Effects of Garment Weight on Arm Movement Speed, Heart Rate, and Perceived Exertion: A Pilot Study

by

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Abstract

Many workers routinely wear personal protective clothing (PPC). This protection may compromise work performance by promoting heat stress, increasing the energy expenditure demands of the job, and inhibiting movement. This pilot study investigated the effects of garment weight on gross arm movement. Five male subjects performed a reciprocal target touching task and a cranking task while wearing a light Tyvek™ shirt, a heavy fire fighter turnout coat, and two sets of weights equivalent in mass and distribution to the shirt and the coat. Trial durations were less than three minutes to preclude perspiration and heat stress artifacts. Movement time, cranking speed, heart rate response, and psychophysical response data were collected. Minimal garment and weight effects were found on objective measures of movement time (increased, $p < .15$), cranking speed (decreased, $p < .10$) and heart rate for the target touching task (increased, $p < .15$). Garment weight did significantly ($p < .05$) affect subjective ratings of perceived exertion and increased difficulty.

Relevance to Industry

This pilot study addresses the question of whether garment weight affects a worker's performance capability for short duration tasks requiring rapid arm movements. Worker's wearing protective clothing may frequently make such movements during emergency situations and during normal task performance. A methodology for assessing gross arm movement performance is presented.

Keywords

protective clothing, performance measurement, fire fighters, mobility, comfort, arm movement

Introduction

Many American workers routinely wear some form of protective clothing on the job. Such clothing ranges from simple coveralls to gas-tight hazardous material (HAZMAT) protective suits, from gloves made of cotton to coats of Tyvek™[1], Saranex™[2], Nomex™[3], and other exotic fabrics. Most personal protective clothing (PPC) is designed to protect the worker from environmental hazards. This protection may compromise work performance and comfort, however. Common complaints include increased heat stress, loss of mobility, reduced dexterity/tactility, and general discomfort (Battelle Columbus Division, 1988; Rosenblad-Wallin, 1981).

Much of the ergonomic research performed to date on protective clothing has focused on alleviating heat stress. Table 1 lists some examples of this work.

(Insert Table 1 here.)

Relatively few studies have sought to identify those garment parameters which contribute to heat

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[1]Tyvek is a registered trademark of E.I. duPont de Nemours & Co.
[2]Saranex is a registered trademark of Dow Chemical Co.
[3]Nomex is a registered trademark of E.I. duPont de Nemours & Co.

generation. Huck and McCullough (1988) demonstrated that use of self-contained breathing apparatus (SCBA) significantly increased energy expenditure and heart rate for fire fighters wearing various clothing designs. They also demonstrated that subjects were able to discriminate among different configurations of turnout clothing with regard to thermal sensation. Using a set of treadmill tests, Doerr (1988) concluded that "the imposition of a whole body suit, such as the PHE (propellant handler's ensemble), can result in significant physiologic work on the user due to the protective system alone." Based on these findings, it is reasonable to suspect that clothing weight, friction, stiffness and other mechanical factors restrict movement and contribute to heat generation and increased metabolic expenditure.

Protective clothing has also been shown to adversely affect task performance. Huck (1988) demonstrated reduced mobility, i.e. range-of-motion, for fire fighters wearing turnout ensembles. She also found a small, but statistically significant, change in upper body mobility among different coat designs. Several other studies have also demonstrated reductions in range-of-motion associated with various types of protective clothing (Saul and Jaffe, 1955; Nicoloff, 1957; Alexander and

Laubach, 1973; Bachrach and Egstrom, 1974; Alexander et al., 1979; Gregoire et al., 1985; Bensel et al., 1987).

Numerous researchers have shown degradation in the performance of specific tasks when subjects wore protective ensembles. Some of these studies are listed in Table 2.

(Insert Table 2 here.)

While it is clear that protective clothing can, and often does, inhibit task performance, it remains to be determined which garment attributes contribute to these performance decrements (e.g. friction, stiffness, bulk, weight, fit, etc.). Further, the quantitative relationships among garment attributes and performance are poorly understood. The potential benefits to garment designers and users of knowing the relative importance of these attributes include: a better understanding of which garment characteristics are most likely to impair motor performance and increase heat generation, improved productivity through better fabric selection and garment design, and more accurate prediction of worker performance capabilities stemming from knowledge of expected impediments.

The purpose of this study was to determine if a single attribute, garment weight, affects performance during arm movement tasks. Most work tasks require the use of the hands and therefore involve arm movements. Garment weight on the lower extremities has been shown to affect performance on a treadmill walking task (Legg and Mahanty, 1986; Jones et al., 1984) , but we are unaware of any studies with comparable findings for arm movements. A major objective of this study was to isolate weight effects from other garment effects, such as friction and stiffness. A task requiring various levels of movement accuracy was used to determine the effect of garment weight on arm movement speed. The study also sought to determine if garment weight was related to performance on a submaximal cranking task. In addition to task performance, the effect of garment weight on heart rate and perceived exertion was evaluated.

Method

Five subjects, described below, performed two different tasks while wearing each of five garment conditions. A reciprocal target touching task was developed using a paradigm similar to that introduced by Fitts (1954). It required subjects to alternately touch targets with a wand at maximal speed with minimal misses. This task was designed to simulate motions that might be used by a fire fighter raking plaster, by a farmer applying pesticides with a wand, or by a construction worker removing asbestos. The second exercise was a cranking task in which subjects rotated a handle on a hand ergometer at a pace they felt was "moderate but comfortable".

Variables of Interest and Experimental Designs

Table 3 lists the variables of interest for both tasks.

(Insert Table 3 here.)

A repeated measures experimental design with blocking on subject was used to eliminate subject effects (Neter et al., 1985). A diagram of this design used for the reciprocal target touching task is shown in Figure 1.

(Insert Figure 1 here.)

Pre-pilot testing revealed that motor learning and fatigue effects introduced significant error for the cranking task when a repeated measures design was applied. A special experimental design was developed to offset these effects. Following three control condition trials (i.e. no garment, no weight), subjects performed eight trials, alternating between treatment conditions and the semi-nude control condition. Data from the first two trials were discarded to reduce learning effects. This design is illustrated in Figure 2.

(Insert Figure 2 here.)

Dependent Variables

Movement time and Crank rate. Performance measurements included mean move time for each target touching trial and degrees of rotation for each two-minute cranking trial. The time between leaving one target and touching the next constituted a single move time. Move times were averaged within each trial. For the cranking task, the total degrees of rotation were recorded for 120 seconds to measure work rate.

Heart rate. Beginning and ending heart rates were recorded for each trial, with the difference being used as a measure of physiological stress.

Borg's Rating of Perceived Exertion. The third set of dependent measures included subjective ratings of perceived exertion (Borg, 1982) and a rating of increased difficulty. Subjects completed feedback forms (see Appendix) to obtain these ratings after each target touching trial and after each treatment trial for the cranking task. The

Borg rating of perceived exertion (RPE) required the subject to circle a number on a scale from 0 to 10.

Visual analog rating of increased difficulty. Visual analog scales have been shown to effectively measure pain and work comfort (Scott and Huskisson, 1976; Price et al., 1983; Ulin et al., 1990). In this study, subjects were presented with a ten centimeter line with the verbal anchors "not at all" and "made task nearly impossible" at either end. They were asked to place a mark on the line to indicate how much the garment increased the difficulty of the task. The distance of the mark from the "not at all" end was taken as a measure of increased difficulty due to the experimental conditions.

Independent Variables

Garments. Five garment treatments were used: light weight set (LW), light garment (LG), heavy weight set (HW), heavy garment (HG), and semi-nude control (C). The purpose for using the light and heavy weight sets was to place the same amount of weight on the subjects' arms and torso as the light and heavy garments provided, but without introducing other restrictive effects inherent within garments. The weight sets left the joints exposed, minimizing the pulling, stretching, hobbling, or sliding that normally occurs during arm movement (Kirk and Ibrahim, 1966; Watkins, 1984).

Two garments were selected which represented both ends of the weight spectrum for commonly used upper body protective garments: a long sleeved, size Large, Tyvek shirt and a traditional 89 cm (35 in) length fire fighter turnout coat, size medium. The single layer Tyvek shirt had set-in sleeves and weighed 63.5g (0.14 lb). The turnout coat consisted of a Nomex aramid outer shell and a thermal liner, composed of a moisture barrier bonded to Nomex and a Nomex batt quilted to a Nomex face cloth. It also had set-in sleeves and weighed 2.744 kg (6.05 lb). Both garments were designed to be worn over normal work uniforms. Each garment was weighed in sections corresponding to the upper arm, lower arm and torso, as well as complete units. The weights for each section are shown in Table 4.

(Insert Table 4 here.)

Two sets of comparable weights were made which were equal in mass to the weights presented in Table 4. Sleeve weights were fabricated from elasticized cloth wraps, with pockets containing lead shot attached to the heavier set. Sleeve weights were held in position on the subjects' arms by placing a thin layer of foam gauze between the skin and the weight fabric and securing with velcro. This enabled repeated application of weights on each subject without the use of adhesives. Torso weights were fabricated from a shortened tank top shirt and from a winter weight sporting vest. Lead shot was added to the latter vest in front and back pockets to achieve a weight distribution similar to the turnout coat. When worn by a subject, each set of equivalent weights (two lower arm weights, two upper arm weights and a vest) applied essentially the same weight as either the Tyvek shirt or the turnout coat, but with minimal restriction due to friction, bulk, stiffness and other mechanical factors associated with the comparable garment.

Target size. Three sets of targets were used for the target touching task. Fitts' Index of Difficulty,

$$ID=\log_2[2A/W]$$

(where A=distance between targets and W=target width) for the small, medium and large sized targets was approximately 7.58, 6.17 and 4.58, respectively. The reason for using targets of different sizes was to determine whether heavy garments affected relatively precise motions more than movements requiring less precision.

Subjects. Five healthy male students, aged 18 to 30, were recruited. Anthropometric measurements confirmed that all subjects were within the size range specified by the manufacturers for appropriate fit of the garments. Table 5 contains descriptive statistics for the subject pool.

Controlled Variables

Skin friction. Short trial durations were used to minimize any sweating, since moisture can result in increased friction between skin and cloth (Gwosdow et al., 1986). A measurement of skin friction using a strip of either Tyvek or Nomex lining material and a method similar to that described by Gwosdow et al. (1986), was performed immediately before and after each trial in which either test garment was worn. No measurable differences in skin friction were observed for any of the Tyvek shirt trials, and rarely for any of the turnout coat trials. The few changes that were detected for the latter treatment were slight and were assumed to be inconsequential.

Garment parameters. As described in the garment section above, both of the selected test garments had set-in sleeves.

Both the Tyvek™ and Nomex™ fabrics exhibited relatively low stretch/high power characteristics.

Fit and subject anthropometry. To ensure appropriate fit, care was taken to recruit only those subjects with anthropometries that fell within the manufacturers' sizing guidelines for both test garments.

Apparatus/Equipment

The apparatus for the target touching task is shown in Figure 3. Conductive brass discs were inlaid into squares of plywood and electrically connected to the printer port of an Acer (IBM compatible) 286 computer. Targets were ringed with a wide, dark blue background to enhance contrast. A test wand was constructed from aluminum tubing and electrically connected to the computer. The bend in the stylus allowed the subject to see the stylus tip at all times. A computer monitored the elapsed time whenever the stylus either touched or left a target, and recorded movement times between targets. One target was mounted with a vertical orientation on the target stand the other was placed in a horizontal orientation above the floor as shown. Both targets were in the subject's sagittal plane.

(Insert Figure 3 here.)

The second task utilized the device shown in Figure 4: a Baltimore Therapeutic Equipment Co. Work Simulator configured as a hand ergometer. The subjects performed a two-handed cranking motion with the axis of rotation adjusted to the subject's armscye (armpit) height. A constant resistance of 0.35 kg-m (30 in-lbs) was set to prevent the sensation of free-wheeling. Degrees of rotation and exercise duration were automatically recorded.

(Insert Figure 4 here.)

Heart rate was monitored throughout the experiment by a Polar Vantage XL™ Heart Rate Monitor. This system used an elasticized chest strap with surface electrodes and transmitter to relay the ECG signal to a receiver held by the researcher. No wires or adhesives were used, minimizing interference with movements. Displayed heart rates were averaged over 15 second intervals, with updating every five seconds. This system was also used to ensure rest periods between trials allowed recovery to baseline levels.

Procedures

Subjects practiced the target touching task immediately prior to data collection. During the practice session, subjects were allowed to select the most comfortable hand and foot locations on the wand and floor, respectively. These positions were marked and the subject was instructed to maintain these placements throughout each trial.

Each subject then performed one trial for each combination of garment (light weights, light garment, heavy weights, heavy garment, and control) and target size (small, medium and large) for a total of 15 trials. Trial sequence was randomized. Each trial consisted of 55 cycles, wherein moving the stylus from the top target to the bottom target and back to the top constituted one cycle. Data from the first five cycles was discarded to reduce any learning effects. Subjects were instructed to go as fast as possible without missing targets. The computer beeped following each cycle in which a target was missed and displayed the percentage of targets missed. If the miss percentage exceeded 10% the experimenter verbally encouraged the subject to hit the targets. Miss rates did not exceed 15% for any subject on any trial.

For the cranking task, a brief set of practice trials was performed until the subject felt comfortable with the task. Subjects were asked to turn the crank at "a moderate but comfortable pace" for eleven two minute trials. The first three trials were always performed in the control condition, i.e. no upper body garment. Trials 4,6,8 and 10 were performed under the four treatment conditions, with the sequence randomized. Odd numbered trials 5 through 11 were performed in the control condition.

Data Analysis

Data analysis and statistical testing were performed using the SYSTAT™ software package, Version 3.0 (Wilkinson, 1987) on a Zenith Z-286 (IBM compatible) microcomputer. Movement time data from the target touching task were analyzed using analysis of variance (ANOVA) for the repeated measures design with blocking on subject, thereby excluding errors from variability between subjects (Neter et al., 1985). Garment treatment effects were also analyzed using paired t-testing of the movement time data averaged across target sizes.

Analysis of the cranking task performance data was performed using ANOVA contrasts between treatment values and control results from adjacent trials, with subjects being a blocking variable. (For example, data from the first treatment trial, #4, were compared to the means of the values from trials #3 and #5.) This experimental design minimized the errors associated with motor learning and fatigue.

Heart rate data were analyzed in the same manner as the objective performance data.

Subjective responses, i.e. ratings of perceived exertion and ratings of increased difficulty, were analyzed using both ANOVA and the nonparametric Kruskal-Wallis test (Neter et al., 1985; Lehmann, 1975) with subject used as a blocking variable.

Results

Performance Effects

Figure 5 presents results for movement times in the target touching task. Movement time was clearly a function of target size ($p<0.001$). Neither garment weight nor garment type had a significant effect on movement time, with the possible exception the heavy garment treatment. The contrasts between the heavy weight (HW) and heavy garment (HG) times, and between the control (C) and heavy weight conditions were marginally significant ($p=0.141$ and $p=0.046$ respectively; means in seconds: C = 0.956, HW = 0.982, HG = 1.033). Small target movement times tended to be longer while wearing the turnout coat than for the other garment conditions. This effect was not apparent for the larger targets.

(Insert Figure 5 here.)

Results of cranking trials are presented in Table 6. Cranking speed was not significantly affected by any of treatment conditions, with one exception. The cranking rates when wearing the heavy turnout coat tended to be slower than those for the adjacent control conditions ($p=0.091$; means in 100 deg/min: C_{HG} = 252, HG = 236).

(Insert Table 6 here.)

Change in Heart Rate

Results of heart rate analysis are presented in Figure 6 and Table 7. Heart rate in the target touching task increased with target size ($p<0.001$). Garment weight and garment type effects were minimal and generally not significant for either the target touching or cranking tasks.

(Insert Figure 6 here.)

(Insert Table 7 here.)

Rating of Perceived Exertion

Table 8 and Figure 7 summarize the rating of perceived exertion data for the target touching task. Target size effects on the subjective rating of perceived exertion were not significant. Garment weight and type were significant however, for the target touching task ($p=0.003$). The Kruskal-Wallis analysis supported this result. Analysis of the full model ANOVA contrasts suggests garment weight was responsible for most of this effect. Figure 7 indicates perceived exertion increased with garment weight. The effect of light vs. heavy conditions was significant ($p=0.044$; means in sec.: light = 1.2, heavy = 2.5). However, contrasts between treatments with similar weights, i.e. LW vs. LG and HW vs. HG, indicated no significant effect for garment parameters other than weight ($p=1.000$ and $p=0.465$, respectively).

(Insert Table 8 here.)

(Insert Figure 7 here.)

Table 9 and Figure 8 summarize the rating of perceived exertion data for the cranking task. These data were collected for the four treatment conditions of the cranking task, but not for the control conditions. Analysis of variance indicated a marginally significant garment effect ($p=0.049$). This effect was only evident in the contrast between the Tyvek™ shirt and the turnout coat however ($p=0.097$; mean ratings: LG = 1.9, HG = 3.0), and not in any of the other contrasts in Table 9. Figure 8 shows ratings of perceived exertion for the heavy garment condition tended to be higher for the cranking task than the other treatments. The Kruskal-Wallis analysis found no significant effect.

(Insert Table 9 here.)

(Insert Figure 8 here.)

Rating of Increased Difficulty

Subject ratings for the amount that test garments increased the task difficulty are summarized in Figures 9 and 10 and Table 10. Ratings of increased difficulty closely followed the ratings of perceived exertion. Target size was not a significant factor (p=0.419), but garment weight and garment type were significant (p=0.001). Analysis of the contrast Light vs. Heavy (Figure 9) indicates that weight contributed significantly to task difficulty, with other garment factors contributing little, if any. Wearing heavy weights or heavy garments increased the perceived difficulty of the target touching task. Very similar results were found for ratings of increased difficulty in the cranking task (Table 10 and Figure 10). All of these findings were consistent with the results of the Kruskal-Wallis analysis.

(Insert Figure 9 here.)

(Insert Table 10 here.)

(Insert Figure 10 here.)

Discussion

Only five subjects participated in this pilot study. To achieve the desired 95% confidence level, an additional eighteen subjects would be needed.

The small number of subjects results in significance levels which may be misleading, as well as inaccurate mean estimates. It is likely that some of the effects which were marginally significant or not significant, may be found to be significant with a larger sample size. Inaccuracy of mean estimates masks trends that would otherwise be evident when the data are plotted. Conclusions drawn from the data should therefore be considered tentative.

Effects on Performance

The fact that movement time between targets for a reciprocal tapping task varies inversely with the target size is well established (Fitts, 1954). The purpose of this experiment was to quantify garment weight effects on movement time. The results of this experiment suggest that garment weight may increase movement time and reduce arm movement efficiency, but the significance of these effects is marginal for short duration tasks. Little evidence was found to suggest that other garment factors play a significant role in reducing movement speed, although they may have a minor affect when the garments are very heavy. With heavy garments, it is likely that any performance decrement results from increased stiffness, bulk, and friction, as well as weight. The effects of loose fitting light garments on movement appear to be negligible.

Cranking task performance showed little effect from the garment treatments, although the heavy turnout coat did result in a slight reduction in cranking speed. Since the cranking task required less than a maximal effort on the part of the subject, it is perhaps indicative of an actual work pace that one might expect. The findings from this experiment suggest that heavy garments may result in a worker reducing his work rate voluntarily, but any reduction will probably be minimal for very short tasks, assuming the worker is well motivated.

Heart Rate Effects

Target size was the most significant factor for the target touching heart rate data. This is understandable when one considers that as target size increases, the Index of Difficulty decreases and arm movement speed increases. Touching the small targets required precise motor skill. This meant that much of the task was performed using relatively small muscle groups while the larger muscle groups maintained the somewhat static postures necessary for accurate positioning. Although heart rate increases abruptly with sustained isometric efforts greater than 15 percent of the maximal voluntary contraction (Astrand and Rodahl, 1986), it is unlikely that any of the muscular contractions involved in this exercise approached that level. Touching the larger targets required very little positioning and was essentially a rapid, gross movement exercise involving large muscle groups. A substantial increase in heart rate would be expected for this task since the larger the muscle mass involved, the greater the heart rate response will be (Astrand and Rodahl, 1986).

It is reasonable to assume that a heavy garment will also add to the cardiac load for the target touching task, since movement would involve moving more mass and greater muscular contraction. Significant weight effects on heart rate were not found however. This may be a consequence of the short trial durations, since heart rate may not stabilize in the first two minutes of exercise (Astrand and Rodahl, 1986). Perhaps the additional strain on the body from garment weight was so small that heart rate was not sensitive enough to provide a measurable response. The ANOVA results do suggest however, that a slight garment effect may result, stemming from a combination of factors including garment weight. We suspect the added stiffness, bulk, and friction associated with the heavier garment mechanically resists movement more than those presented by the Tyvek shirt or the set of heavy weights.

Since the cranking task was performed submaximally at a pace chosen by the subject, he essentially had to make a trade-off decision during each treatment trial. If the garment or weight set being worn did not affect his performance or heart rate, then he would simply work at the same pace for the treatment condition as for the control trial just finished. If the treatment did affect him, then he would have to subconsciously decide whether to increase his heart rate to maintain task performance, or sacrifice performance to maintain an acceptable level of physiological stress. The data suggests subjects chose the latter strategy. This is probably consistent with actual work situations where workers choose their own pace.

It is well known that heart rate increases with heat stress (Astrand and Rodahl, 1986). Part of the increase in heart rate experienced when wearing the turnout coat may have resulted from physiological stresses not directly associated with task performance. The short trial durations were specifically designed to minimize these effects. The goal was to eliminate changes in skin friction caused by sweating as well as increases in heart rate resulting from heat imbalance. Whether or not these objectives were fully met is not clear, although verbal questioning of the subjects, observation, and skin friction testing all indicated sweating was indeed very minimal. The few reports of hot sensations that were received were nearly always described as "just beginning". We therefore concluded that any effects of heat stress on heart rate were probably negligible.

Psychophysical Measures

The subjective ratings of perceived exertion and increased difficulty were well correlated. Both measures were strongly affected by garment weight, but not by other garment factors. Evidently the subjects felt any hindrance due to friction, stiffness, or other factors were minor or non-existent compared to that imposed by garment weight.

Target size did not significantly effect either set of subjective ratings. Subjects did not distinguish a difference in perceived exertion between touching the small targets which necessitated a slower pace, and the fast touching of the large targets. All subjects reported low exertion for both target conditions, despite being asked to perform the task as quickly as possible.

Certainly garment weight and the rating of increased difficulty were positively correlated.

There was poor correlation however between the objective and subjective measures. Heart rate changes did not always increase, nor performance decrease, even though subjects reported higher perceptions of exertion or increased difficulty due to the treatment. This result suggests that for gross arm movement tasks of short duration, performance may not actually be compromised by a garment, despite the worker's perception that the garment weight is making the task more difficult.

Directions for Future Research

Several research areas need development, in addition to completing this study with more subjects. A similar study using much longer trials is needed to better understand the effect of garment weight on heart rate. This would also improve the transferability of the results to actual work tasks. Several other garment parameters should also be isolated and their effects on task performance studied, specifically friction, bulk, stiffness, stretch, fit and style. Work tasks vary greatly in their movement demands. Before an accurate model can be developed for predicting the effects protective clothing will have on a worker's performance, the effects that each of the above garment parameters have on a wide variety of movements will need to be quantified.

Aside from the specific issues of protective clothing research, the relationship between objective and subjective measures should be investigated to ensure that relevant measures are being used in studies dealing with protective garments. Finally, the experimental paradigm developed in this study for submaximal tasks should be validated.

Conclusions

This pilot study dealt only with gross arm movements as affected by the weight of upper body garments. All trials were necessarily of short duration to minimize sweating. Minimal garment and weight effects were found on objective measures of movement time, cranking speed and heart rate. Garment weight did significantly affect subjective ratings of perceived exertion and increased difficulty. Effects of other garment parameters on performance were not significant. The apparent lack of significant garment effects may have resulted in part from the small number of subjects.

An experimental paradigm was developed for submaximal testing which successfully reduced intertrial noise. Several areas were also identified for additional research.

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Table 1: Examples of studies on heat stress and protective clothing.

Topic	Studies
Human thermoregulatory response	Rodahl and Guthe, 1988 Astrand and Rodahl, 1986 Parsons, 1988 Nunneley, 1986
Tolerance times	Van de Linde and Lotens, 1981 Konz et al., 1981 Lotens, 1986 Pandolf et al., 1987 Fine, 1987
Heat transfer and measurement	Rodahl and Guthe, 1988 Holmer, 1988 Lotens, 1986 Kimball, 1983 Fine, 1987 Tharion et al., 1986 Konz et al., 1981
Sweat evaporation	Nunneley, 1986 Doerr, 1988 Ross and Clark, 1988 Pandolf et al., 1989 Veghte and Annis, 1989 Holmer, 1988
Artificial cooling techniques	Allan, 1988 Crockford, 1988 Proctor, 1988 Featherstone, 1988 Garwood, 1988 Richardson et al., 1988 Pandolf et al., 1987

Table 2: Examples of Protective Clothing Studies on Task Performance

Study	Task or Work
Alexander and Laubach, 1973	Piloting USAF aircraft
Bachrach and Egstrom, 1974	Underwater maintenance
Dunlap and Assoc. et al., 1965a	Infantry maneuverability
Dunlap and Assoc. et al., 1965b	Digging foxholes
Harris, 1985	Military maintenance
Johnson and Sleeper, 1986	Purdue Pegboard Test
Kelly et al., 1987	Computerized tasks
King and Frelin, 1982	Basic medical tasks
King and Frelin, 1984	Basic medical tasks
Veghte, 1988	Simulated HAZMAT task
Waugh and Kilduff, 1984	Missle component repair
Wick et al., 1984	Military maintenance

Table 3: Experimental Variables

Dependent Variables

Objective Measures:
- Movement time (target task)
- Crank rate (cranking task)
- Heart rate change

Subjective Measures:
- Rating of Perceived Exertion (Borg 10 point scale)
- Rating of Increased Difficulty (Visual analog scale)

Independent Variables
- Target size (3 levels)
- Garment/Weight (5 levels)
- Subject

"Controlled" Variables
- Skin friction (sweating)
- Sleeve Style (set-in)
- Stretch (assumed to be negligible)
- Fit (garments were appropriately sized for each subject)
- Cranking task resistance
- Subject anthropometry

Table 4: Weights of garment sections

Section	Tyvek Shirt	Turnout Coat
Lower arm (each)	4.5g (0.01 lb)	209g (0.46 lb)
Upper arm (each)	7.3g (0.02 lb)	238g (0.52 lb)
Torso	40.4g (0.09 lb)	1,787g (3.94 lb)
Total garment	63.5g (0.14 lb)*	2,744g (6.05 lb)*

* Discrepancy between sum of section weights and total garment weight is due to 2.5% measurement error and rounding.

Table 5: Descriptive Statistics for the Subject Pool

Dimension	Mean	S.D.	Range
Age (yrs)	25.8	4.12	18 - 30
Height (cm)	176	5.87	166.5 - 183.5
Weight (kg)	76.2	4.56	69.6 - 83.6
Lengths (cm):			
Wrist to Elbow*	27.4	1.07	26 - 29
Elbow to Shoulder	35.5	1.61	33 - 37.5
Wrist to Shoulder (elbow extended)	58.1	1.80	56 - 61
Wrist to Shoulder (elbow flexed)	63.4	2.40	61 - 67.5
Shoulder to Neck	17.3	0.68	16 - 18
Shirt sleeve size	82.9	2.50	79 - 86
Shoulder width (back)	47.7	1.60	45 - 49.5
Neck to Waist (back)	50.6	0.80	49 - 51
Neck to Waist (front)	47.6	1.39	45 - 49
Girths (cm):			
Wrist	17.4	0.49	16.5 - 18
Forearm	28.6	0.58	28 - 29.5
Upper arm	33.5	1.70	31.5 - 36.5
Elbow (extended)	26.9	0.37	26.5 - 27.5
Elbow (flexed)	31.4	0.86	30 - 32.5
Shoulder	49.1	2.84	44 - 52
Neck	38.3	2.18	35 - 41.5
Both Shoulders	110.8	2.77	108.5 - 116
Upper Chest	101.1	3.09	96.5 - 105.5
Mid Chest	97.9	2.65	94 - 102
Lower Chest	90.7	2.68	87 - 95
Abdomen	84.6	4.77	77 - 90
Waist	85	3.52	79 - 89
Hips	102.1	5.83	93 - 111

Table 6: ANOVA Results for Cranking Task Performance

Contrast:	F	p-Value	Rotation/minute (100 deg/min)
C vs. LW	1.953	0.235	C_{LW} = 248 LW = 241
C vs. LG	0.734	0.440	C_{LG} = 253 LG = 249
C vs. HW	1.514	0.286	C_{HW} = 255 HW = 235
C vs. HG	4.927	0.091	C_{HG} = 252 HG = 236

(Note: Cranking task treatment trials were only compared to their adjacent control trials. For further explanation, see the Experimental Design and Data Analysis sections above.)

Table 7: ANOVA Results for Cranking Task Heart Rate

Contrast	F	p-Value	Contrast Means:	
C vs. LW	2.539	0.186	C_{LW} = 22.5	LW = 26.0
C vs. LG	0.003	0.958	C_{LG} = 29.7	LG = 29.8
C vs. HW	0.117	0.749	C_{HW} = 24.7	HW = 26.8
C vs. HG	0.001	0.972	C_{HG} = 28.5	HG = 28.4

(Note: Cranking task treatment trials were only compared to their adjacent control trials. For further explanation, see the Experimental Design and Data Analysis sections above.)

Table 8: Repeated Measures ANOVA Results for Target Touching Rating of Perceived Exertion

Independent Variables: target size, garment weight + garment type (Full Model)
[C=control, LW=light weights, LG=light garment, HW=heavy weights, HG=heavy garment]

Effects	F	p-Value
Target size	0.332	0.730
Weight + Type	7.251	0.003
Interaction	2.527	0.038

Contrasts:	F	p-Value	Contrast Means:	
LG vs. HG	41.286	0.008	LG = 1.2	HG = 2.6
C vs. HG	20.163	0.021	C = 1.2	HG = 2.6
C vs. LG	0.000	1.000	C = 1.2	LG = 1.2
LW vs. HW	3.533	0.157	LW = 1.2	HW = 2.3
C vs. HW	6.303	0.087	C = 1.2	HW = 2.3
C vs. LW	0.000	1.000	C = 1.2	LW = 1.2
LW vs. LG	0.000	1.000	LW = 1.2	LG = 1.2
HW vs. HG	0.697	0.465	HW = 2.3	HG = 2.6
Weights vs. Garments	0.754	0.449	Weights = 1.8	Garments = 2.1
Light vs. Heavy	11.310	0.044	Light = 1.2	Heavy = 2.5

(Note: One case was deleted due to missing data.)

Table 9: Repeated Measures ANOVA Results for Cranking Task Ratings of Perceived Exertion

(ANOVA performed across four garment types, control condition excluded.)

Effect	F	p-Value		
Garment	3.524	0.049		
Contrasts:			**Contrast Means:**	
LW vs. LG	.0167	0.704	LW = 1.8	LG = 1.9
HW vs. HG	2.250	0.208	HW = 2.4	HG = 3.0
LW vs. HW	2.250	0.208	LW = 1.8	HW = 2.4
LG vs. HG	4.654	0.097	LG = 1.9	HG = 3.0

Table 10: Repeated Measures ANOVA Results for Cranking Task Rating of Increased Difficulty

(ANOVA performed across four garment types, control condition excluded.)

Effect	F	p-Value		
Garment	7.058	0.005		
Contrasts:			**Contrast Means:**	
LW vs. LG	0.351	0.585	LW = 0.7	LG = 0.5
HW vs. HG	0.305	0.610	HW = 3.4	HG = 3.7
LW vs. HW	5.747	0.075	LW = 0.7	HW = 3.4
LG vs. HG	9.032	0.040	LG = 0.5	HG = 3.7

GARMENT

TASK CONDITION	No Garment (Control)	Light Weight Wt. #1	Light Weight Garment	Heavy Weight Wt. #2	Heavy Weight Garment
Fitts' Task Small Target					
Fitts' Task Medium Target					
Fitts' Task Large Target					

<u>Dependent Variables</u>

Heart Rate
Subjective Rating
Fitts' Mean Movement Time

Figure 1: Experimental design for Target Touching Task

Condition	Control	Control	Control	Treatment #1	Control
Trial #	1	2	3	4	5

Treatment #2	Control	Treatment #3	Control	Treatment #4	Control
6	7	8	9	10	11

<u>Dependent Variables</u>

Heart Rate
Subjective Rating
Cranking Speed (degrees of rotation/min)

Figure 2: Experiment Design for Cranking Task

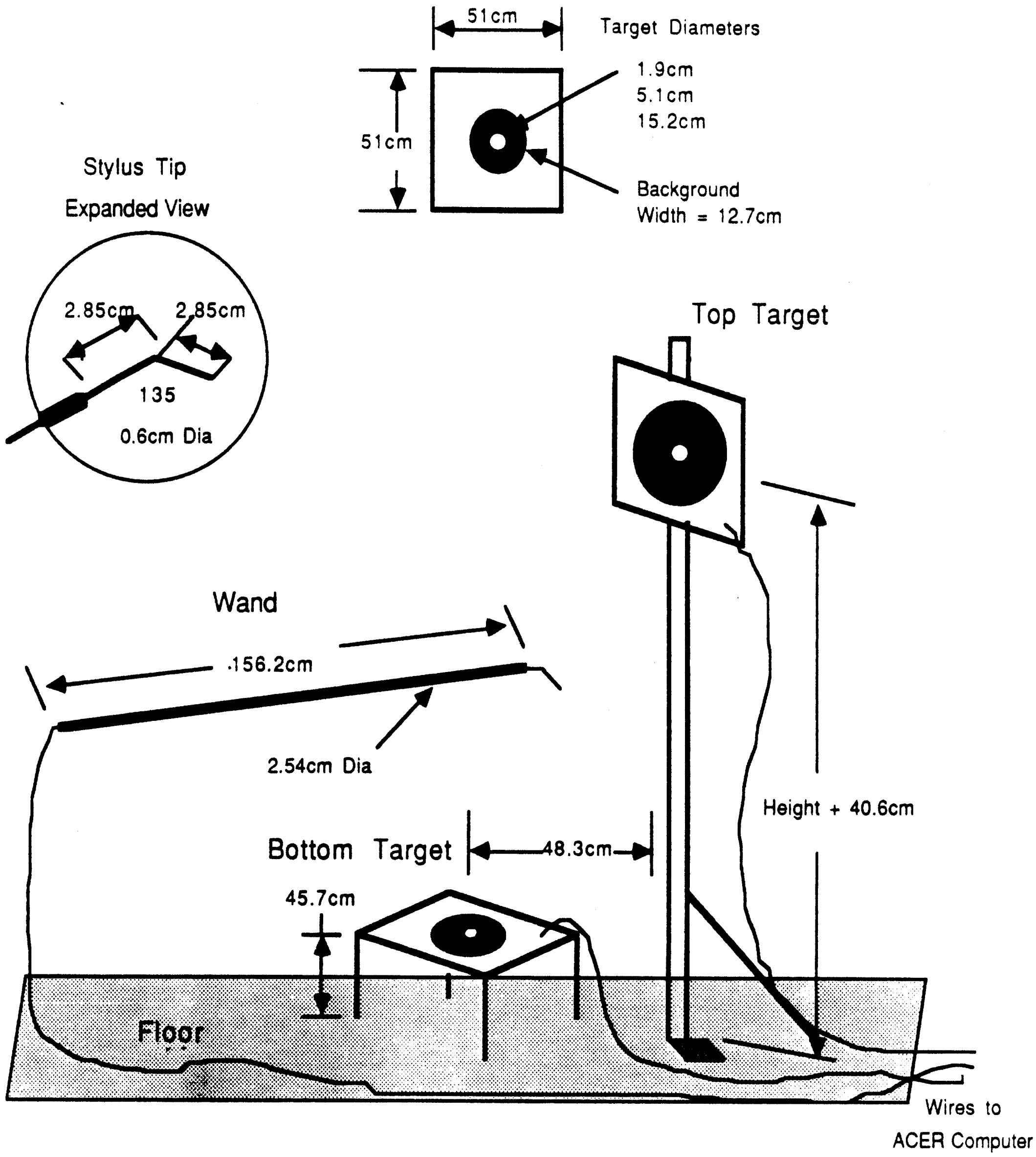


Figure 3: Apparatus for Target Touching Task (Not to Scale)

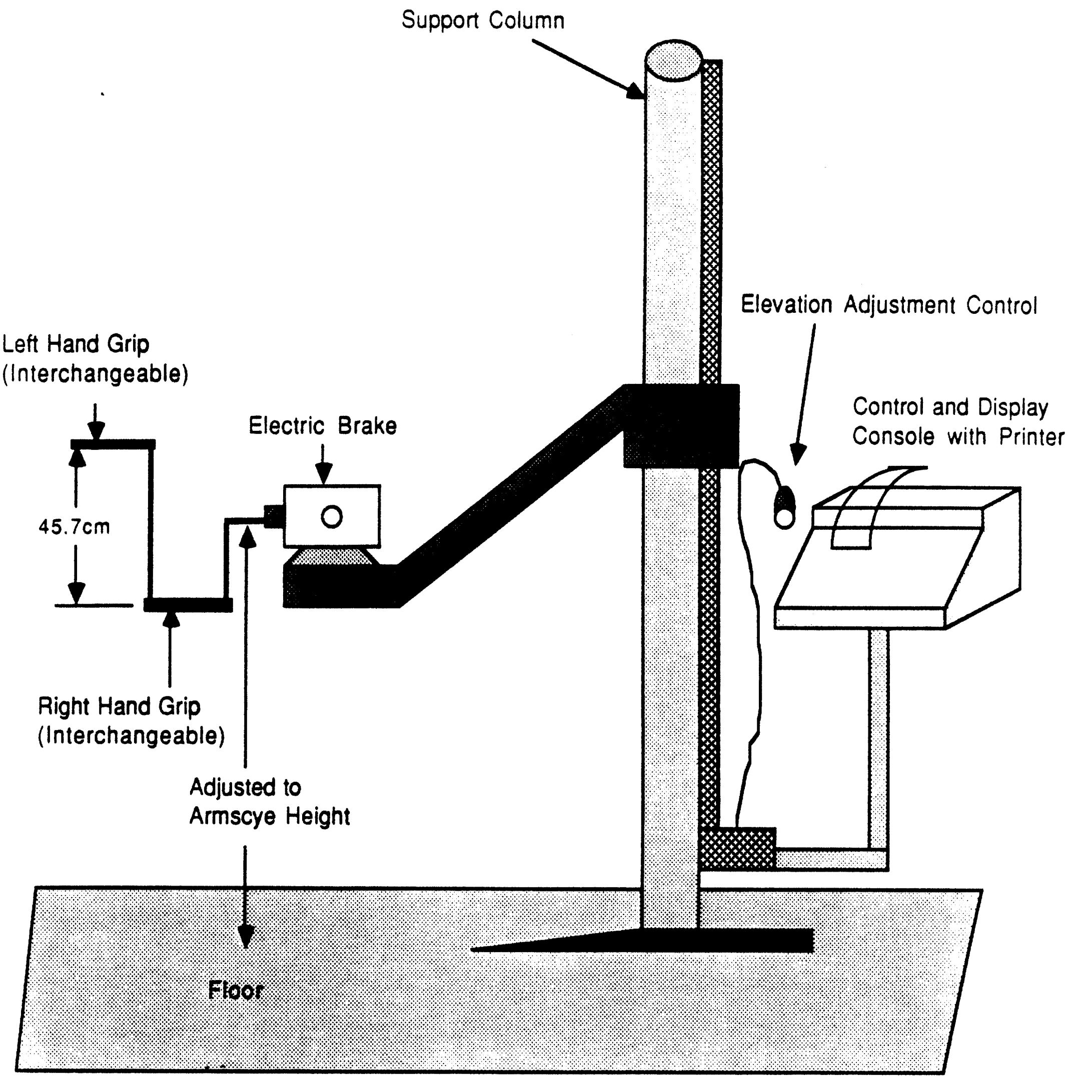


Figure 4: Baltimore Therapeutic Equipment Co. Work Simulator used for Cranking Task (Not to Scale)

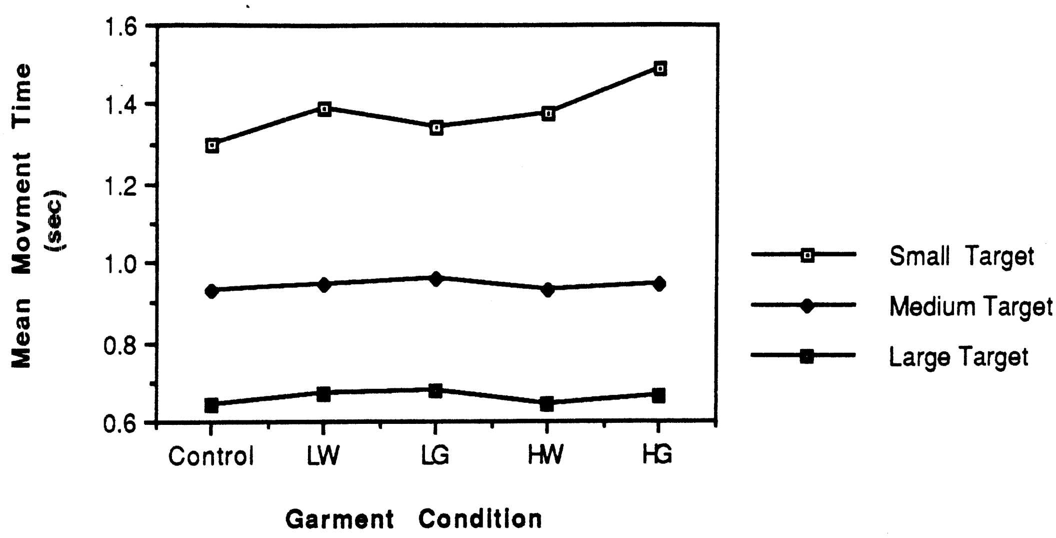


Figure 5: Mean Move Times for each Garment Condition by Target Size

(ANOVA results for main effects and selected contrasts. Target size: $p<0.001$, Weight + Type: $p=0.448$, Interaction: $p=0.405$; C vs. HG: $p=0.141$, HW vs. HG: $p=0.046$)

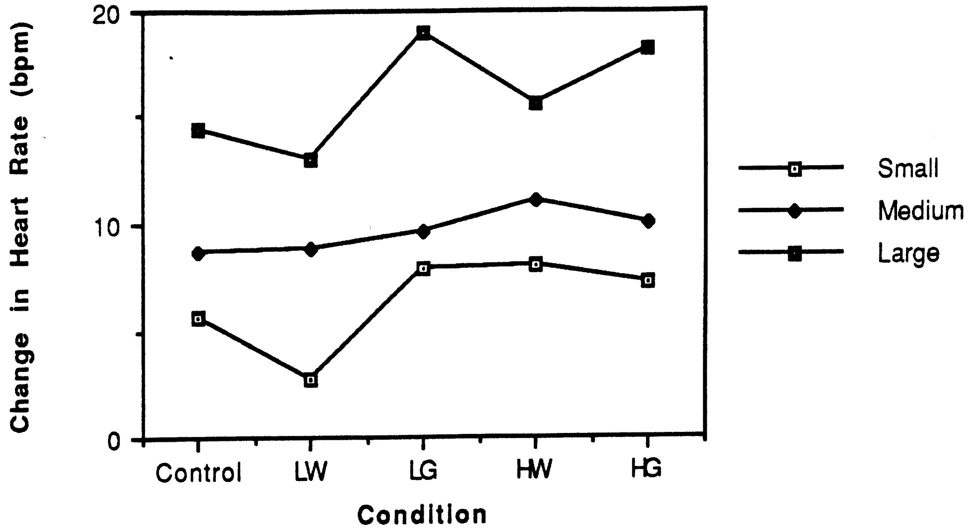


Figure 6: Mean Heart Rate Change for each Condition by Target Size

(ANOVA results for main effects and selected contrasts. Target size: $p<0.001$, Weight + Type: $p=0.297$, Interaction: $p=.876$; C vs. HG: $p=0.102$)

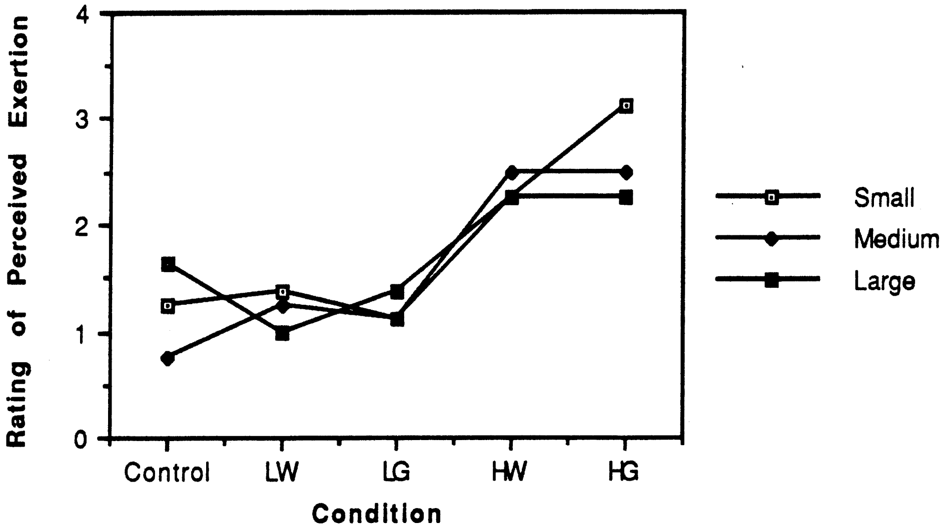


Figure 7: Mean RPE for each Condition by Target Size

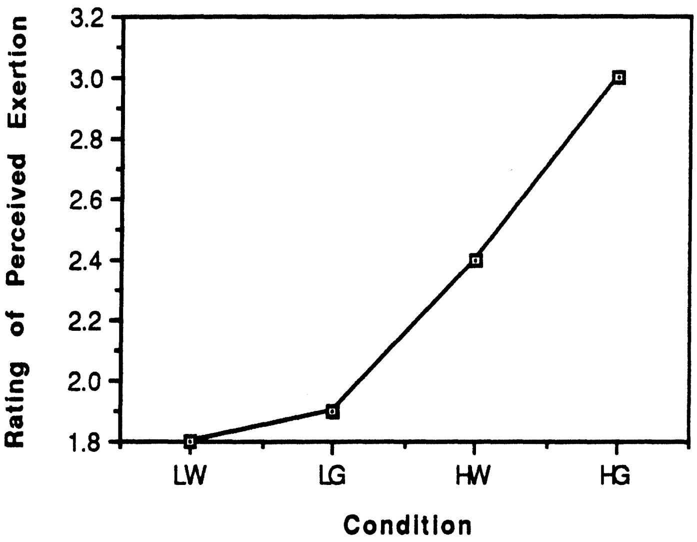


Figure 8: Mean Ratings of Perceived Exertion for Cranking Task

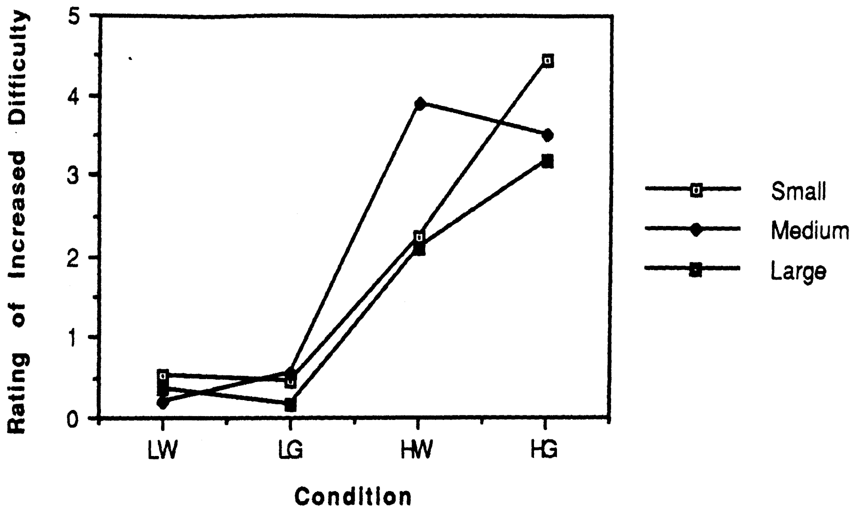


Figure 9: Mean Ratings of Increased Difficulty by Target Size

(ANOVA results for main effects and selected contrasts. Target size: p=0.419, Weight + Garment: p=0.001, Interaction: p=0.205; Weights vs. Garments: p=0.394, Light vs. Heavy: p=0.005)

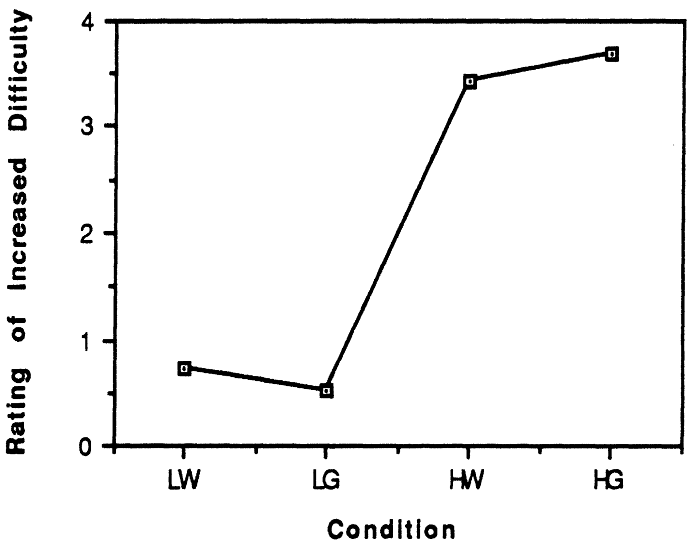


Figure 10: Mean Ratings of Increased Difficulty for Cranking Task

Appendix

SUBJECT FEEDBACK FORM

Task Performance

1) Circle the number on the following scale corresponding to the level of exertion required by this task.

0	Nothing at all
0.5	Very, very light
1	Very light
2	Light
3	Moderate
4	Somewhat hard
5	Hard
6	
7	Very hard
8	
9	
10	Very, very hard
*	Maximal

2) Place a mark on the line below to indicate how much the garment you wore increased the difficulty of the task.

Not at all |____| Made task nearly impossible

3) For the task just completed, rank the following movements according to the amount they were interfered with by the garment. Start by assigning the number 1 to the motion most impeded by the garment and continue until all movements have been assigned a number. If absolutely necessary, you may assign the same rank to more than one movement. (Ties are allowed.)

Target touching task:

______ Lifting the stylus off the targets
______ Moving the wand downward quickly
______ Moving the wand upward quickly
______ Positioning the stylus and touching the upper target
______ Positioning the stylus and touching the lower target

Cranking task:

______ Extending the arms at the top of the cycle (Moving the hand past 12:00 position)
______ Flexing the arms at the bottom of the cycle (Moving the hand past 6:00 position)
______ Raising the arms when close to the body (Moving the hand past 9:00 position)
______ Lowering arms when from the body (Moving the hand past 3:00 position)

4) Rate the overall comfort of the garment worn in this task by drawing a vertical mark on the line below:

Extremely Comfortable |____| Extremely Uncomfortable

5) Please refer to the diagrams. List the letters of those regions of the body where the garment you wore created discomfort. (You may find it easiest to start with the most discomforting area and continuing until all areas where discomfort was experienced have been listed. Do not include regions that did not experience discomfort.)

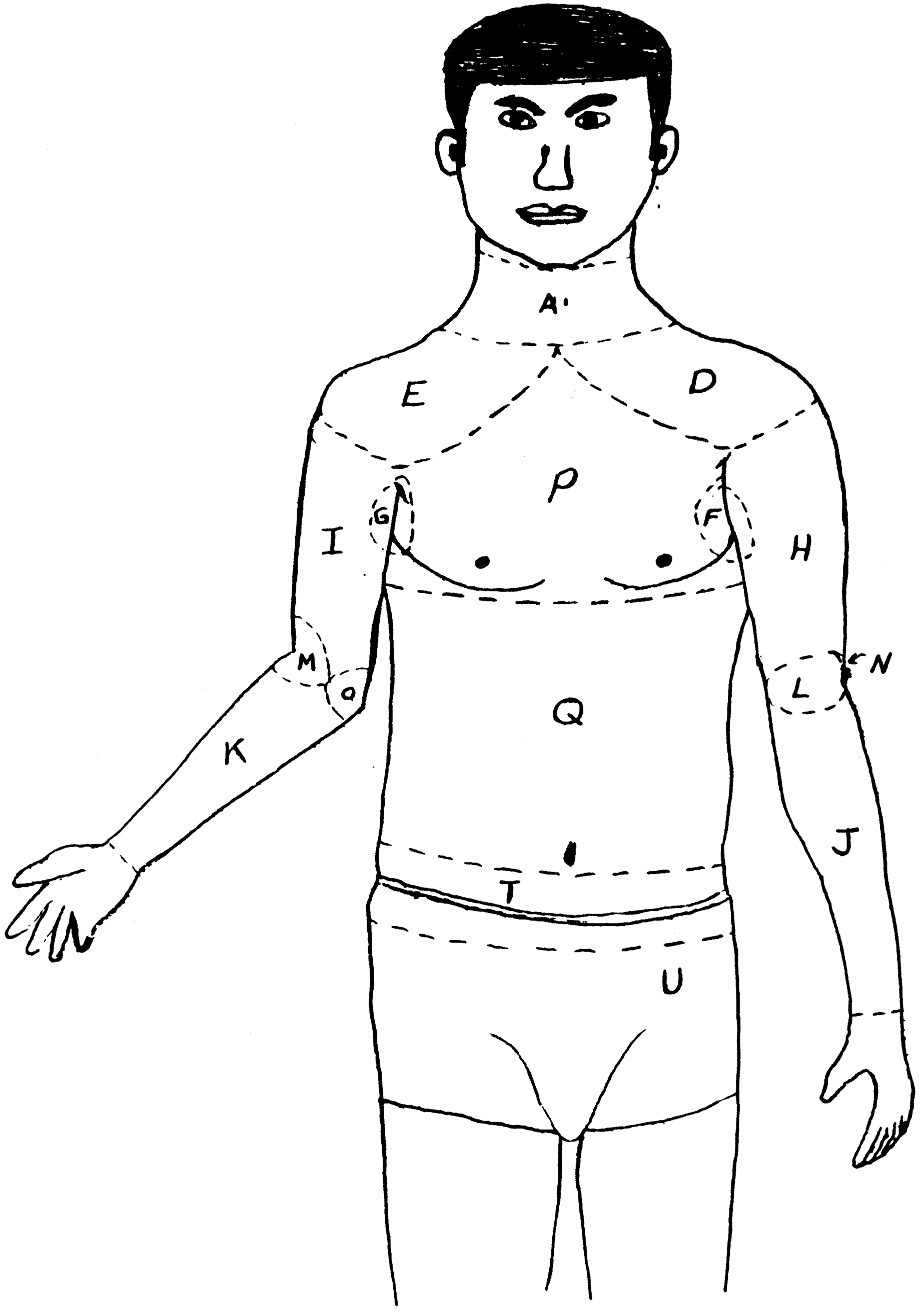
A	Neck	L	Left elbow interior
B	Back of left shoulder	M	Right elbow interior
C	Back of right shoulder	N	Left elbow exterior
D	Front of left shoulder	O	Right elbow exterior
E	Front of right shoulder	P	Upper chest
F	Left underarm (armpit area)	Q	Lower chest and stomach
G	Right underarm	R	Upper back
H	Left upper arm	S	Lower back
I	Right upper arm	T	Waist
J	Left lower arm	U	Hips
K	Right lower arm		

After you have identified the discomfortable body regions, enter the number(s) corresponding to the type(s) of discomfort experienced in the second column for each of the identified regions. Use the number codes below:

1 Fatigue
2 Rubbing, friction, or chafing
3 Localized pressure
4 Resistance to movement, mechanical pulling
5 Fit too tight
6 Fit too loose, floppy
7 Wet sensation
8 Other (Describe briefly off to the side)

Region	Discomfort type(s)
______	____________________
______	____________________
______	____________________
______	____________________
______	____________________
______	____________________
______	____________________
______	____________________
______	____________________
______	____________________

6) Make any general comments about the comfort of the garment worn in this task and its effect on your ability to perform on the back of this sheet.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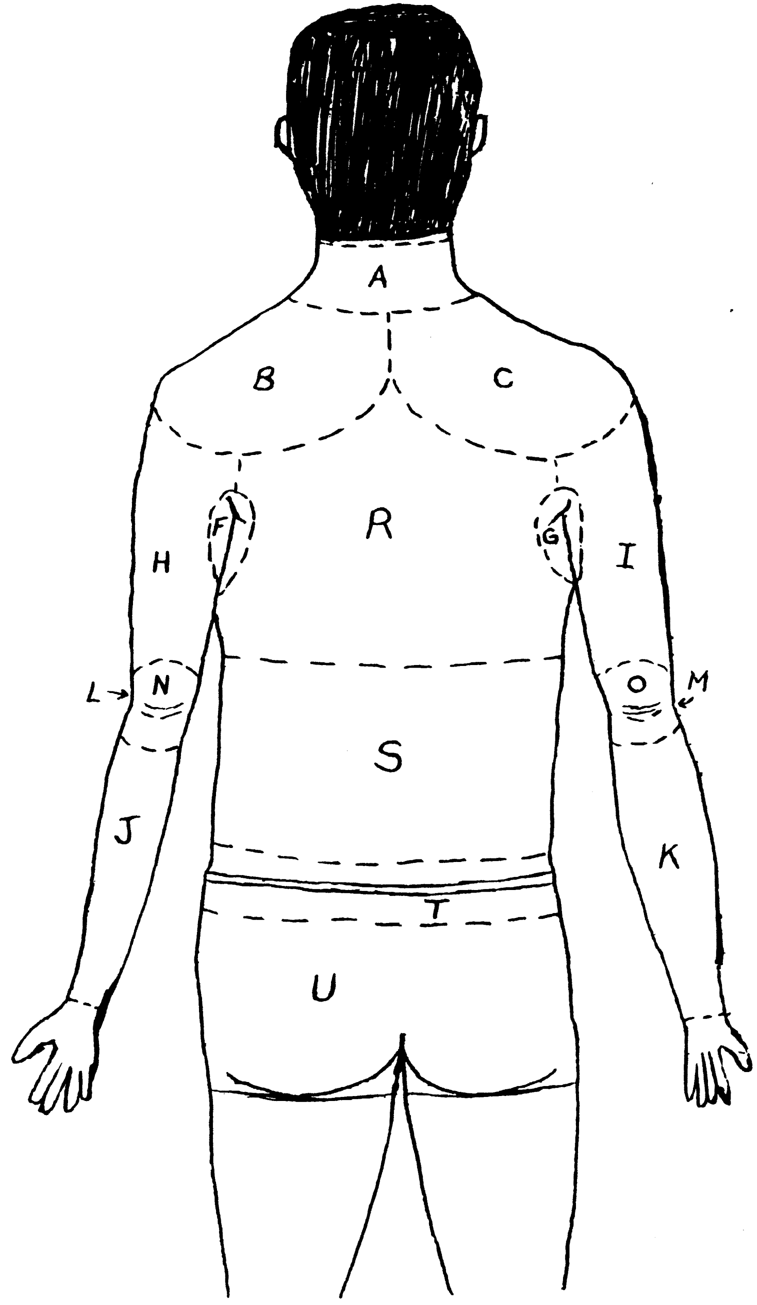
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