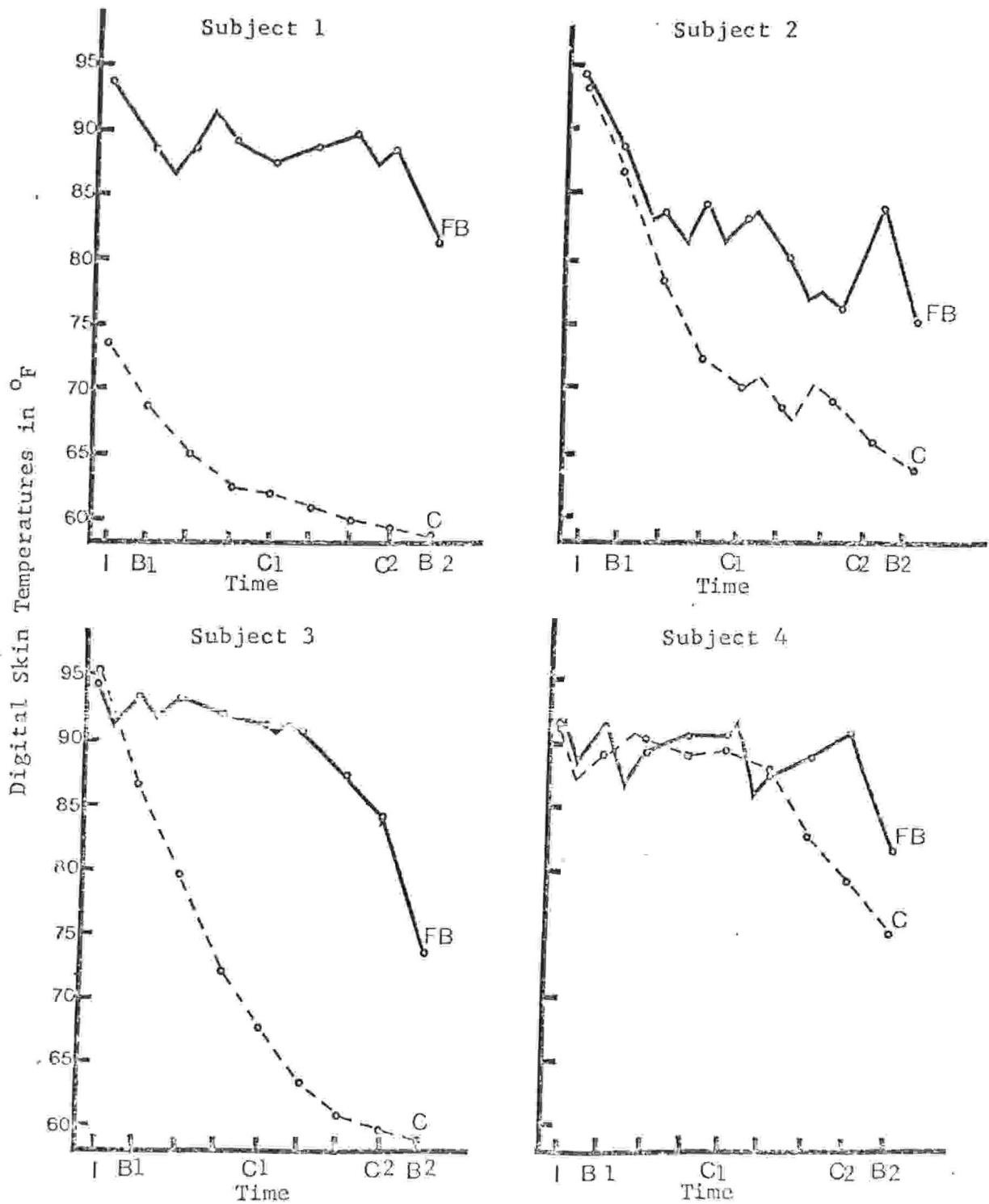


Figure 14. Digital temperature records for each subject. Solid line gives temperatures on Feedback day, dashed line gives temperatures for Control day. Heavy black dots indicate temperatures at 5-minute intervals. Points of inflection in curves which occur between dots are extreme temperatures reached between readings.

a large decrease was shown immediately after conditioning. The decrease in this final baseline in Feedback sessions was greater than any other decrease for a 5-minute period for either session. Although it appears from this graph that subjects had lower initial temperatures for the Control session than for the Feedback session, it can be seen from Figure 14 that this was due to an extremely low temperature for Subject 1 for the Control session. Initial temperatures for the other three subjects were comparable on the two days.

Figure 14 shows that only one subject (Subject 4¹) showed any overlap of temperatures during the conditioning period over the two days. This subject did not show evidence of cooling in his Control session until 25 minutes into the session. No further increases were shown by him after that time. In his Feedback session, however, he showed an increase from that point to the end of the conditioning period. For this subject and all other subjects the largest decrease for a 5-minute period was seen in the final baseline period of the Feedback session, indicating a reversal in trend time-locked to the change from conditioning to baseline. In addition, no subject showed increases in the Control session which were equal in magnitude to his increases in the Feedback session.

Regarding Subject 1, it should be noted that although he began the Control session at a much lower level than the Feedback session, his curve for the Feedback session was not only higher but showed increases not shown on the Control session. Moreover, like the other subjects,

1 Subject I2 from Experiment I.

Subject 1 showed his greatest decrease for a 5-minute period immediately following conditioning. This indicates that the observed difference for the two days was due to more than a difference in level.

Only two subjects (Subjects 3 and 4) showed variability in their temperatures during the initial 5-minute baseline, but all four subjects began the conditioning period with temperatures greater than 85°F (29.4°C). This level was considerably higher than temperatures at the beginning of conditioning in Experiment I (with the exception of subject I2).

Although the design was not completely counterbalanced after the elimination of two of the original subjects, an acclimation effect does not appear to be biasing the results. Subjects 1, 2, and 4 were run with the Feedback session first and still showed a greater degree of cooling on the second day, or Control session. No systematic differences were apparent between these subjects and Subject 3 who was run with the Control session first.

The greatest differences between Feedback and Control days were observed in Subjects 1 and 3. Both of these subjects had been in the Feedback group of Experiment I. However, since Subject 1's initial Control temperature was so much lower than his initial Feedback temperature, there is no strong basis for drawing any conclusions about a practice effect of previous feedback training from only these two subjects.

Subjective Comfort Ratings

Figure 15 shows the graph of subjective comfort ratings averaged over the four subjects. Comfort ratings during the conditioning period were higher and more stable for the Feedback session than for the Control session, but with termination of conditioning, comfort ratings on the

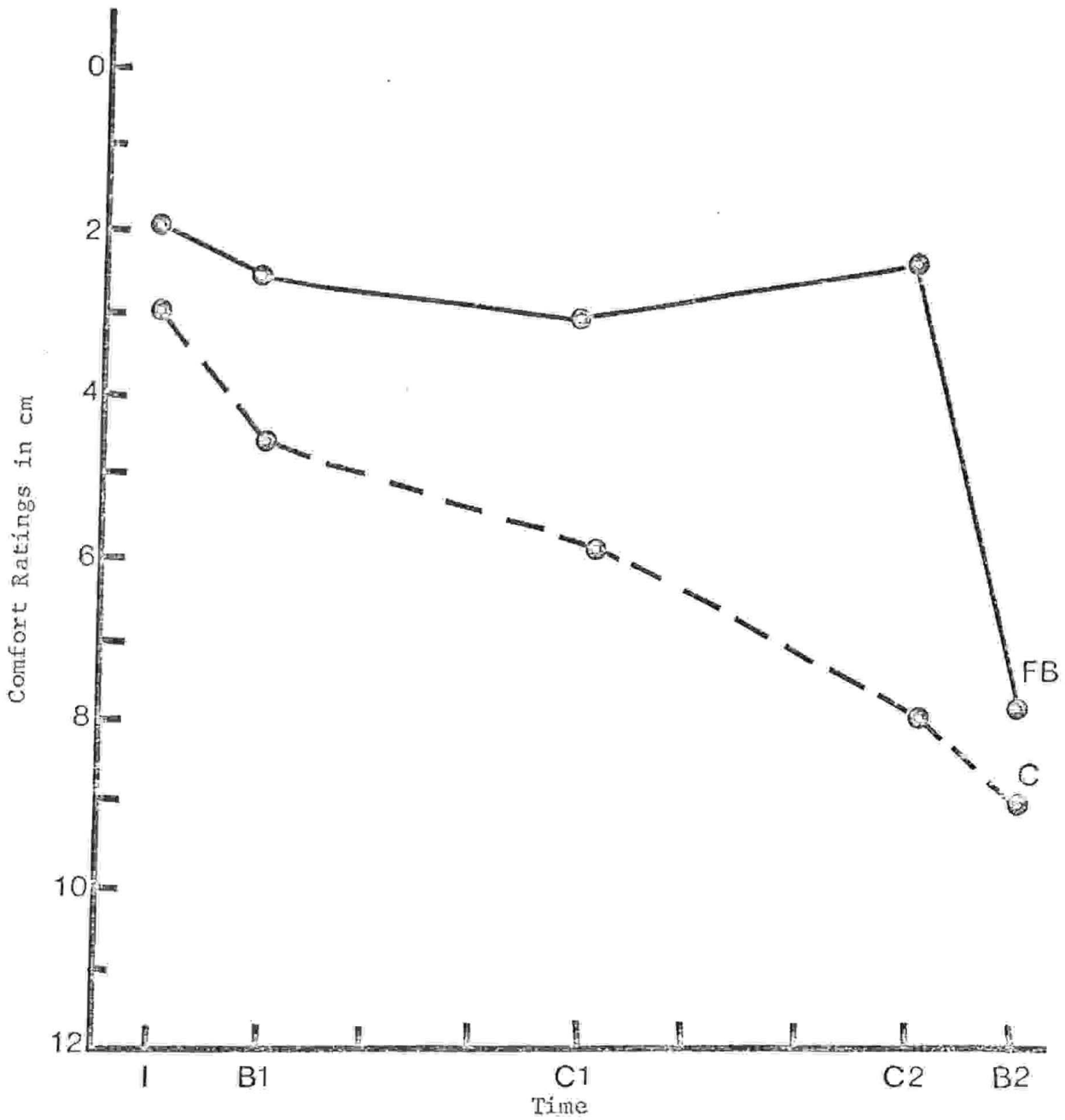


Figure 15. Comfort ratings plotted over time for each session. Lines reflect averages for all subjects. Solid line is Feedback day. Dashed line is Control day. Larger numbers reflect more discomfort.

Feedback session fell to a level comparable to the Control level for the same time.

The trends for individual subjects are shown in Figure 16. All subjects showed greater comfort ratings at the end of the conditioning period (C2) in the Feedback session than in the Control session. Two of the subjects (2 and 4) reported being more comfortable after conditioning than at any other time on either day. Two of the four subjects (2 and 3) also showed clearly greater comfort ratings halfway through the conditioning period (C1) in the Feedback session than at the equivalent time in the Control session. Subjects 1 and 4 gave comparable ratings at C1 for both sessions.

The averaged data for comfort ratings and digital temperature (Figures 13 and 15) show a very strong relationship between digital temperature and comfort. In particular, it should be noted that the greatest decrease in comfort for a 5-minute interval occurred at B2 in the Feedback session, which coincided with the greatest 5-minute decrease in digital temperature, and again, was time-locked to the end of the conditioning period. In addition, the slight increase in comfort which occurred at C2 in the Feedback session coincided with the slight increase in temperature at C2 in the same session. Data for individual subjects (Figures 14 and 16) support the relationship of digital temperature to comfort, although the minute by minute changes were not as highly correlated as suggested by the averages.

Room Temperature Ratings

Figure 17 presents the data for room temperature ratings averaged across the four subjects. Comparing Figures 13, 15, and 17, a good

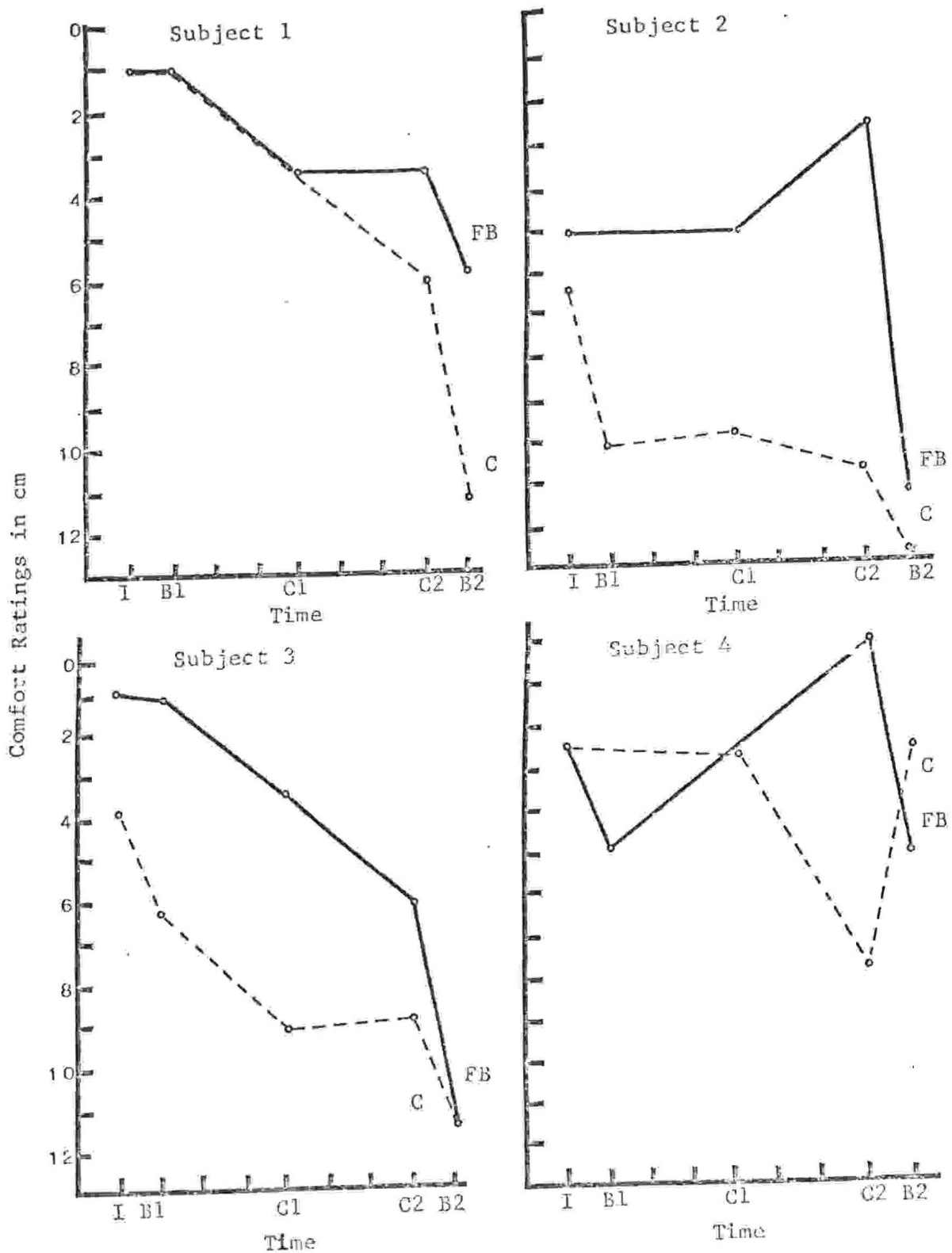


Figure 16. Comfort ratings plotted over time for each session for each subject. Solid line denotes Feedback ratings, dashed line denotes Control ratings. Ratings were taken only at points I, B1, C1, C2, and B2. Larger numbers on vertical axis reflect more discomfort.

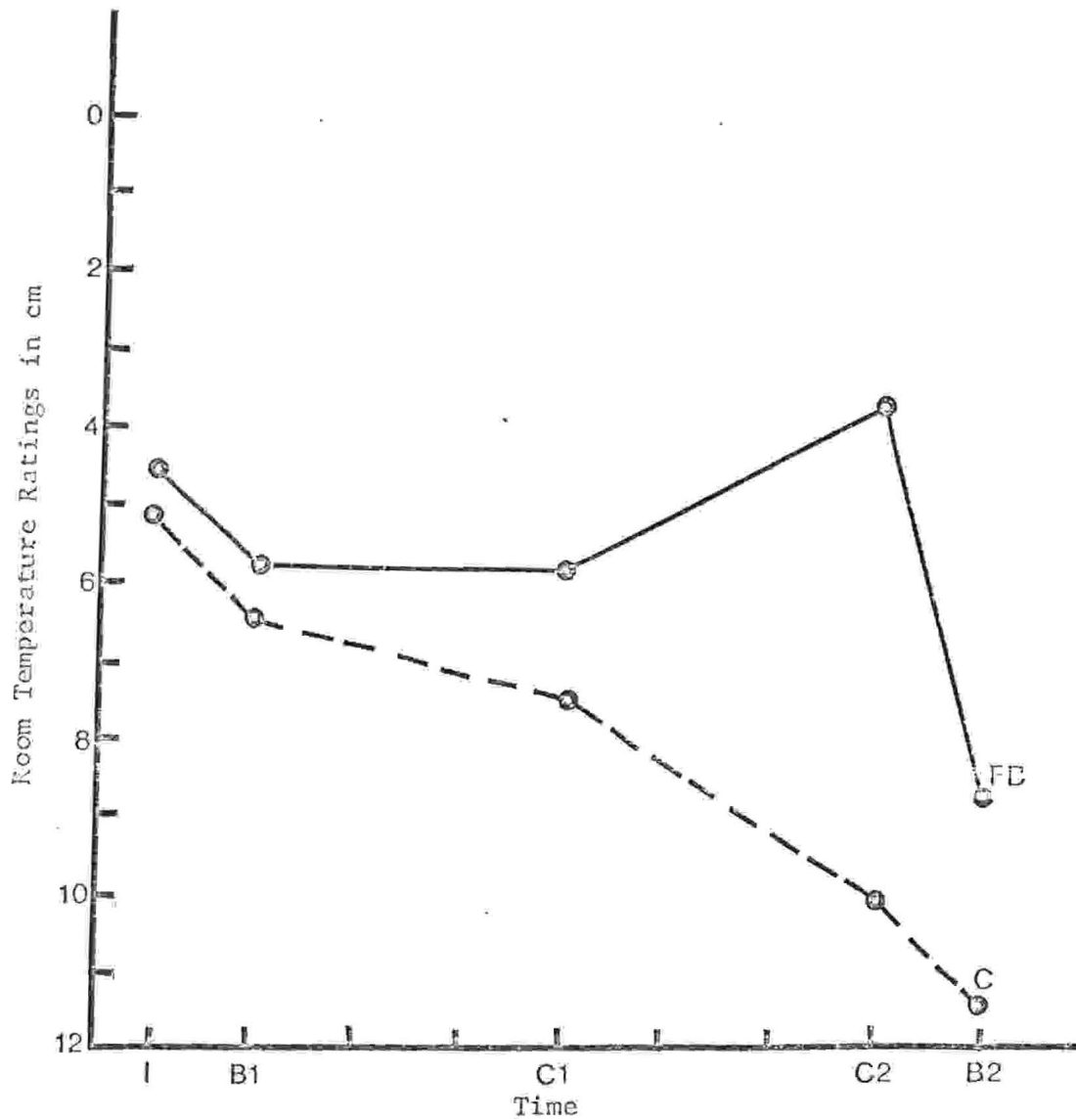


Figure 17. Room temperature ratings plotted over time for each session, reflecting averages of all subjects. Solid line reflects Feedback ratings, while dashed line reflects ratings on Control day. Larger numbers reflect colder ratings.

correlation can be seen between digital temperature, comfort ratings, and temperature sensation. Subjects rated the room as warmer in the Feedback session than in the Control session. Again, the greatest increase in cold sensation coincided with the greatest decrease in comfort and greatest decrease in digital temperature at B2 in the Feedback session, again time-locked with the end of the conditioning period. And, again, a slight decrease in cold sensation at C2 in the same session coincided with increased comfort and digital temperature at the same time.

The pattern of response for each subject is shown in Figure 18. Again, all subjects showed warmer ratings at the end of the conditioning period (C2) for the Feedback session than for the Control session. Once again, although a good correlation existed between room temperature ratings and both digital temperature and comfort ratings, this correlation was not as high for individual subjects (Figures 14, 16, and 18) as is suggested by comparing the averages (Figures 13, 15, and 17).

Digital Dexterity Task

A 2(condition) x 2(time) repeated measures analysis of variance was done on scores for the dexterity task. The F table for this analysis is presented in Table 12. The only significant effect was a main effect for conditions. There was a significant difference in performance on the two conditions with higher scores in the Control session than in the Feedback session ($F_{1,3} = 13.364, p = .035$). These results are graphed in Figure 19.

Since, with the incomplete counterbalancing, conditions and practice effects were confounded, it is useful to examine the individual results underlying this main effect. The data for individual subjects is

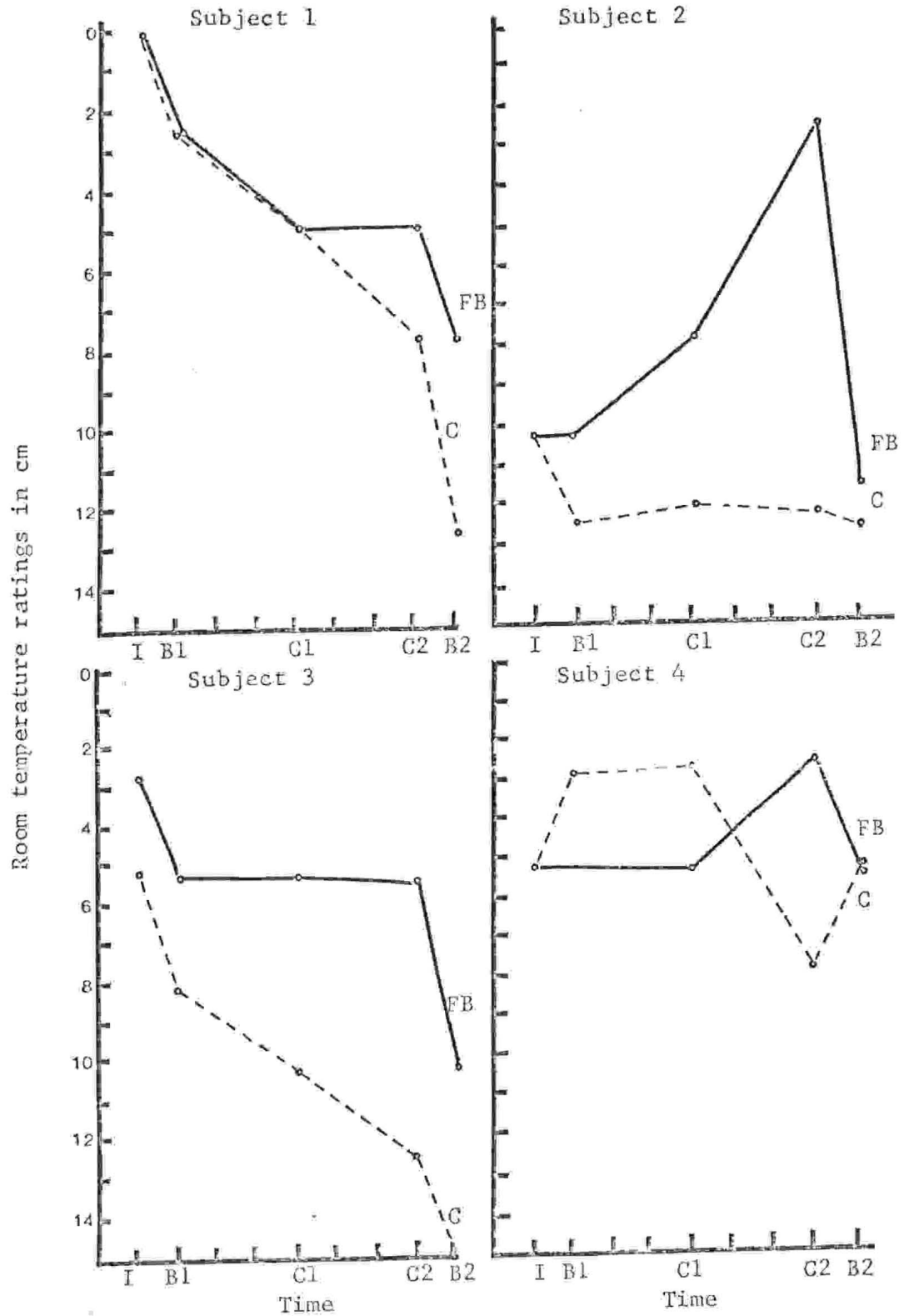


Figure 18. Room temperature ratings plotted over time for each session for each subject. Solid line reflects Feedback day; dashed line reflects Control day. Ratings were taken only at points I, B1, C1, C2, and B2. Larger numbers on vertical axis reflect colder ratings.

Table 12
 F Table for Digital Dexterity Task Analysis, Experiment II

Source	DF	Mean Square	F-Ratio	Probability
Subjects	3			
Conditions	1	3.06	13.364	0.0354*
Error (Subjects/Conditions)	3	0.23		
Time	1	3.06	5.444	0.1018
Error (Subjects/Time)	3	0.56		
Conditions x Time	1	0.06	0.273	0.6376
Error (Subjects/Condition x Time)	3	0.23		

* significant

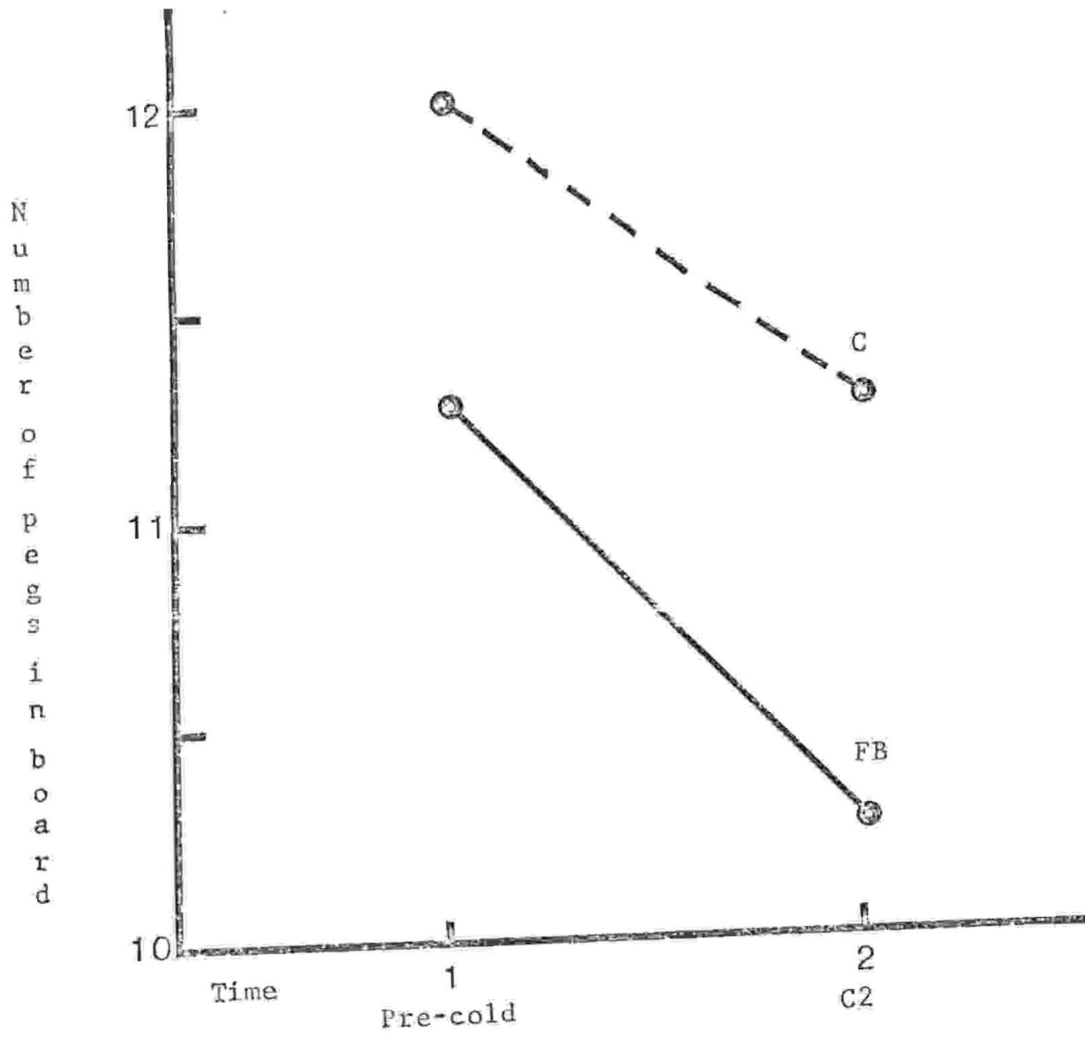


Figure 19. Number of pegs placed in board in 30 seconds for digital dexterity task. Graph is average for all subjects on each trial on each day. Solid line is Feedback session, dashed line is Control session.

presented in Figure 20. It should be noted that only one subject, Subject 3, did not have a higher score on the task for his first trial in the Control session. This was the subject who was run in the opposite order from the rest of the subjects. This subject did his Control session first while the others had done their Feedback session first. His score on the task was the same on the initial trial on both days. This score was also the highest score on the task for all subjects. In light of this, it is possible that the higher average scores on the baseline day were the result of a practice effect for Subjects 1, 2, and 4. If this is the case, Subject 3 may have reached a plateau and therefore not shown a practice effect for this reason.

No clear trends are suggested by this data with regard to cold decrement and the effect of conditioning. It should be noted that despite the suggestion of practice effects across sessions, no subject showed increases in performance within a session and subjects showed a decrement in performance in 5 out of 8 sessions. It is also interesting to note that three of the four subjects (Subjects 2, 3, and 4) showed a decrement in performance on the Feedback session even though two of these subjects (Subjects 2 and 3) showed no decrement on the Control session.

Reasoning Test

A 2(condition) x 2(time) repeated measures analysis of variance was done on scores from the reasoning test. The F table from this analysis is presented in Table 13. Only a significant main effect for time was found with subjects showing higher scores for the second test in each session ($F_{1,3} = 12.000$, $p = .041$). This result is graphed in Figure 21. Figure 22 presents the data for individual subjects. No

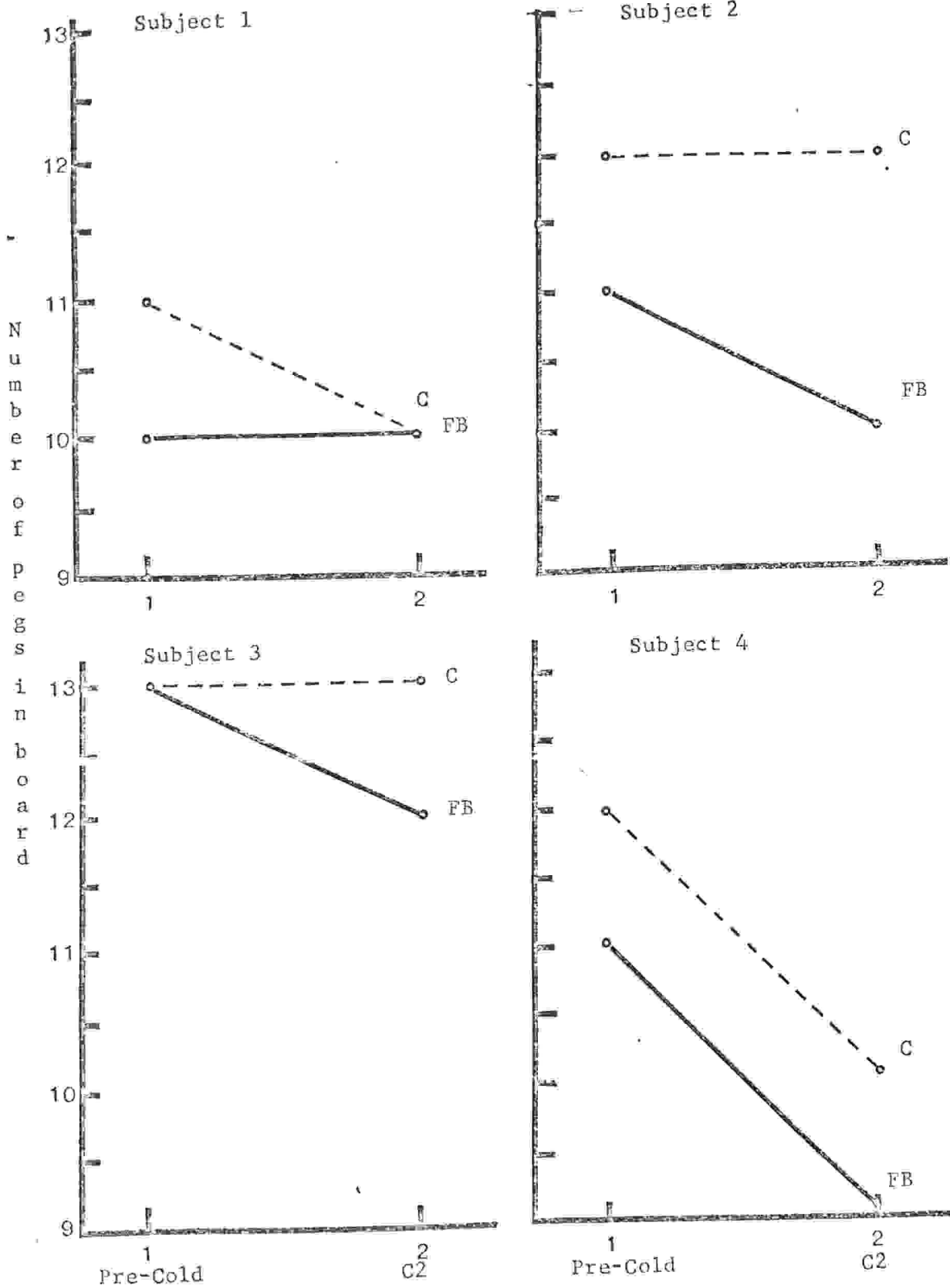


Figure 20. Number of pegs placed in board in 30 seconds by each subject on the digital dexterity task. Solid line is performance on Feedback day and dashed line is performance on Control day.

Table 13
F Table for Reasoning Test Analysis, Experiment II

Source	DF	Mean Square	F-Ratio	Probability
Subjects	3			
Conditions	1	4.00	1.333	0.3318
Error (Subjects/Conditions)	3	3.00		
Time	1	4.00	12.000	0.0405*
Error	3	0.33		
Conditions x Time	1	1.00	0.500	0.5305
Error (Subjects/Condition x Time)	3	2.00		

* significant

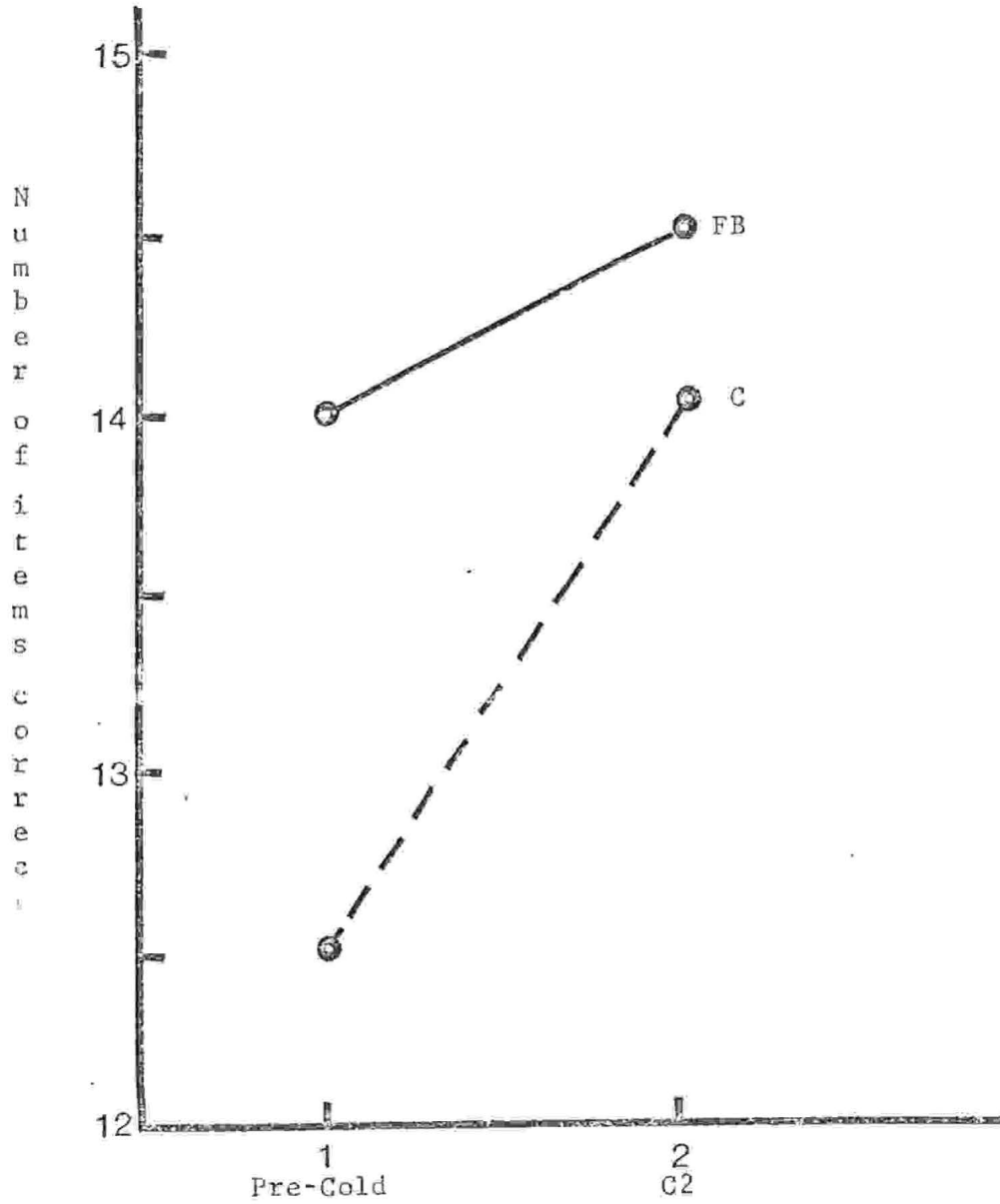


Figure 21. Scores on Mental Reasoning Test averaged over all subjects. Solid line is performance on Feedback day, dashed line is performance on Control day.

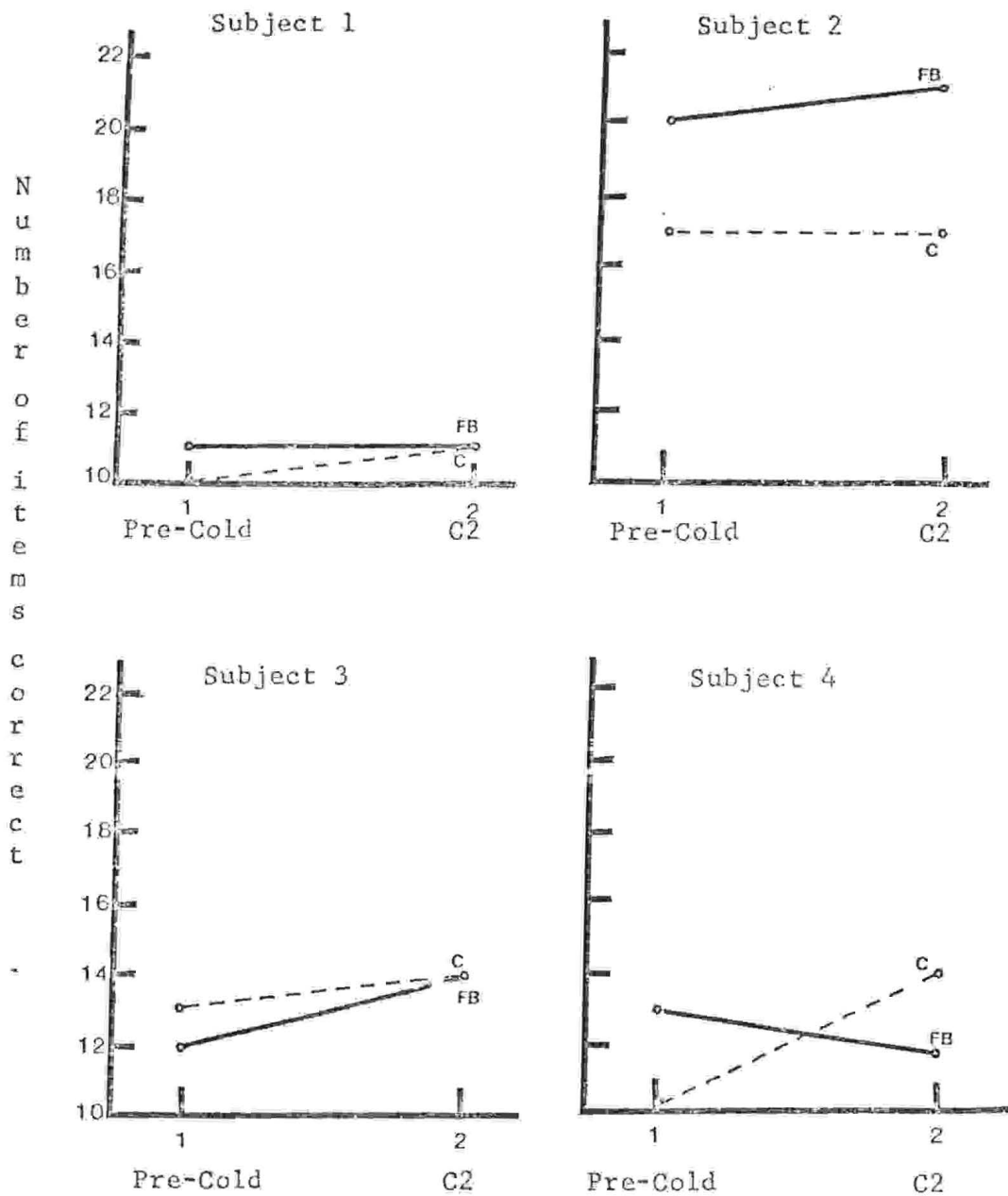


Figure 22. Scores on Mental Reasoning Test for each subject. Solid lines reflect performance on the Feedback day while dashed lines reflect performance on the Control day.

clear differences existed between performance on the two days, but averaging the scores for the two days together for each subject, all subjects showed improvement on the second administration of the test within a session.

Discussion

Digital Skin Temperature

The consistent pattern of results across all four subjects in this study clearly shows that it is possible to exercise voluntary control over digital temperatures in a cold environment. During the Feedback sessions, subjects maintained relatively high temperatures throughout most or all of the 30-minute conditioning period. In contrast, all four subjects showed steady decreases over at least the last half of the conditioning period in Control sessions, with three of the four showing steady declines for the entire period. In addition, all subjects showed large decreases immediately following the conditioning period in the Feedback session.

It was suggested in Experiment I that in order for large and sustained increases to occur as the result of feedback, digital temperature at the beginning of the feedback period must be both high and variable. The present study suggests that the high initial temperature is the critical factor. While all subjects demonstrated high temperatures at the onset of the conditioning period, only two of the four showed variability in their temperatures prior to this time. All subjects showed feedback effects, however, and there was no difference in the magnitude of this effect between subjects with or without variability. Of course, the possibility cannot be absolutely ruled out from these data that some spontaneous variability occurred in some or all subjects during the conditioning period itself, but the data from the Control sessions offer little support for positing variability as a necessary factor.

Rating Scales

Subjective comfort ratings and ratings of room temperature coincided very well with changes in digital temperature, especially if averaged data is considered. Subjects gave higher comfort ratings and warmer room temperature ratings in Feedback sessions than in Control sessions. Moreover, in Feedback sessions, the termination of the conditioning period was followed by a sharp drop in both comfort and temperature ratings coincidental with the decline in digital temperature at this same time. There are at least three possible explanations for this phenomenon. First, it is possible that the concentration involved in voluntarily controlling digital temperature decreased the subjects' sensitivity to or awareness of the cold on those days. Second, it is possible that subjects expected to feel warmer if they were increasing their finger temperatures, and since feedback showed them they were successful, they then felt warmer. The third explanation is that digital temperature changes in themselves were instrumental in changing comfort and temperature sensations. This third explanation is consistent with the high correlations reported in Experiment I between digital temperature, comfort ratings, and room temperature ratings in both men and women in all groups, even though the cooling curves were different for each sex. It is self evident that since those effects were unrelated to feedback effects, those correlations could not have been accounted for in terms of a concentration or expectancy factor.

Task Performance

Contrary to prediction, improvement in task performance due to increased digital temperatures and comfort was not found. Practice effects

apparent in both tasks used in this study (lending support to findings of Experiment I), plus the incomplete counterbalancing make it difficult to assess the effects of treatments. It is interesting to note that on the dexterity task three subjects showed a decrement in performance in the Feedback session even though two of them had shown no decrement in the Control session. Since all subjects in this study were males, this supports the finding from Experiment I that feedback training was actually interfering with performance on the task. All subjects in Experiment II reported that the conditioning period had required intense concentration and was very tiring. It is possible that these two factors actually resulted in lowering performance on the task since it was administered immediately after conditioning. Although the trend toward a decrement in performance within sessions was not statistically significant in this study, it should be remembered that the second test was given after only 35 minutes of exposure. In Experiment I, no significant decrement in performance occurred until 45 minutes of exposure. Further studies should be done with a more stable and sensitive test to determine if there is a stable decrement in performance related to conditioning, and if this decrement is only seen for males as suggested by Experiment I.

If conditioning requires such intense concentration that performance on tasks is inhibited, the practical applicability of increasing digital skin temperature is severely limited. Further studies are necessary to determine if the amount of concentration required is reduced with additional training to the point where it is feasible to conduct routine activity while keeping digital skin temperature elevated.

Evaluation of Methodology: Controls and Mediation

In order to draw conclusions about the effects of operant conditioning procedures upon autonomic responses, a number of methodological issues must be considered. Katkin and Murray (1971) presented a critical review of the existing studies in the area and proposed stringent criteria to be used in evaluating whether or not observed effects could be attributed to operant conditioning, and whether these effects were specific to the system being conditioned. These criteria were (1) that results should demonstrate that the response in question has shown appropriate change in frequency, amplitude, or probability of occurrence over a free operant rate obtained in a baseline period; (2) that comparisons be made between experimental groups and appropriate controls; and (3) that data be free from obvious alternative explanations such as cognitive or peripheral mediation. While these criteria have been criticized as too stringent (e.g., Crider et al., 1971), they may be useful guidelines for discussion of the present study.

Following a strict interpretation of Katkin and Murray's first criterion, one would have to conclude that subjects in Experiment II failed to condition, since, during the Feedback session, temperatures in the conditioning period were generally not higher than those in the preconditioning baseline period. However, as Crider et al. (1971) have pointed out, autonomic variables do not tend to show steady operant rates, but rather tend to change over time. This was especially true in the present study where the environmental constraint of cold exposure tended to effect a steady decline in peripheral temperature. In view of this, the comparison of equivalent exposure times between experimental and

control sessions (a within-subjects application of Katkin and Murray's second criterion) provides a more accurate means of assessing conditioning effects than does the use of the preconditioning baseline. Insofar as subjects showed consistently higher temperatures in the conditioning period during Feedback sessions than in comparable periods during the Control sessions, it may be concluded that the conditioning procedure had a definite effect on skin temperature and subjective comfort and temperature ratings. The exact nature of this effect, however, cannot be inferred from the present data. This brings us to a discussion of Katkin and Murray's second criterion with respect to the "appropriateness" of the control session.

In biofeedback, as in any experimental design, the controls must be appropriate to the question(s) being asked by the study. No previous studies had looked at the possibility of using conditioning to increase peripheral temperature under a cold constraint. Thus, the present study was exploratory in nature, asking the question "Can individuals voluntarily produce increases in their digital skin temperatures in the cold?" The control used here (the same individuals not attempting to increase temperatures under the same environmental constraint) is an appropriate control for such an exploratory question. This control does not allow for determining the factors in the feedback situation which enabled the subjects to produce increases in temperature. Since the results of this study showed that individuals are able to voluntarily increase digital skin temperature in the cold, it is of interest to examine alternative controls which might aid in determining exactly which factors in the feedback situation were relevant to the effects observed.

The conditioning method used here included (1) instructions to increase temperature, and (2) the provision of visual and auditory feedback stimuli with the implicit demand to attend to it. A control group such as the one used in Experiment I, where subjects were instructed to increase their digital temperatures but not provided with immediate feedback, would aid in determining the effectiveness of instructions alone. (Since there were no clear differences in temperatures between the Feedback and Instruction groups in Experiment I, or between either of these groups and the Control group, that study provided no clear evidence for the relative effectiveness of instructions or feedback.) A similar strategy could be used to determine the relative effectiveness of visual versus auditory feedback by running these two modes of feedback as independent conditions. The feedback situation, however, introduces other potential sources of confounding. First, there is the possibility of effects resulting from the concentration involved in attending to the feedback. Subjects, in fact, reported intense concentration and effort; and, as discussed above, the data from the dexterity task suggested effects resulting from this concentration. A second problem has to do with the potential for the stimulus and reinforcing properties of the feedback itself to elicit effects independent of the instrumental contingency between feedback and temperature. This problem was discussed earlier with regard to the subjective ratings of comfort and temperature made in this study. One way of separating the concentration and stimulus-elicited effects from the feedback contingency might be to require groups to perform a vigilance task using visual and auditory stimuli, assuming that concentration required in the vigilance and

feedback tasks could be equated. An alternate method which is often used to assess the effects of both concentration and elicited effects of feedback stimuli is the method of noncontingent feedback. Such a procedure presents control subjects with conditions and stimulation identical to that of the experimentals, except that the feedback in this case is not contingent upon the response, and so, by definition, should not produce any instrumental effects upon it. Although this approach appears quite appropriate on first consideration, problems inherent in the method may actually bias the results. For example, if the control subject is using a strategy which is effective in producing the desired effect, erroneous feedback may induce a change in this strategy, thereby producing artificially low performance in the control subject and inflating the estimate of performance in the experimental group. If, in addition to adopting an effective strategy, the control subject also has some means of internal feedback to success (for example, feeling an increased finger pulse in the present study), a realization that the feedback is erroneous may occur. In this case the subject might choose to ignore the feedback provided and either persist in the strategy or stop trying to produce the effect, both responses producing quite different results, and both equally difficult to evaluate post hoc. The latter case has the potential for the additional disadvantage of making the subject distrust experimental situations. Since subjects in psychological studies quite often participate in more than one study, the implications of making subjects less responsive to instructions and explanations provided in experimental situations should not be a minor concern. Regardless of this aspect of noncontingent feedback, the results obtained from such a

control group are not always clear and experimenters should be very careful in the interpretation of such results.

Katkin and Murray's (1971) third criterion deals with the problem of mediation. The issue may be expressed as follows: if autonomic changes are observed in feedback studies, the effects may be the result of elicited cognitive or skeletal responses which in turn elicited either conditioned or unconditioned responses in the autonomic system being observed. Related to and implied by the mediation issue is the question of the specificity of observed effects to the system upon which feedback is contingent. In the present study, for example, general relaxation of skeletal muscle may have elicited an unconditioned reduction in sympathetic (SNS) activity resulting in, among other things, peripheral vasodilation; or thoughts of sitting on a hot, sandy beach may have elicited conditioned peripheral vasodilation. Black (1966) has pointed out that such peripheral and cognitive mediation is of interest only if one is concerned with proving conditioning of a specific autonomic system rather than control of that system. Since the present study was not concerned with specificity, it was not designed to eliminate the possibility of mediation. Moreover, in terms of practical application of this technique, such mediation may greatly enhance its effectiveness. It still, however, may be of interest to discuss the mediation problem from the broader perspective of possible physiological mechanisms or systems involved in the effects. These may be of interest both from a theoretical viewpoint and from the practical point of suggesting more effective means of training than the one used here. Several possible mechanisms can be suggested as a guide for future research.

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First, the observed increase in temperature might have been the result of more blood reaching the skin in the hands. This could be merely the result of inhibition of the adrenergic SNS fibers causing vasoconstriction in the cold, or possibly a combination of inhibition of these adrenergic fibers and activation of the cholinergic SNS fibers causing vasodilation. Fox and Hilton (1958) have proposed that this sympathetic vasodilation is the result of the release of bradykinin from the sweat glands which receive direct cholinergic SNS innervation rather than from direct cholinergic innervation of the blood vessels. If their hypothesis is correct, the remote possibility of increased sweat gland activity under the cold stress of the present study would make inhibition of vasoconstriction a more logical possibility than active vasodilation.

The second method for increasing digital skin temperature would involve a redistribution of the venous return. During cold exposure, venous return from the extremities normally occurs through deep venous plexuses allowing countercurrent heat exchange between warm arterial blood and the cooler venous blood. The net result is that arterial blood is greatly cooled when it reaches the extremities while the venous blood is warmed when it reaches the core. In a warm environment, venous return is shifted to surface vessels, thus reducing countercurrent heat exchange and allowing more heat to pass to the environment. The result is warmer blood reaching the extremities (Bullard, 1971). While it is believed that this redistribution is accomplished through sympathetic control, the precise mechanisms are not known (Bligh, 1973). The redistribution of venous return, therefore, can effect changes in digital

skin temperature independent of changes in peripheral blood flow. Such a mechanism may have been involved in the increase of digital skin temperature seen in the present study, possibly in combination with an increase in blood flow.

A third method of producing the observed temperature increases may have been through increased metabolic activity which might have resulted in warmer blood reaching the hands. Possibly the most logical way for this to occur in this study would have been through shivering. While no visible shivering was noted during the feedback periods, it is possible that EMG recordings might have picked up an increase in activity. In addition, increased chemical thermogenesis, heart rate, or respiration might also have occurred.

It is interesting to note that these three mechanisms for increasing digital temperature are not mutually consistent. For example, skeletal relaxation as a basis for generalized inhibition of SNS activity would conflict with the expectation of heightened activation implicit in increased metabolic activity. Monitoring only blood flow or temperature at the periphery would not be sufficient to differentiate these possibilities. For this reason, regardless of which or what combination of these mechanisms was involved in the present study, the question of the specificity of observed effects is still of interest.

If the observed effects were the result of a metabolic increase, how general an increase was it? Did it involve an increase in muscular activity, an increase in tissue metabolism, or some combination of both? And likewise, if the effect was one of relaxation, was it a relaxation of the SNS as Wickramaskera (1973) has suggested, or did it involve relax-

ation of not only the SNS but of skeletal muscle activity too?

If the effect was specific, what systems were involved? For example, if inhibition of innervation to the vasculature was involved, did this include all peripheral blood vessels, only blood vessels in the hands, or only vessels in one of the hands analogous to the case of rats conditioned to respond with differential blood flow in the two ears (DiCara and Miller, 1971)?

In addition to the theoretical interest in the mechanisms underlying the peripheral temperature effects, the consequences that increased digital temperature might have for core temperature are also of interest. Did increasing digital skin temperature when homeostatic mechanisms required it to decrease cause a concomitant decrease in core temperature or merely a redistribution in peripheral temperatures? If no drop in core temperature was found in this exposure, would a longer or more severe exposure have produced a core temperature decrease? Could subjects have shown peripheral temperature increases in a more severe exposure? Would disruption of homeostatic mechanisms in more severe exposures have deleterious effects?

While the present study has demonstrated that subjects can control digital skin temperature in the cold, it obviously has raised many more questions, such as the above, which must be answered before the practical applicability of such a technique can be adequately assessed. Studies monitoring skeletal muscle activity, respiration, heart rate, blood flow, corollary changes in temperature occurring over the rest of the body's surface and changes in core temperature may provide us with a more complete understanding of the factors influencing comfort and temperature sensations,

as well as a better understanding of other factors involved in voluntarily controlling temperature.

References

- Adams, T., and Covino, B. Racial variations to a standardized cold stress. Journal of Applied Physiology, 1958, 12, 9.
- Andersen, K. L., Løyning, Y., Nelms, J. D., Wilson, O., Fox, R. H., and Bolstad, A. Journal of Applied Physiology, 1960, 15, 649.
- Baddeley, A. D. A 3-minute reasoning test based on grammatical transformation. Psychonomic Science, 1968, 10, 341-342.
- Balke, B., Cremer, H.D., Kramer, K., and Reichel, H. Klin. Wschr., 1944, 23, 204. (Carlson, L.D., and Hsieh, A.C.L. Cold. In O.G. Edholm and A.L. Bacharach (Eds.), The Physiology of Human Survival. New York: Academic Press, 1965.)
- Belding, D. Chapter in L. H. Newburgh, (Ed.). Physiology of Heat Regulation and the Science of Clothing. New York: Hafner, 1968.
- Black, A.H. The operant conditioning of heart rate in curarized dogs: Some problems of interpretation. Paper presented at the meeting of the Psychonomic Society, St. Louis, October 1966.
- Bligh, J. Temperature Regulation in Mammals and Other Vertebrates. Amsterdam: North-Holland Publishing Company, 1973.
- Bortoluzzi, E., and Montoli, E. Metilfenidato farmacoantibrivido. Minerva Anestesiol., 1961, 27, 22-24.
- Bullard, R.W. Temperature Regulation. In E. E. Selkurt, (Ed.). Physiology. (Third Edition). Boston: Little, Brown and Company, 1971.
- Burton, A.C. Physiology and Biophysics of the Circulation. Chicago: Year Book Medical Publishers, 1972.
- Carlson, L.D., and Hsieh, A.C.L. Cold. In O.G. Edholm and A.L. Bacharach (Eds.), The Physiology of Human Survival. New York: Academic Press, 1965.

- Carlson, L.D., Burns, H.L., Holmes, T.H., and Webb, P.P. Journal of Applied Physiology, 1953, 5, 672. (Carlson, L.D., and Hsieh, A.C.L. Cold. In O. G. Edholm and A. L. Bacharach (Eds.), The Physiology of Human Survival. New York: Academic Press, 1965.)
- Chatonnet, J. and Cabanac, M. The perception of thermal comfort. International Journal of Biometeorology. 1965, 9, (2), 183-193.
- Christie, D. J., and Kotses, H. Bidirectional operant conditioning of cephalic vasomotor response. Journal of Psychosomatic Research, 1973, 17, 167-170.
- Clark, R. E., and Cohen, A. Manual performance as a function of the rate of change in hand skin temperature. Journal of Applied Physiology, 1960, 15, 496-498.
- Clark, R. E., and Jones, C. E. Manual performance during cold exposure as a function of practice level and the thermal conditions of training. Journal of Applied Psychology, 1962, 46, (4), 276-280.
- Crider, A. B., Schwartz, G. E., and Shnidman, S. On the criteria for instrumental autonomic conditioning: A reply to Katkin and Murray. In T. Barber, L. V. DiCara, J. Kamiya, N. Miller, D. Shapiro, and J. Stoyva (eds.) Biofeedback and Self-Control. Chicago: Aldine-Atherton, Inc., 1971.
- DiCara, L. V., and Miller, N. E. Instrumental learning of vasomotor responses by rats: Learning to respond differentially in the two ears. In T. Barber, L. DiCara, J. Kamiya, N. Miller, D. Shapiro, and J. Stoyva (eds.) Biofeedback and Self-Control. Chicago: Aldine-Atherton, Inc., 1971.
- DuBois, E. F., Ebaugh, F. G., and Hardy, J. D. Basal heat production

- Hammel, H. T. Metabolic and thermal response of man to chronic moderate cold exposure. Arctic Aeromedical Laboratories Publication, June, 1960.
- Hardy, J. D. Control of heat loss and heat production in physiologic temperature regulation. Harvey Lectures, 1953-1954, 49, 242-270.
- Hart, J. S., Sabeau, H. B., Hildes, J. A., Depocas, F., Hammel, H. T., Andersen, K. L., Irving, L., and Foy, G. Thermal and metabolic responses of coastal Eskimos during a cold night. Journal of Applied Physiology, 1962, 17, 953.
- Hofeller, K., Wichman, H., and Fahrion, S. Digital vs. analog visual feedback in autogenic training of hand temperature. Paper presented at Western Psychological Association, April 1975.
- Irving, L. Arctic Life of Birds and Mammals Including Man. New York: Springer-Verlag, 1972.
- Katkin, E. S., and Murray, E. N. Instrumental conditioning of autonomic-ally mediated behavior: Theoretical and methodological issues. In T. Barber, L. V. DiCara, J. Kamiya, N. Miller, D. Shapiro, and J. Stoyva (Eds.) Biofeedback and Self-Control. Chicago: Aldine-Atherton, Inc., 1971.
- Keatinge, W. R. Direct effects of temperature on blood vessels: Their role in cold vasodilation. In J. D. Hardy, A. P. Gagge, and J. A. J. Stolwijk (Eds.), Physiological and Behavioral Temperature Regulation. Springfield, Ill: Charles C. Thomas, 1970.
- Lisina, M. E. The role of orientation in the transformation of involuntary reactions into voluntary ones. In L. G. Veronin, A. N. Leontiev, A. R. Luria, E. N. Sokolov, and O. S. Vinograd (Eds.), Orienting

- Reflex and Exploratory Behavior. Washington: American Institute for Biological Science, 1965.
- Lockhart, J. M. Effects of body and hand cooling on complex manual performance. Journal of Applied Psychology, 1966, 50, (1), 57-59.
- MacCanon, D. M., and Eitzman, D. D. Effect of oxygen inhalation on response to cold exposure. Journal of Applied Physiology, 1961, 16, 627-632.
- Mackworth, N. H. Cold acclimatization and finger numbness. Royal Society of London. Proceedings. Series B. Biological Sciences. 1955, 143, 392-407.
- Pugh, L. G. Tolerance to extreme cold at high altitude in a Nepalese pilgrim. Journal of Applied Physiology, 1963, 18, 1234-1238.
- Rennie, D. W. in M. E. Ferrer (Ed.), Cold Injury. New York: Josiah Macy, 1958. (Carlson, L. D., and Hsieh, A. C. L. Cold. In O. G. Edholm and A. L. Bacharach (Eds.), The Physiology of Human Survival. New York: Academic Press, 1965.)
- Roberts, A. H., Kewman, D. G., MacDonald, H. Voluntary control of skin temperature: Unilateral changes using hypnosis and feedback. Biofeedback and Self-Control, Annual for 1973, Chicago: Aldine, 1974.
- Sargent, J. D., Green, E. E., and Walters, E. D. Preliminary report on use of autogenic feedback training in treatment of migraine and tension headaches. Psychosomatic Medicine, 1973, 35, (2), 129-135.
- Scholander, P. F., Hammel, H. T., Andersen, K. L., and Löyning, Y. Metabolic acclimation to cold in man. Journal of Applied Physiology, 1958a, 12, 1-8.
- Scholander, P. F., Hammel, H. T., Hart, J. S., LeMessurier, D. H., and

- Steen, J. Journal of Applied Physiology, 1958b, 12, 211.
- Snyder, C., and Noble, M. Operant conditioning of vasoconstriction. Biofeedback and Self-Control, an Aldine Reader, Chicago: Aldine-Atherton, Inc., 1971.
- Stevens, S. S. Mathematics, measurement, and psychophysics. In S. S. Stevens (Ed.), Handbook of Experimental Psychology, New York: Wiley and Sons, Inc., 1951.
- Stevens, S. S. Psychophysics. New York: John Wiley and Sons, Inc., 1975.
- Teichner, W. H. Manual dexterity in the cold. Journal of Applied Physiology, 1957, 11, (3), 333-338.
- Wickramaskera, Ian E. Temperature feedback for control of migraine. Journal of Behavior Therapy and Experimental Psychiatry, 1973, 4, 343-345.
- Winslow, C. E. A., and Herrington, L. F. Temperature and Human Life. Princeton, N. J.: Princeton University Press, 1949.
- Winslow, C. E. A., Herrington, L. P., and Gagge, A. P. Physiological reactions of the human body to varying environmental temperature. American Journal of Physiology, 1937a, 120, 1-20.
- Winslow, C. E. A., Herrington, L. P., and Gagge, A. P. Relations between atmospheric conditions, physiological reactions and sensations of pleasantness. American Journal of Hygiene, 1937b, 26, 103-115.

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Title of Thesis

VOLUNTARY INCREASES IN DIGITAL SKIN TEMPERATURE
DURING A MILD COLD EXPOSURE

Author



Signature

Johnnye Lynn Lewis

Name

May 6, 1976

Date