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BIOMECHANICAL COMPARISON OF THE CURRENT ARMY CHEMICAL, BIOLOGICAL AND RADIOLOGICAL PROTECTION SUIT AND TWO PROTOTYPE SUITS

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This is a study comparing the biomechanical characteristics of the current U. S. Army CBR suit, Overgarment 84, and two prototypes, "C" and "D", developed by the Naval Surface Warfare Center and the Marine Corps Research and Development Command. This study assessed the range of motion in the three CBR suits using a biomechanical analysis. Fourteen anthropometric measurements were used representing gross body movement. Measurements on each of the CBR suits and on a swim suit baseline were compared using a repeated measure ANOVA to determine which CBR suit was least restrictive as measured by the fourteen movements assessed. While the three CBR suits demonstrated a restriction in movement when compared to baseline measures, neither of the CBR suits differ significantly for each other. Implication of the trends in the data are discussed.

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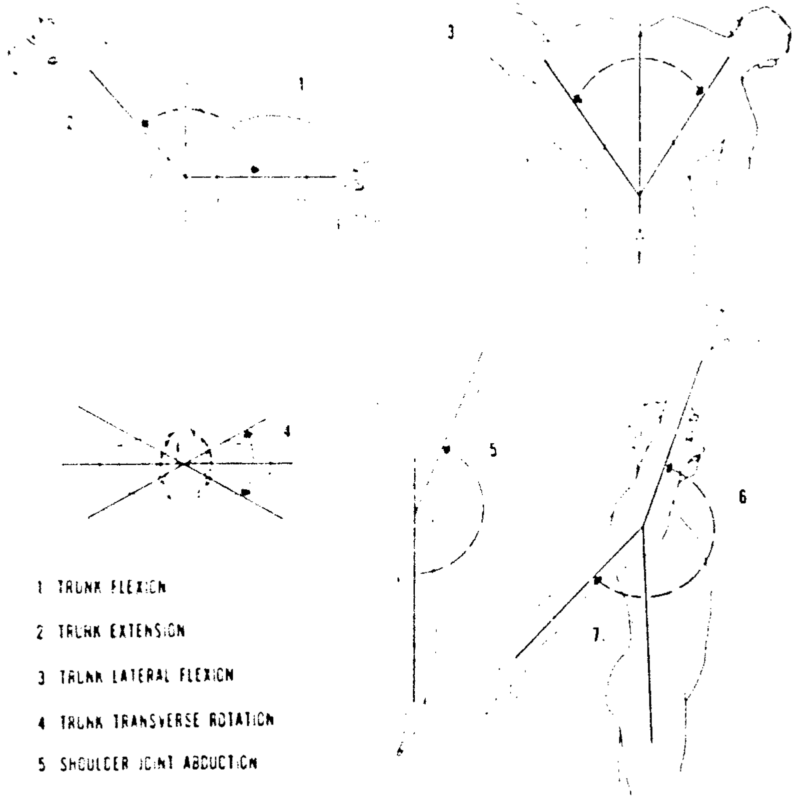
INTRODUCTION

Systematic human engineering of chemical, biological, and radiation (CBR) protective ensembles is crucial for optimal soldier performance on the battlefield. Human factors considerations are sometimes waived as relatively insignificant to the overall design of protective suits; however, these considerations affect safety and performance in such suits. Much of the data available have focused on work/rest cycles and performance degradation due to heat exhaustion (1). Other studies have focused on the reduction of manual dexterity (2), speech intelligibility, and visual fields (3).

Another limitation on performance is the reduction in overall flexibility when encumbered by protective gear (4). Flexibility is Measured in terms of dynamic anthropometry, a biomechanical analysis that qualitatively assesses joint angle changes and range of motion while performing volitional movements (5). Joint movement is assessed at the angle formed by the long axes of two adjoining body segments (link lines) or, in some cases, of the angle formed by one body segment and a vertical or horizontal plane, and total range of movement is measured between the two extreme positions of the joint (6). This range of movement is not only limited by attached muscles, tendons, and ligaments (i.e. their intrinsic bulk and resting length as well as their placement with respect to the bone), but also by the joint body configuration and the amount of surrounding fatty tissue. Movement of body segments occurs through individual muscles acting (through tendons and ligaments) on one or more bones which act as levers about a joint axis in response to muscle contraction or extension. In the intact human subject, individual muscles usually act within a range of lengths estimated to be between 0.7 to 1.2 times the resting length (7). Thus, depending on the point of muscle attachment, a fairly wide range of motion is permitted. Significantly, all of these factors vary from individual to individual and also within individuals under varying conditions.

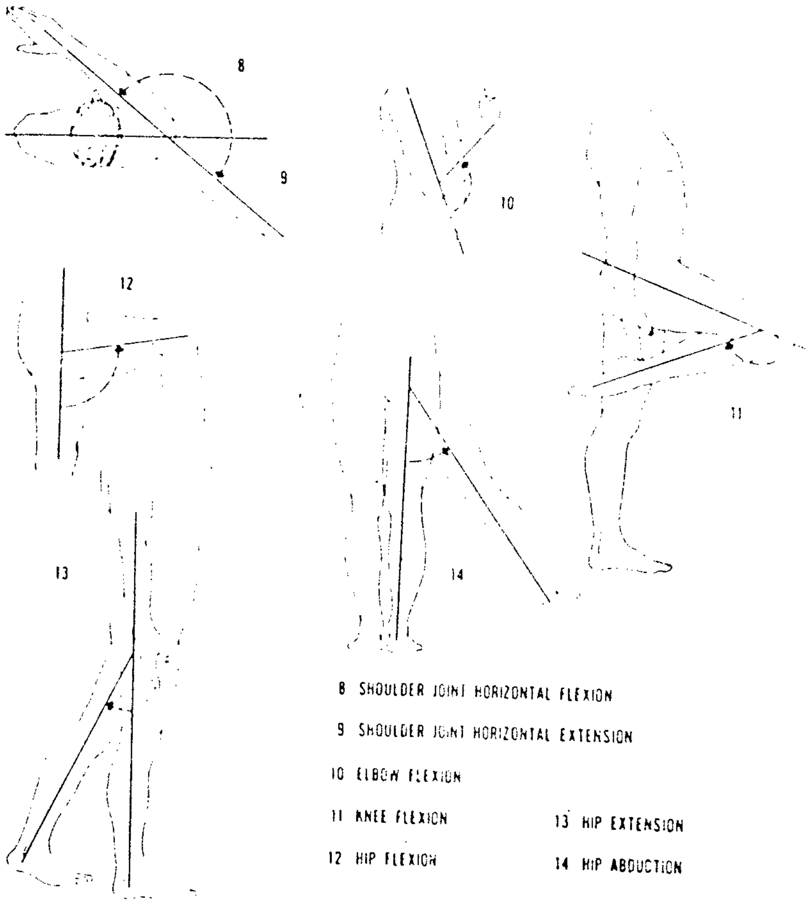
In order to compare the flexibility of various protective suits, measurement of the individual, undressed or in loose clothing must first be undertaken to determine optimal range of motion given the internal mechanical limitations listed above. Once the optimal ranges are determined for each individual, the imposed external mechanical limitations of each suit can then provide the basis for comparative flexibility analysis (5).

Standard positions and reference points for biomechanical measurements are required to conduct comparative dynamic anthropometry. Bachrach, Egstrom, and Blackmun (1975) chose fourteen different range of motion measurements representing the gross body movements required by Navy divers and most likely to be affected by a protective suit (Fig. 1a and 1b). These movements represent fundamental requirements for most physical activity, justifying their use in evaluating CBR protective suits. These fourteen movements included four general types of motion involving five different joints. The general types of movement were flexion (reducing the joint angle), extension (increasing the joint angle), abduction (movement away from the body midline), and rotation (twisting). The joints measured were the shoulder, elbow, hip, knee, and trunk. As technological advances in CBR suit materials occur, suit construction must be assessed to ensure maximum protection and minimal degradation of Mobility. Comparison between existing suits and prototypes using dynamic anthropometry serve to encourage enhancement of CBR suit



1 TRUNK FLEXION
2 TRUNK EXTENSION
3 TRUNK LATERAL FLEXION
4 TRUNK TRANSVERSE ROTATION
5 SHOULDER JOINT ABDUCTION
6 SHOULDER JOINT FLEXION
7 SHOULDER JOINT EXTENSION

FIGURE 1a



8 SHOULDER JOINT HORIZONTAL FLEXION
9 SHOULDER JOINT HORIZONTAL EXTENSION
10 ELBOW FLEXION
11 KNEE FLEXION
12 HIP FLEXION
13 HIP EXTENSION
14 HIP ABDUCTION

FIGURE 1b.

mobility and avoid selection of candidate suits that do not meet or exceed an existing suit's dynamic anthropometry. The comparison is based on the concept that a suit which least hindered motion would be more advantageous on the battlefield. This study reports the results of a biomechanical analysis to compare the flexibility of three chemical, biological, and radiological (CBR) protective suits: OG84 (Fig. 2) (Army production model), Prototype C (Fig. 3), and Prototype D (Fig. 4) (two suits developed by the United States Marine Corps).

METHOD

Subjects

Eight male service personnel (two Navy and six Marine Corps) served as subjects. They ranged in height from 67 to 76 in. (170.2 to 193.0 cm), in weight from 140 to 188 lbs (63.5 to 85.5 kg), and in age from 19 to 32 years (Table 1).

Suits

The weight and thickness of each suit is compared in Table 2. The OG84 is a two-piece overgarment composed of a nylon/cotton fabric and a polyurethane foam layer impregnated with activated carbon powder. It has zipper closures and does not include its own hood, thus requiring a butyl-rubber-coated cloth hood attached to the gas mask. Prototypes C and D are also two-piece overgarments composed of a nylon/cotton fabric, but these suits contain Von Blucher carbon spheres rather than carbon powder. Prototypes C and D include their own hood and have velcro closures. The XM40-A gas mask and the same butyl-rubber overboots and gloves were worn with each suit. The three suits served as the independent variables.

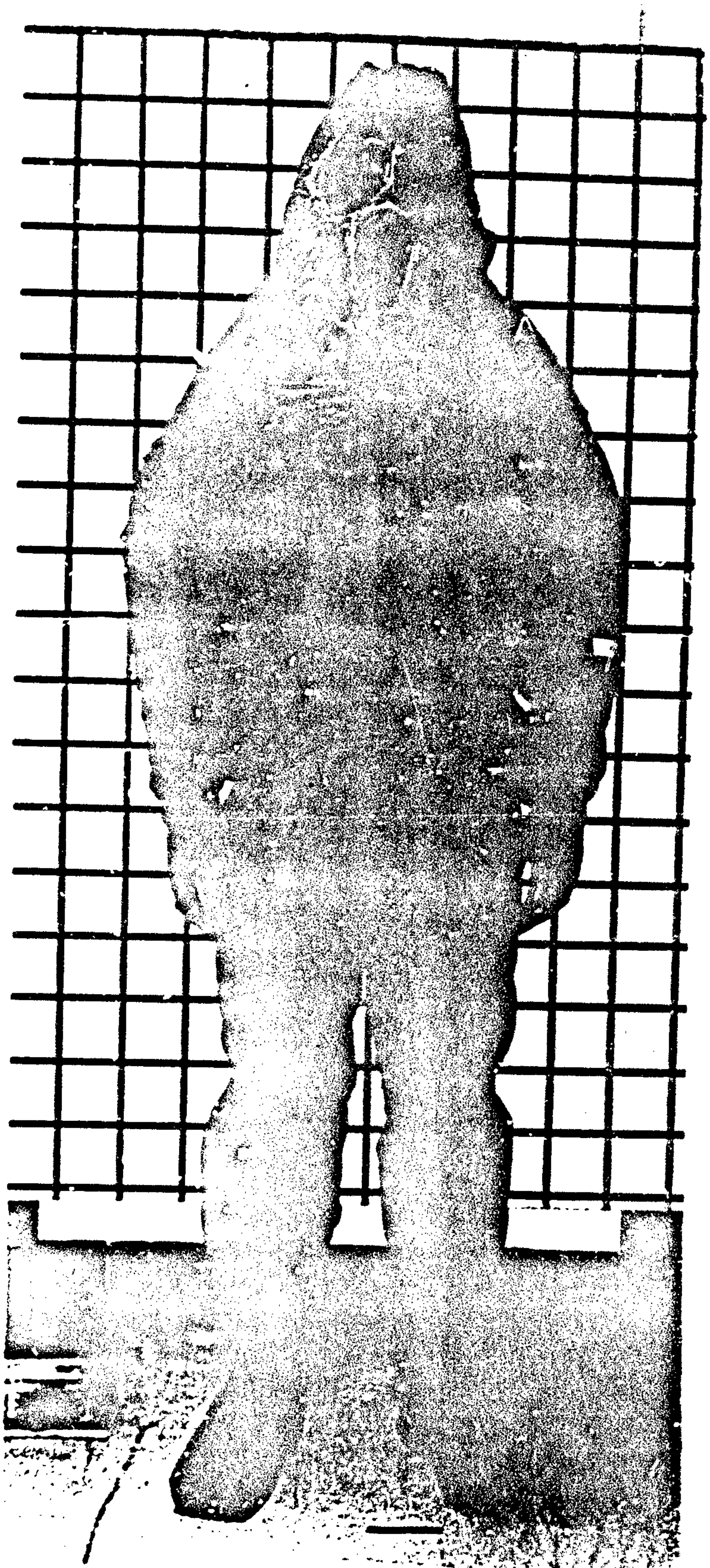


FIGURE 2

FIGURE 3

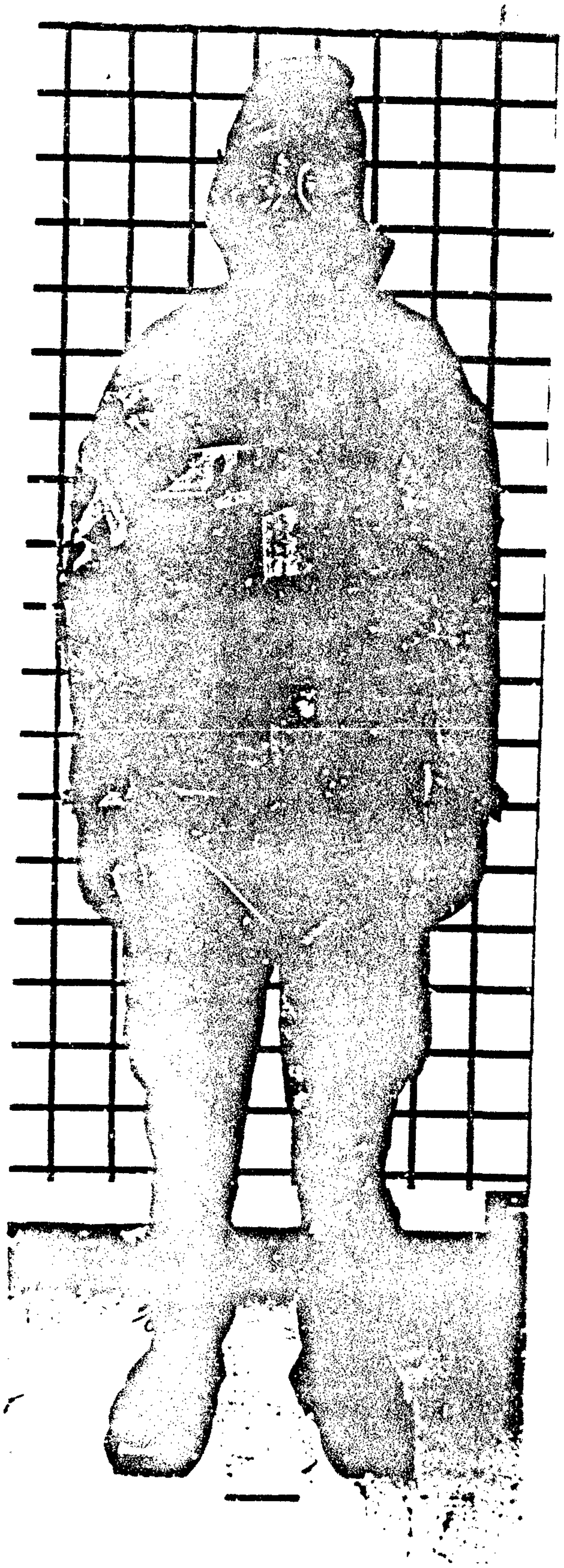


FIGURE 4

TABLE 1

Subjects: Physical Characteristics

Subject	Height (in.)	Height (m)	Weight (lb)	Weight (kg)	Age (yr)
1	67.0	1.70	170	77.1	19
2	69.0	1.75	175	79.4	20
3	75.0	1.91	170	77.1	20
4	58.0	1.73	140	63.5	20
5	74.0	1.88	183	83.0	22
6	69.0	1.75	148	67.1	20
7	76.0	1.93	183	85.5	24
8	70.0	1.78	180	81.8	32
Mean	71	1.80	169.25	76.8	22.1
S.D.	3.5	.09	16.9	7.7	4.3

TABLE 2

Suits: Physical Characteristics

Suit	Weight (kg) Jacket	Weight (kg) Trousers	Weight (kg) Total	Thickness (cm)
OG84	1.3	1.4	2.7	.310
Prototype C	1.9	2.0	3.9	.145
Prototype D	1.6	1.8	3.4	.180

Measurement Methodology

The standards of positions and reference points for biomechanical measurement developed by Bachrach, Egstrom, and Blackmun (1975) were adopted for use in this study.

Procedure

Subjects were first familiarized with the testing protocol and allowed to practice each motion to provide uniformity of all motions among subjects. Each subject attended two sessions, one in which his baseline measurements were recorded in loose clothing and another in which measurements were repeated in each suit. Each subject served as his own control.

Each session began with a 20 minute warm-up period during which the subject was led through a series of standard stretching exercises. Preparatory stretching was considered important to prevent an increase in subject flexibility over the length of the testing session. In this way measurements recorded would not favor those suits tested near the end of the session. The session measurements began with a randomly selected suit and proceeded sequentially through the other two suits. The subject was asked to complete each movement to his fullest possible range of motion without jerking or extreme straining. Each movement was measured three times, with the criterion measure being the mean of the three recordings. In order to prevent muscle fatigue, measurements in different suits were never taken consecutively; each subject was given a 25 minute rest period between suit tests.

During each session frontal and overhead views of each subject were videotaped. After all sessions were complete the video tapes were then replayed and photographs taken at the fullest range of each motion.

Measurements were then made directly from the photographs using a protractor. This method of measurement was considered preferable to the use of a goniometer as it precluded the need for the subject to hold the extreme position of each motion for an extended period of time.

RESULTS AND DISCUSSION

Table 3 enumerates the test findings for the fourteen movements, presenting means and standard deviations for each trial condition (baseline and suits: OGX, Prototype C and Prototype D). Statistical analysis of these data were accomplished using a repeated measures analysis of variance program (BMDP 2V.11) on an IBM 370 computer. Each movement was treated separately. Those movements yielding a significant F-test were then analyzed with the Scheffe' test (8) to determine which suit means differed significantly ($p < .05$) from each other. The Scheffe' test was selected because it is considered a stringent test that reduces the probability of a Type One error (finding significance where none exists).

Inspection of the tabular results indicate that of the fourteen movements performed in the suits, only two movements, trunk lateral flexion and shoulder joint abduction, did not differ significantly from the baseline values. In all other movements a significant difference was found for one or more of the suit conditions (F-test). The post hoc analysis of these movements revealed a significant difference between the baseline and the suit condition or conditions. These findings were notable in that, while significant differences from baseline measures were found for suit conditions, no significant differences were found between suits on each of the fourteen movements.

TABLE 3

RANGE OF MOTION

Region	No.	Movement		Baseline	CBR Suits		
					OG84	Prototype C	Prototype D
Trunk	1.	Trunk Flexion	x̄	129°	124°	*121°	*120°
			S.D.	7	8	8	8
			Range	116.8-138.5	111.0-134.5	108.5-129.5	107.0-129.0
	2.	Trunk Extension	x̄	52°	46°	45°	*43°
			S.D.	9	11	8	6
			Range	43.1-71.2	31.6-68.9	35.4-54.8	33.4-54.8
	3.	Trunk Lat. Flex.	x̄	42°	38°	*37°	*37°
			S.D.	3	6	4	3
			Range	39.1-46.8	28.3-46.3	31.0-43.8	33.3-42.8
	4.	Trunk Trans. Rota.	x̄	63°	65°	63°	60°
			S.D.	19	13	12	13
			Range	28.2-88.6	45.7-85.0	49.7-84.3	38.7-81.3
Shoulder	5.	Shoulder Joint Abd.	x̄	178°	175°	172°	173°
			S.D.	9	6	7	4
			Range	169.7-183.0	168.4-185.9	158.0-178.0	163.3-177.8
	6.	Shoulder Joint Flex.	x̄	180°	179°	*176°	177°
			S.D.	6	5	4	5
			Range	169.7-189.9	169.5-185.2	168.8-180.4	166.4-181.9
	7.	Shoulder Joint Ext.	x̄	74°	61°	60°	*57°
			S.D.	9	18	8	13
			Range	51.8-90.2	40.4-87.7	45.2-73.2	43.0-71.2
	8.	Shoulder Joint Hor.	x̄	121°	110°	107°	*104°
			S.D.	9	9	8	8
			Range	99.2-126.2	97.4-121.0	94.5-119.7	99.2-113.6
	9.	Shoulder Joint Hor. Ext.	x̄	49°	42°	*38°	*36°
			S.D.	12	13	15	11
			Range	31.0-67.3	22.8-65.8	15.5-66.0	15.0-51.0
	10.	Elbow Flexion	x̄	140°	*132°	*127°	*132°
			S.D.	5	7	6	10
			Range	132.1-146.8	120.9-141.2	118.7-134.3	115.6-146.0
Hip	11.	Knee Flexion	x̄	[illegible]	125°*	126°*	127°*
			S.D.	8	8	8	7
			Range	118.8-143.5	112.7-136.0	113.8-138.0	113.9-136.8
	12.	Hip Flexion	x̄	[illegible]	93°*	91°*	90°*
			S.D.	8	5	9	6
			Range	95.7-119.4	83.6-96.7	73.6-100.7	82.4-100.0
	13.	Hip Extension	x̄	35°	26°*	26°*	27°*
			S.D.	7	4	5	6
			Range	26.1-45.9	22.3-35.6	15.6-31.2	13.3-31.6
	14.	Hip Abduction	x̄	70°	63°	55°*	55°*
			S.D.	11	12	13	12
			Range	58.0-86.1	42.3-82.6	38.6-82.8	40.7-78.2

* $p < .05$ (Scheffe' test, compared to baseline)

The mean values for suit OGX on the fourteen movements generally differed less from baseline values than did those of Prototypes C and D. The OGX suit did differ significantly from the baseline on only four of the fourteen movements, while Prototype C differed on nine movements and Prototype D differed on eleven movements.

A review of the tabular results by body regions (i.e. trunk, shoulder, and hip) indicates that for movements associated with the trunk region (trunk flexion, trunk extension, trunk lateral flexion, and trunk transverse rotation) the OGX suit did not differ significantly from the baseline measurements. Prototype C differed significantly on two of the four movements and Prototype D differed on three of the four movements.

The movements associated with the shoulder (shoulder joint abduction, shoulder joint flexion, shoulder joint extension, shoulder joint horizontal flexion, shoulder joint horizontal extension, and elbow flexion tended to differentiate the OGX suit from prototypes C and D. Prototype D was found to significantly differ from the baseline on four of the six shoulder movements and Prototype C differ significantly on three movements. The OGX suit differed on only one movement (elbow flexion) from the baseline measurement.

The hip movements (knee flexion, hip flexion, hip extension, and hip abduction) yielded a significant difference from the baseline for two or more suit conditions. The OGX suit differed from baseline on three of the four movements. Prototype C differed from the baseline measures on all four movements, as did Prototype D.

The demonstrated reduction in movements of the hip region by these suits is significant in that tasks requiring these movements are those expected of combat personnel.

The object of this study was to differentiate CBR suits based on flexibility using 14 distinctive movements. From Table 3 it can be seen that on 11 of these movements (i.e. movements 1,2,3,4,5,6,7,8,9,11 and 14) OG84 yielded a mean value greater than Prototype C or D. However, statistical analysis did not determine that these means differed significantly. Therefore, it is concluded that while OG84 may appear to be more flexible, it is not sufficiently different from Prototypes C and D. The failure to differentiate these CBR suits based on range of motion (flexibility) may be attributed to uniformity of suit design across the three suits studied. The only apparent difference in design construction is the integrated hood of the prototypes. Movement four, transverse rotation of the trunk, best assessed the impact of an integrated hood on flexibility, and it can be seen from Table 3 that no statistical difference was demonstrated between the mean values of the baseline and either of the three suits, one without a hood (OG84) and two with hoods (Prototype C and D) for movement four. Thus, it would appear that the addition of an integral hood does not interfere significantly with lateral movement.

In addition, the failure to differentiate these suits by range of motion measures indicate that suits of nylon/cotton fabric containing Von Blucher spheres do not significantly differ in flexibility when compared to suits of nylon/cotton containing powdered carbon (OG84). The superior Von Blucher sphere material (9) can therefore be used in suit construction without impairing flexibility. In light of recently published heat stress testing results indicating the superiority of the Von Blucher sphere in reducing the heat load associated with CBR suit wearing (9), the finding of no significant difference in flexibility should bring this suit material to the fore as the material of choice for CBR suit construction.

The most disturbing finding presented in this study is the apparent reduction in movement associated with locomotion. The movements of the hip region (Table 3, movements 11-14) are associated with walking, running, stepping, jumping, and climbing. This study found that for these movements, significant degradation occurred. A decrease for the OG84 suit was demonstrated on all four movements with three representing a significant decrease. A significant decrease for these four movements was demonstrated for both Prototypes C and D suits.

Thus, it appears that when properly fitted, subjects in this study experienced a significant decrease from baseline value in movements that would ordinarily be expected of field units; namely, movements required to run, walk, climb, jump, and step while wearing any of these CBR suits. If this cross suit sample is indicative of the current state of CBR suit sizing, particularly with regard to the pants component, serious review may be necessary if ground troops in CBR suits are to be expected to conduct defensive and offensive operations.

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