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The Effect of Size and Fabric Weight of Protective Coveralls on Range of Gross Body Motions

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THE EFFECT OF SIZE AND FABRIC WEIGHT OF PROTECTIVE COVERALLS ON RANGE OF GROSS BODY MOTIONS

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This study evaluated the effects of garment size and fabric weight on range-of-motion (ROM). Ten male subjects performed a series of twelve gross body movements while wearing each of nine similarly styled coveralls. The coveralls were undersized, appropriately sized, and oversized, and were constructed from three different weights of poly/cotton fabric. A balanced 3 × 3 repeated measures experimental design was used, along with a seminude control condition. ROM was measured with a two-arm manual goniometer. Garment size significantly affected ($p < .05$) ROM for all movements except shoulder extension and trunk lateral flexion. Compared to seminude ROM, undersized garments reduced the mean ROM by as much as 24% in the case of hip flexion. Fabric weights on ROM were significant for shoulder extension and elbow, hip, knee, and shoulder horizontal flexion. Fabric weight affected ROM less than garment size. Interaction effects between fabric weight and size generally were not significant. These results demonstrate that undersized garments can measurably reduce the wearer's movement capability. Providers of protective clothing should ensure that garments are not undersized and should consider the benefits of oversizing against possible safety and wearer acceptance problems.

Personal protective clothing (PPC) enables humans to work safely in environments that are potentially injurious, but it can also negatively affect work performance. In addition to the well-established problems of heat stress[1] and wearer discomfort,[2] protective garments have been shown to reduce task efficiency[3–6] and range-of-motion (ROM) capability.[7–12] To control these negative performance effects, we must understand how work performance is affected by specific garment attributes. Methods for assessing performance capabilities are needed to assist with PPC development and selection. ROM is one of several performance measures that have been used for studying garment effects. This study investigates the effect of two garment attributes, garment size and fabric weight, on ROM at selected joints.

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BACKGROUND

Definitions

To facilitate discussion of garment effects on performance, several terms are defined. "Garment ease," or simply "ease," is the difference between the interior volume of a garment and the anthropometric volume of the wearer. Ease refers to the amount of unoccupied space within a garment available to accommodate movement and ventilation. Size refers to a preestablished set of garment dimensions specified by the manufacturer. Size also must be considered relative to the wearer's anthropometry. Clothing may be described as:

- undersized (having dimensions that are too small for the wearer, based on the manufacturer's recommended sizing for subjects' heights and weights)
- oversized (having dimensions that are too large, based on the manufacturer's recommended sizing for subjects' heights and weights, resulting in excessive ease)
- appropriately sized (having dimensions that match the wearer's anthropometry, based on the manufacturer's recommended sizing for subjects' heights and weights).

ROM refers to the maximum angular change available at a joint,[13] i.e., a measure of the full extent of movement that a person has at a joint. ROM typically is measured in degrees from a reference position, which often is taken to be either a neutral posture or a position at the limit of movement in a given direction. ROM impediment occurs when ROM is diminished by an external agent such as clothing. It may be quantified as either the percent reduction in movement capability or as a subjective assessment of restriction. This paper will be limited to objectively measured ROM.

Effects of Comfort, Size, Garment Weight on Work Performance

Protective clothing is more readily accepted if it is comfortable, fits well, and does not impede work performance.[2,14–17] Further, PPC often is worn in situations where work efficiency is important in order to reduce labor costs, worker stress, and duration of exposure to hazardous conditions. While the effects of improper sizing on worker comfort and performance are not well understood, workers frequently must wear PPC that fits poorly due to a limited selection of sizes and styles. Trade-offs occur between the expense of manufacturing and/or stocking more sizes versus the cost (sometimes not recognized) associated with reduced productivity and/or prolonged exposures to hazardous environments.

Garment weight also has been shown to compromise task performance[18–20] and affect comfort.[21] However, the authors are unaware of studies demonstrating a relationship between garment weight and ROM.

Workers wearing PPC often are required to make gross body movements, as exemplified by the tasks listed in Table I. Some of the more common movements are illustrated in Figure 1.

A few studies have used gross movements to quantify PPC effects on ROM.[7,12] Both Huck[7] and Bachrach et al.[12] performed subsequent experiments in which they demonstrated increased physiological load[22] and compromised task performance[3] for subjects wearing garments similar to those used in their initial ROM studies. However, neither of these later performance studies specifically investigated relationships among garment-induced ROM impediment and reductions in task performance.

Objectives

The specific objectives of this study were to (1) evaluate the effects of garment size on ROM and (2) evaluate the effects of fabric weight on ROM.

METHODS

Experimental Design

The independent variables selected for this study were garment size relative to subject anthropometry and fabric weight. Three levels of size and three levels of fabric weight were used. The sizes were defined as undersized, appropriate, and oversized, based on the manufacturer's recommended sizing; and the fabric weights were described as light, medium, and heavy. The dependent variable, range of motion, was assessed by measuring the range of angular change of a body segment about a joint with respect to a defined neutral posture (or linear distances in the case of trunk flexion and lateral trunk flexion).

The experimental design, shown in Table II, was a balanced 3 × 3 repeated measures design with Subjects as a blocking variable. Each of 10 subjects performed 5 replications of all movements in each of 9 treatment conditions, as well as in a seminude control condition. The movement sequence was identical for all subjects.

The order of the treatment conditions was systematically sequenced across subjects so that each condition was presented first once. Although sequencing the treatment order inextricably confounds Subject with Order, it is a practical approach for eliminating any order effects. Again, note that Subject is the blocking variable. ANOVA was independently applied to each of the 12 movements to evaluate the significance of size and fabric weight.

TABLE I. Examples of Tasks Involving Gross Body Movements

Movement	*Tasks*
Elbow Flexion	manual material handling; steering a vehicle; hammering
Shoulder Flexion	overhead work
Shoulder Extension	shoveling; pulling hose/lines; raking
Shoulder Abduction	operating controls; firing a rifle; overhead work
Shoulder Horizontal Flexion	steering a vehicle; pulling hose/lines
Shoulder Horizontal Extension	sweeping; pulling hose/lines
Trunk Flexion	picking up objects; manual material handling
Trunk Extension	maintenance tasks requiring backward bending; overhead work
Trunk Lateral Flexion	material handling; cutting tree limbs from aerial bucket
Hip Flexion	ladder climbing; squatting; driving with foot pedals
Hip Abduction	straddling holes; stepping sideways
Knee Flexion	climbing; squatting; crawling

Note: Jobs such as maintenance work, logging, and material handling frequently involve any or all of the movements listed.

Test Garments

The treatment garments were long-sleeved coveralls, worn over the same undergarments as were used in control trials. Control trial apparel (the seminude condition) consisted of athletic shorts, briefs, socks, and athletic shoes. The coveralls had a zippered front with a covering flap, a snap at the top of the zipper and another at the waist, set-in sleeves with snaps at the wrists, an elasticized waist, and two expansion pleats running vertically down either side of the back from the top of the shoulder to the waist.

The coveralls were manufactured by Lion Apparel from each of three woven fabrics. The fabrics were 4.25 oz./yd^2 65/35 poly/cotton, 7.25 oz./yd^2 50/50 poly/cotton, and 10.0 oz./yd^2 50/50 poly/cotton. Maximum shrinkage specifications per the manufacturer were 3.0%, 3.0%, and 3.5%, respectively. The same patterns were used for all fabrics within a size type, and all coverall styles were identical. Stretch properties of the three test fabrics were measured using the procedure described in ASTM D 3107 Standard Test Method for Stretch Properties of Fabrics Woven from Stretch Yarns.[23] Fabric samples were preconditioned using the same wash-dry cycles as for the test garments, described below. The average percentage stretch for the light-, medium-, and heavy-weight fabrics was 1.8%, 5.1%, and 4.9%, respectively.

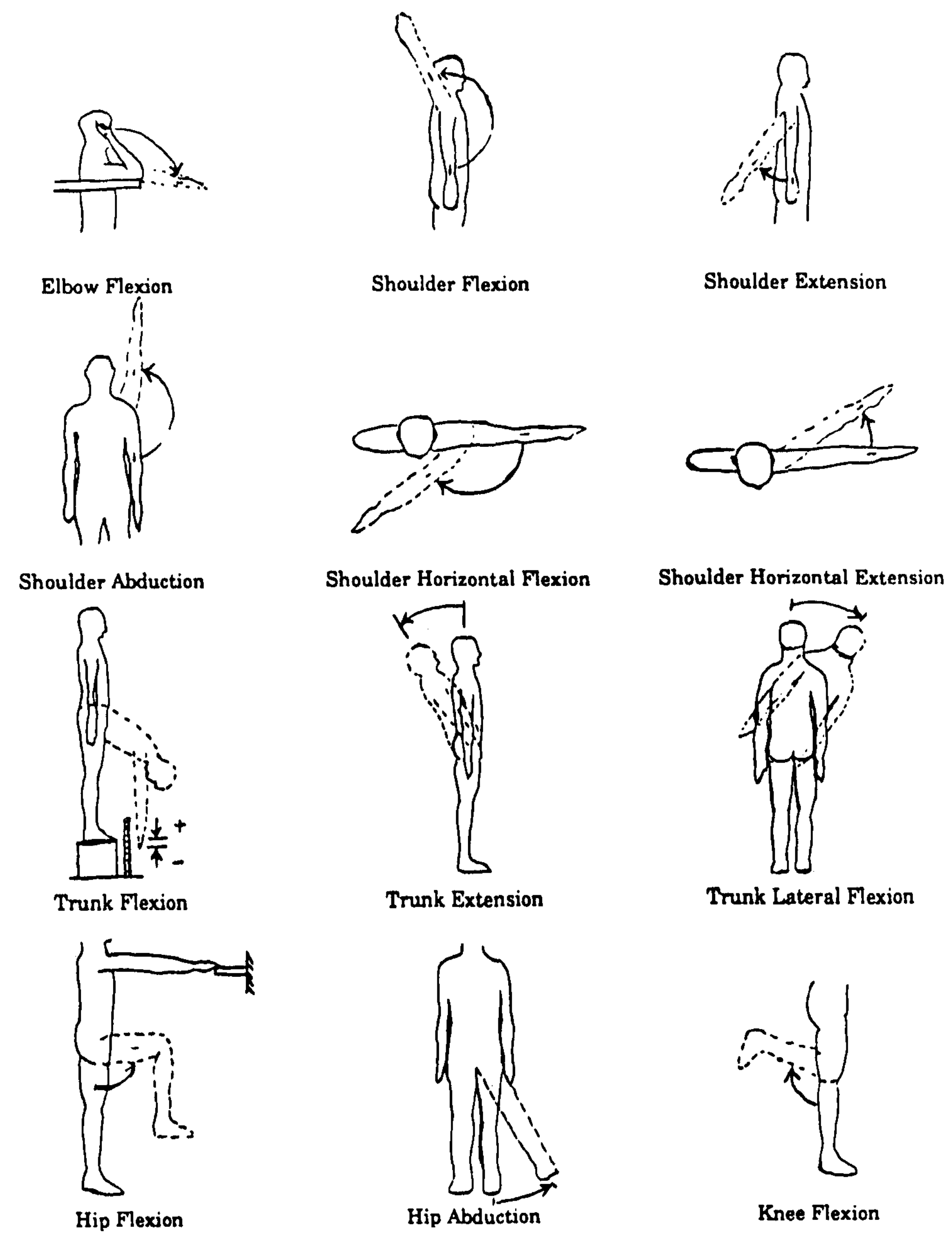

FIGURE 1. Basic movements used for assessing ROM; movements were similar to those performed in previous studies of garment effects on ROM[7]

All garments were machine washed and tumble dried three times prior to testing to assure dimensional stability. This laundering was performed per the manufacturer's laundering instructions. Since some of the garments were worn by multiple subjects, the garments also were washed by the researchers per the manufacturer's instructions and measured for dimensional change prior to use by each subject. This process assured that all subjects wore freshly washed garments at the beginning of each treatment.

Four sizes of coveralls were supplied by the manufacturer: small regular, medium regular, large regular, and extra large regular. Each subject wore three sizes of coveralls: an appropriately sized set determined from the manufacturer's recommended sizing chart (medium or large, depending on the subject's height and weight), an undersized set (small or medium), and an oversized set (extra large).

Subjects

Ten healthy male college students participated, ranging in age from 19 to 31 years. Stature ranged from 173.1 to 187.5 cm (35th to 95th percentile for U.S. Army personnel; 37th to 96th percentile for U.S. civilians), and weights from 66.0 to 94.1 kg (15th to 90th percentile U.S. Army, 19th to 87th percentile civilian).[24]

Movement Measurement

Test movements were adapted from Saul and Jaffe[8] and Huck,[7] and are illustrated in Figure 1. Two movements measured by Huck,[7] shoulder rotation and hip extension, were eliminated from the test battery. In pilot testing prior to this study, garment effects on these two movements were not measurable, so they were deleted in an effort to shorten the testing period.

Joint angles were measured using a two-arm goniometer. Trunk flexion was determined using a stool with an attached ruler, and measured as the vertical distance from a finger-tip to the standing surface (reaches short of the stool surface were taken as positive, and those extending below the standing surface were negative). Trunk lateral flexion was measured with a cloth tape as indicated by displacement of the infra thyroid landmark (Adam's apple) relative to the vertical at the neutral posture.

Test Procedure

Height and weight data were collected from each subject prior to testing and used in selecting 9 test garments from a pool of 12.

The subject performed a pre-established set of stretching exercises to loosen shoulder, torso, hip, and leg muscles. He then donned the specified test garment, fastening all snaps. Elapsed

TABLE II. Experimental Design for Study of Garment Size and Fabric Weight Effects on Range of Motion (Numbers Indicate Treatment Presentation Sequence)

		Garment Treatments								
		Lightweight Fabric			Medium-Weight Fabric			Heavy-Weight Fabric		
Subject #	*Seminude*	*U*	*A*	*O*	*U*	*A*	*O*	*U*	*A*	*O*
1	1	2	3	4	5	6	7	8	9	10
2	10	1	2	3	4	5	6	7	8	9
•						•				
•						•				
•						•				
10	2	3	4	5	6	7	8	9	10	1

Key: U = undersized
A = appropriately sized
O = oversized

time between the stretching exercises and the initiation of test movements was approximately 20 minutes. The subject was asked to perform the first movement 5 times, followed by 5 repetitions of the second movement, and continuing through all 12 test movements. For each movement, the subject was instructed to "move as far as you can without straining." ROM measurements were taken during each movement with the goniometer/measuring tape. The movement sequence (beginning with elbow flexion and ending with knee flexion as depicted in Figure 1) was maintained for all conditions and subjects. All trials were completed in a single testing session, with a lunch/dinner break of approximately one hour given at the approximate midpoint.

Data Reduction and Analysis

ROM data from each set of five repetitions were averaged. This was done to mitigate any order effect that might result from subjects repeatedly moving to ROM limits. Averaging over five repetitions also reduces the effect of measurement error.

Repeated measures analyses of variance (ANOVA) were independently performed on the data sets from each of the 12 movements using the SAS/STAT v. 6.0[25] statistical package. Mean ROM values were averaged by garment size and by fabric weight for each subject, yielding six means for each movement-specific data set. Differences among these within-subject means were then compared using Bonferoni family confidence intervals; e.g., undersized ROM means were compared with appropriately sized ROM means, lightweight fabric ROM means were compared with medium-weight fabric ROM means, etc. A total of three pairwise evaluations was performed for each independent variable. (Readers are invited to request additional details regarding the test methods from the first author.)

RESULTS

Mean ROM values are shown by size and fabric weight in Table III for each test movement.

Results of the repeated measures analysis of variance (ANOVA) are presented in Table IV. Garment size had a statistically significant effect ($p < .05$) on all movements except shoulder extension and trunk lateral flexion. Fabric weight had a significant effect on elbow flexion, shoulder extension, shoulder horizontal flexion, hip flexion, and knee flexion. Interaction

TABLE III. Mean Values for Size and Fabric Weight Effects

	Garment Size ROM Means[A]			Fabric Weight ROM Means[A]			Seminude
Movement	*Under*	*Approp.*	*Over*	*Light*	*Medium*	*Heavy*	*ROM Means*[A]
Elbow Flexion	130.4	133.4	133.7	134.6	131.5	131.4	138.9
Shoulder Flexion	127.6	142.1	149.0	142.5	138.3	137.9	165.1
Shoulder Extension	50.9	52.3	52.5	53.1	49.8	52.8	57.6
Shoulder Abduction	120.6	132.6	139.6	133.5	128.7	130.6	147.7
Shoulder Horizontal Flexion	114.5	120.4	123.2	122.9	116.5	118.7	126.3
Shoulder Horizontal Extension	35.8	40.0	41.0	39.5	38.4	38.9	42.7
Trunk Flexion	9.5	6.1	4.6	6.1	7.2	7.0	2.2
Trunk Extension	23.4	25.7	26.6	25.2	24.6	25.8	27.1
Trunk Lateral Flexion	23.2	24.0	24.1	24.0	23.8	23.6	24.9
Hip Flexion	76.4	84.1	84.3	85.0	79.5	80.4	100.9
Hip Abduction	42.5	44.1	45.7	45.2	43.9	43.3	51.3
Knee Flexion	90.1	92.1	93.0	92.7	89.8	92.6	103.0

[A] All ROM values are in degrees of movement except Trunk Flexion and Trunk Lateral Flexion, which are in centimeters.

TABLE IV. Repeated Measures Analyses of Variance (ANOVA) for Each Movement

Movement	*Source*	*F-Value*	*p-Value*[A]
Elbow Flexion	Weight	6.85	.006
	Size	5.49	.020
	W × S	0.52	.719
Shoulder Flexion	Weight	1.55	.240
	Size	19.89	<.001
	W × S	0.46	.765
Shoulder Extension	Weight	4.05	.035
	Size	2.16	.160
	W × S	1.34	.279
Shoulder Abduction	Weight	1.26	.307
	Size	30.28	<.001
	W × S	0.90	.477
Shoulder Horizontal Flexion	Weight	10.86	<.001
	Size	14.55	<.001
	W × S	2.69	.046
Shoulder Horizontal Extension	Weight	0.01	.988
	Size	19.66	<.001
	W × S	0.58	.632
Trunk Flexion	Weight	4.80	.035
	Size	14.98	.003
	W × S	1.47	.255
Trunk Extension	Weight	0.17	.836
	Size	3.91	.049
	W × S	1.16	.343
Trunk Lateral Flexion	Weight	0.21	.816
	Size	1.11	.342
	W × S	0.64	.640
Hip Flexion	Weight	9.45	.004
	Size	19.17	<.001
	W × S	3.55	.015
Hip Abduction	Weight	2.34	.132
	Size	4.62	.031
	W × S	1.91	.152
Knee Flexion	Weight	3.99	.043
	Size	6.40	.008
	W × S	1.15	.350

[A] Huynh-Feldt adjusted p-Value. (By convention, p-values less than .05 are considered to be "statistically significant," with significance level increasing as the p-value approaches .00.)

effects between size and fabric weight were generally not significant. The only two exceptions were shoulder horizontal flexion ($p = 0.046$) and hip flexion ($p = 0.015$).

Figure 2 shows the grand means of the hip flexion angles by treatment condition. The trends in these data are typical for other movements as well: ROM generally increased with increasing garment size, while fabric weight had a smaller effect.

Quantifying Effects on ROM

A treatment/control ratio can be calculated by dividing the mean ROM value for a treatment condition by the mean value for the seminude control condition. This ratio quantifies the treatment effect by representing the fraction of unimpeded ROM that was achieved when wearing the test garment. The percent reduction in measured ROM may then be found as follows:

$$\%\ \text{ROM reduction} = (1 - \text{treatment ROM mean/control ROM mean}) \times 100.$$

Table V contains the percent reductions in ROM for the size and fabric weight variables, along with their level of statistical significance.

ROM was reduced under each treatment condition for nearly all movements.

Garment Size

The results in Table V and Figure 2 suggest that undersizing has a large effect on ROM. Bonferoni pairwise comparison tests[26] were performed to test significance between sizes; the results are summarized in Table VI. In general, differences in ROM effects between the undersized and appropriately sized coveralls were significant, but differences between appropriately sized and oversized were not.

Fabric Weight

Based on the ROM reduction percentages in Table V, ROM capability appears to decrease slightly with increased fabric weight, but this trend is less apparent than that for garment size. Bonferoni pairwise comparisons among fabric weights were only significant for elbow flexion, shoulder horizontal flexion, and hip flexion. For each of these movements, ROM effects were significantly different between the lightweight coveralls and coveralls made from the medium- and heavy-weight fabrics, but differences between medium-weight and heavy-weight coveralls were not significant.

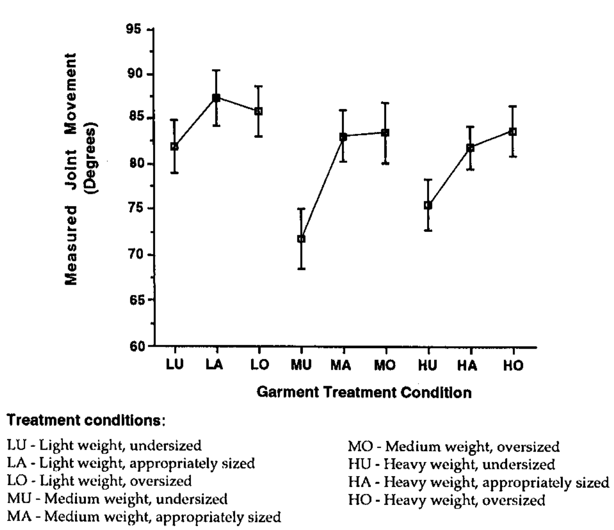

FIGURE 2. Hip flexion angles measured with a goniometer; means of 10 subjects, 5 trials per garment condition.

TABLE V. Mean Percent Reduction in Range-of-Motion by Garment Size and Fabric Weight as Compared with Seminude Condition[A]

Movement	*Garment Size*			*Fabric Weight*		
	Undersized	*Appropriate*	*Oversized*	*Light*	*Medium*	*Heavy*
Elbow Flexion	6% (.006)	4% (.006)	4% (.011)	3% (.066)	5% (.001)	5% (.005)
Shoulder Flexion	22 (.001)	14 (.003)	10 (.004)	14 (.007)	16 (.003)	17 (.001)
Shoulder Extension	11 (.014)	8 (.034)	8 (.047)	7 (.091)	13 (.004)	8 (.028)
Shoulder Abduction	18 (<.001)	10 (.002)	5 (.047)	10 (.004)	13 (.004)	12 (.001)
Shoulder Hori. Flexion	9 (.003)	4 (.092)	2 (ns)	2 (ns)	7 (.011)	6 (.043)
Shoulder Hori. Extension	13 (.084)	4 (ns)	2 (ns)	6 (ns)	6 (ns)	6 (ns)
Trunk Flexion[B]	B	B	B	B	B	B
Trunk Extension	4 (ns)	−2 (ns)	−8 (ns)	−1 (ns)	−1 (ns)	−4 (ns)
Trunk Lateral Flexion[B]	6 (ns)	4 (ns)	3 (ns)	3 (ns)	4 (ns)	5 (ns)
Hip Flexion	24 (<.001)	17 (<.001)	16 (<.001)	16 (<.001)	21 (<.001)	20 (<.001)
Hip Abduction	15 (.004)	13 (.006)	10 (.024)	10 (.016)	14 (.005)	14 (.024)
Knee Flexion	12 (<.001)	10 (.001)	10 (.001)	10 (.001)	13 (.001)	10 (<.001)

[A] Significant p-values are in parentheses; i.e., $p < .05$. p-value represents the probability of rejecting the hypothesis that the mean percent reduction in ROM is not zero when this hypothesis is true.

[B] Trunk flexion and trunk lateral flexion were measured in centimeters rather than in degrees of movement. For trunk flexion, an arbitrary reference point was chosen, resulting in a meaningless percent reduction. Percent reduction values for trunk lateral flexion are meaningful, since a neutral posture was defined as the reference zero point. Percent reduction in this latter case refers to reduction in distance moved rather than in degrees of movement.

DISCUSSION

Effect of Garment Size on ROM

All three sizes of coveralls used in this study constrained movement to some extent. Undersizing restricted movement the most. Oversized coveralls had a smaller detrimental effect on ROM than appropriately sized garments. This suggests a preference for excess garment size (and ostensibly garment ease) over apparel fitted using the manufacturer's recommended size, assuming ROM is the most important size selection criteria.

Constraint Mechanisms

These results can be attributed to three of the mechanisms by which garments act to constrain movement. First, garments can interfere with movement by preventing the body from changing volume or shape. Kirk and Ibrahim[27] demonstrated that skin on the hips, knees, elbows, and back stretches significantly during flexion. Restriction occurs when the garment either lacks sufficient volume or the volume is not distributed as needed; i.e., a key dimension is too short. This effect was presumed to be present in this study, although time and other experimental constraints did not allow for measurement of changes in garment and body volumes during movement.

Second, anchoring or tying of the garment can prevent displacement. Tight clothing exerts forces normal to the skin, resulting in high frictional resistance and possibly mechanical binding (e.g., a tight sleeve that cannot slide up a conical-shaped forearm). Mechanical binding occurs when the garment becomes tied or anchored to the body at one or more sites and cannot slide to accommodate volume changes. Displacement is the change of clothing position on the body; effectively, garment volume moves from one area of the body to another. Clothing is naturally displaced during movement from its original position on the body. The amount of displacement required to facilitate movement depends, in part, on garment ease (unoccupied space within a garment) and the ability of the garment to stretch. Although ease was not measured, the results of this study potentially can be explained by differences in garment ease among sizes. Undersizing results in inadequate ease and mechanical tying. For example, most subjects complained of "tightness" and "pulling" at the crotch and thighs when performing hip flexion in the undersized coveralls. Additional research is needed to fully understand the effects of ease on ROM.

Movement also may be impeded by multiple constraint mechanisms acting together. McConville[28] demonstrated this problem by having soldiers perform a deep squat and then abduct both arms, while wearing a coverall chemical defense overgarment. The overgarments became "tied" to the hips due to the extreme hip flexion.

Since the overgarments were designed to fit loosely at the shoulders (i.e., oversized in this region), the armscye stress lines were located away from the shoulder joint centers during abduction. Shoulder abduction was severely constrained.

The overgarment example also illustrates that multiple and complex movements may be affected by garment fit even though simple movements are not. However, analysis of garment effects on complex movements was beyond the scope of this study.

Movements Not Affected by Size

Garment effects on ROM due to size were not consistent across all movements. Size did not significantly affect shoulder extension. The ROM for shoulder extension is relatively small compared to other gross body movements. Changes in body size and shape at the shoulder are presumed to be comparatively small as well. Therefore minimal ease and displacement are required to accommodate this movement, and ROM is more likely to be constrained by the subject's natural limits. Similarly, the relatively small ranges of motion for trunk extension and trunk lateral flexion may have accounted for the lack of a size effect on these movements.

TABLE VI. Bonferoni Pairwise Comparison Test for Significance of Size Effect (α = .05)

Movement	Undersized vs. Appropriate	Appropriate vs. Oversized	Undersized vs. Oversized
Elbow Flexion	×	—	×
Shoulder Flexion	×	×	×
Shoulder Extension	×	—	—
Shoulder Abduction	×	×	×
Shoulder Horizontal Flexion	×	—	×
Shoulder Horizontal Extension	×	—	×
Trunk Flexion	×	—	×
Trunk Extension	—	—	×
Trunk Lateral Flexion	—	—	—
Hip Flexion	×	—	×
Hip Abduction	—	—	×
Knee Flexion	×	—	×

Key: × = significant difference between means
— = no significant difference between means
α = family confidence level for set of comparisons

Effect of Fabric Weight on ROM

The results of this experiment indicate fabric weight can affect ROM, but that these effects are much less pronounced than size effects. It should be noted, however, that while the fabric weights used in this study were in the normal range for poly/cotton coveralls, the range of PPC fabric weights is much wider. For example, disposable clothing is typically made from fabrics that are much lighter than poly/cotton, and firefighter turnout coats, chemical protective suits, and body armor are constructed from fabrics that are much heavier.

Other Garment Parameters Not Considered

ROM also may be affected by garment form (style), fabric stretch, stiffness, bulk, and the coefficient of friction between the test garment and underlying surfaces. In her study using firefighter turnout coats, Huck(7) demonstrated that garment style can affect ROM, but there is little in the literature for style effects for other types of garments. It appears likely that fabric stretch also may affect ROM, based on the finding that size is an important variable and the earlier discussion of garment ease. Relatively little stretch was provided by the woven fabrics used in this study, a property that is typical of PPC fabrics. Anecdotal evidence from workers wearing bulky winter clothing suggests that stiffness and bulk may indeed restrict mobility, but quantitative evidence is lacking. Coefficient of friction (COF) may play a role in restricting ROM, since garments with high COF resist displacement. COF differences among the fabrics in this study were reduced by selecting materials with similar composition and weaves and were found to be negligible in pretrial testing. With the exception of style, the authors are unaware of studies that have quantified the effects of these other parameters on ROM.

Additional Issues Related to Sizing and Fabric Weight

While differences in ROM were frequently found to be significant between the undersized and appropriately sized garments, ROM differences between the appropriately sized and oversized garments often were not. The marginal benefits of ease gained by oversizing must be weighed against concerns for safety, worker acceptance, and interference with other components of a worker's ensemble. Oversized garments may compromise safety by interfering with manual tasks, obstructing vision, creating tripping hazards, and getting caught in machinery. They also may chafe sensitive regions of the body such as the inner thighs. Worker acceptance of PPC is enhanced if workers feel their personal appearance is not unduly compromised. Improperly fitted clothing also may interfere with the normal operation of other protective equipment or interact with it to increase discomfort.

The finding that fabric weight minimally affects ROM does not mean that this variable should be discarded from the list of garment parameters that may affect worker performance. Clothing weight may be used as a predictor of clothing insulation.[29] Since thermal comfort and heat stress are the most frequently reported ergonomic problems associated with PPC,[2] it would be premature to discount fabric weight based on a study that only examined the ROM aspect of worker performance.

Limitations of the Results

As already discussed, ROM test results should not be extrapolated to job performance; additional studies are needed to quantify relationships between ROM reductions with actual worker performance. It is unclear whether ROM reduction can be used as a reliable predictor of other performance measures, such as movement time and productivity.

This study was limited to male subjects. Females were not used due to gender differences in shape that may affect garment displacement during movement; i.e., larger hips, smaller shoulders and waists, shorter body segments, and different chest forms. Therefore inclusion of females would have required adding gender as an independent variable. It is not known what effect undersizing or oversizing of coveralls would have on ROM for females. If garment stress lines match those for males, then it is likely that ROM would be similarly affected. Proportional differences in anthropometries between males and females suggest that unisex coveralls would fit the two sexes differently, resulting in differences in stress locations. These disparities in fit may alter the types of movements affected by improperly sized garments, as well as the magnitude of the garment effects on ROM. However, the approach for quantifying garment effects on ROM would be the same for females as for males.

CONCLUSIONS

This study has quantified the effect of coverall size and fabric weight on worker ROM. ROM increased with garment size, and fabric weight did not appear to affect ROM as much as size. The significance of both size and fabric weight effects varied substantially among those movements tested.

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