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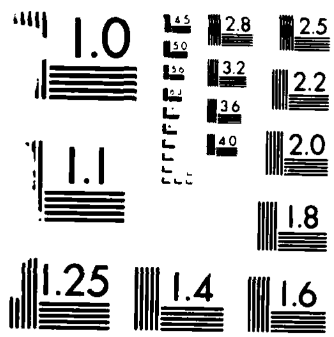

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INFLUENCE OF U.S. ARMY HEADGEAR PARAMETERS ON NECK MUSCLE LOADING AND FATIGUE

Annual Report

Chandler Allen Phillips, M.D., P.E.
and
Jerrold Scott Petrofsky, Ph.D.

December 1982

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Wright State University
Dayton, Ohio 45435

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This study evaluated the endurance times for the lateral and posterior neck muscles when statically and dynamically loaded by 15 headgear configurations (5 different helmet centers-of-gravity and 3 different helmet weights). Systematic variations of these headgear loading configurations was accomplished via a variable C.G.-weight helmet simulator. Various cardiovascular responses, quantitative electromyographic measurements, and recovery responses were also evaluated. Subjects were tested in (continued on reverse)

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an isometric head dynamometer. Results indicate that for the forward-low C.G., the endurance times with 5.0 lb. and 9.0 lb. helmet weights were significantly reduced. ($p < .05$). A pronounced increase in blood pressure, heart rate and rectified E.M.G. amplitude was found for isometric contractions of the neck muscles. The implications of these results to U.S. Army aviator helmet design and helmet-borne avionic devices are discussed.

(p < or = .05.

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SUMMARY

An extensive series of experiments have been conducted to quantify the stress and fatigue of neck muscles as measured by (a) isometric endurance time, (b) characteristic changes in the surface electromyogram and (c) cardiovascular responses. The neck muscles were dynamically and statically loaded by systematic variation of fifteen headgear configura-ations consisting of five different combinations of centers-of-gravity (forward-low, center-low, center-high, right-lateral-low and aftward-low) and three different weights (3.2 lbs., 5.0 lbs. and 9.0 lbs.). 6 subjects would rotate their heads laterally (from side-to-side) for 30 minutes in each of the 15 headgear loading combinations. Immediately thereafter, the subject would position his head in an isometic head dyno-mometer and exert a sustained right lateral neck contraction or forward neck contraction at 70% of his maximum strength, during which endurance time (to fatigue) was recorded, the EMG over the right sternocleidomast-oid muscle, and over the posterior trapezius/splenius muscles was contin-uously recorded, and the systolic and diastolic blood pressure and heart rate was continuously recorded. The results indicate that the endurance times for the forward-low and lateral-right-low C.G.'s at 3.2 lbs. were significantly higher than the other 13 headgear loading combinations, but that endurance times at these two C.G. locations were significantly reduced at helmet weights of 5.0 lbs. and 9.0 lbs. (when right lateral neck muscle contractions were performed). A "trend" was observed in which the endurance time was again relatively high for the aftward-low C.G. location at 9.0 lbs. helmet weight. The RMS amplitude of the EMG continuously increased during a fatiguing contraction, being 60% greater (on the average) by the time of fatigue, and the center frequency of the

EMG power spectrum continuously decreased, being 20% less (on the average) at the fatigue end-point. Systolic blood pressures rose an average 25%, diastolic blood pressures rose an average 40% and heart rates increased 20% (on the average) at the fatigue end-point (compared to resting levels). These results are significant since they provide useful insights into the optimal trade-off between various centers-of-gravity and helmet weight combinations. The results also confirm that the EMG of neck muscles can be used as a noninvasive, objective and quantitative index of neck muscle fatigue, and that there is a significant cardiovascular response associated with fatiguing isometric neck muscle contractions. (This work was supported by U.S. Army contract DAMD17-80-C-0089.)

FOREWORD

Citations of organizations and trade names in this report do not constitute an official Department of the Army endorsement of approval of the products or services of these organizations.

For the protection of human subjects the investigator(s) have adhered to policies of applicable Federal Law 45CFR46.

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INTRODUCTION

Pure isometric exercise is commonly used during postural adjustments such as the neck muscles holding the head (and helmet) erect during (1) flying (and tracking) activity, and (2) driving (and tracking) activity in armored vehicles. Since helmet design influences the onset and recovery from isometric cervical (neck) muscle fatigue, the need exists to objectively quantitate both load on the neck as well as fatigue "end-point." The purpose of this experiment is to determine how cervical muscle loading and fatigue are affected by five headgear centers-of-gravity at three different headgear weights (a total of fifteen combinations) using a variable center-of-gravity and variable weight helmet simulator.

SIGNIFICANCE

Pilots are currently being asked to wear and use more and more headgear. For example, night vision goggles are now being worn in combination with a helmet. An objective evaluation of the cumulative effects of various combinations of headgear on neck muscle tension and fatigue is now needed to establish the optimal "trade-off" between performance requirements and physiological capabilities.

The U.S. Army continues to design and evaluate new helmets for crew members. Impact protection, noise protection and visual protection (among other parameters) are all capable of objective quantitative evaluation with respect to helmet design. Application of EMG amplitude and frequency analysis allows physical tolerance (of the neck muscles) to be an objective, quantifiable parameter which can also be factored into various helmet design configurations.

BACKGROUND

Pure isometric exercise is commonly used during postural adjustments such as the neck muscles holding the head (and helmet) erect during (1) flying (and tracking) activity in helicopters, and (2) driving (and tracking) activity in armored vehicles.

In the last 25 years, a great deal of attention has centered around using the surface EMG as a tool with which to assess the tension exerted by and the degree of fatigue induced in muscle during exercise. Bigland and Lippold (1954), Edwards and Lippold (1956) and Milner-Brown and Stein (1975) all found a linear relationship between the tension exerted during brief isometric contractions and either the integrated or the RMS amplitude of the EMG. Based on this relationship, Messier, et al. (1971) tried to use the EMG amplitude to quantify the tension exerted by contracting muscle. However, the EMG amplitude is also affected by muscle fatigue (Lippold et al. 1960, Eason 1960, DeVries 1968, Lloyd 1971) and therefore, their results can only be applied to unfatigued muscle.

Only recently, however, have the biomechanics of the neck muscles themselves been investigated systematically. Petrofsky and Phillips (1982) demonstrated that the strength-endurance relationship of the neck muscles followed the classic Rohmert (1968) curve which had been defined for the forearm muscles. By evaluating individual neck muscle groups, Phillips and Petrofsky (1981a,b) proposed a physiological basis for helmet design, based upon their characteristic strength-endurance profiles. Furthermore, these characteristic curves were shown to be amenable to quantitative analysis (Phillips and Petrofsky, 1981c).

EMG analysis of the neck muscles in reponse to various headgear loading configurations has been successfully applied by Phillips and

Petrofsky (1982a,b). These studies clearly established quantitative electromyography as a non-invasive index of physiological neck muscle fatigue.

What then remained was to systematically vary a wide range of headgear loading parameters (i.e., center-of-gravity and weight) and observe the characteristic neck muscle responses. It is precisely this topic which is addressed in the following report.

METHODS AND MATERIALS

This section describes how the study was conducted, including use of subjects. This section also includes a brief description of materials and apparatus used in the study.

SUBJECTS

Six subjects were used in these experiments. The subjects were male volunteer university students whose ages, heights, neck sizes, and weights are listed in Table 1. All subjects were informed of all experimental procedures and were medically examined including a thorough history and a complete physical exam. All procedures were fully approved by the committee on human experimentation.

TRAINING

All subjects were first trained to produce a maximum voluntary effort and to sustain that effort to fatigue at the tension used in the study and with the various muscle groups examined here. Isometric training consisted of a series of brief ($<$3 sec.) maximal voluntary contractions (MVC) with an intercontraction interval of 3 minutes. These were followed by a fatiguing isometric contraction. The tension exerted during the fatiguing contraction was set at 70% of the MVC. On any one day, only one direction of contraction was performed and all fatiguing contractions were held at the same percentage of isometric tension. This procedure was repeated on Monday, Wednesday, and Friday of successive weeks until, for any one muscle group (direction), the coefficient of variation (standard deviation divided by the mean) of endurance from day to day was reduced to less than 5%. In practice, the coefficient of variation of strength in these trained subjects was less than 3% from day to day by the end of the training period. Training was conducted at 70% MVC and with both muscle groups examined here. For most subjects, training for any one muscle group averaged about 3 weeks.

ISOMETRIC HEAD DYNAMOMETER

A helmet dynamometer has been developed which can be used to measure the strength and endurance of neck muscles in man in either one of four directions (forward flexion, backward extension, right and left lateral flexion). The dynamometer is based around the army SPH-4 type helmet, but is easily adaptable to other types of military helmets as well. The dynamometer makes it possible to evaluate the effect of various types of dynamic activities and other flight activities on neck muscle strength and neck muscle endurance. It is, therefore, a useful tool in the study of military helmet design and evaluation of the stress induced by flight maneuvers. The isometric head dynamometer has been described in detail by Petrofsky and Phillips (1982).

HELMET SIMULATOR

The systematic assessment of significant helmet design parameters employed a helmet simulator in which both the weight and center-of-gravity were methodically and controllably altered. Such a helmet was developed by Simula, Inc. under subcontract to Wright State University.

The helmet simulator consists of two weight concealment boxes attached to opposite sides of a support ring (headring) which in turn is supported upon the wearer's head by a suspension system taken from an SPH-4 helmet. The weight and c.g. can be altered by positioning variable weights within the concealment boxes. Fabric covers over the boxes prevent the test subjects from obtaining visual clues as to the c.g. location.

The minimum weight of the helmet simulator, without any variable weights in the boxes, is 2.5 lb, slightly less than the weight of most quality crash helmets made by reputable manufacturers. The addition of variable weights to the boxes can alter the center of gravity to simulate the effect of equipment attached to the outside of a helmet. The helmet simulator has been calibrated for weights of 3.2, 4.0, 5.0, 7.0, and 9.0 lb for each of the c.g. locations shown in Table 2. Figure 1 illustrates the range of c.g. variations together with definition of the coordinate axes by which the c.g. locations are measured.

As shown in Figure 1, a point midway between the left and right ear canals has been chosen as the origin of the coordinate axes. The helmet simulator has been provided with adjustment to ensure that an index point on it can be ligned with the ear canals, and also with independent adjustment to permit the suspension system to be made comfortable.

Five headgear centers-of-gravity for three different headgear weights (a total of fifteen headgear combinations) were evaluated (as per Table 3) utilizing the variable center-of-gravity and variable weight helmet simulator. The "essential equivalency" between the variable center-of-gravity and variable weight helmet simulator and selected headgear loading configurations has been reported by Phillips and Petrofsky (1982c).

EXPERIMENTAL PROTOCOL

The experimental protocol may be summarized as follows:

Pre-Exercise MVC

With the subject seated in the helmet dynamometer, the subject would then either perform a brief (3 second) forward MVC (with EMG recorded from the sternocleidomastoid muscle) or a brief (3 second) right lateral MVC (with EMG recorded simultaneously from both the posterior neck muscles and sternocleidomastoid neck muscle). The contraction mode selected, would then be repeated at 3 minute intervals until 3 such contractions were performed. The strongest contraction (highest strength and highest RMS amplitude of the EMG) would then be taken as the reference contraction.

Head Loading Configuration and Exercise Duration

With the subject removed from the isometric head dynamometer, alternating right and left lateral neck rotations were performed while wearing the variable center-of-gravity and variable weight helmet simulator which was set to one of the fifteen headgear combinations. The exercise duration was 30 minutes.

Post-Exercise Contractions

Immediately upon completion of the exercise period, the subject repositioned himself in the isometic head dynamometer, and performed either one of two maneuvers: (1) a target tension of 70% of the pre-exercise MVC was sustained, (in the direction of the pre-exercise MVC), and held to fatigue, the duration of this being called the endurance time; or (2) a brief (3 second) MVC was performed (in the direction of the pre-exercise MVC) immediately, and 1 minute, 3 minutes and 7 minutes following the exercise episodes (0, 1, 3 and 7 minute MVC, respectively).

The order of presentation of the direction of the pre-exercise MVC, the head loading configuration, and post-exercise contractions selected were all randomized for all of the subjects.

ANALYSIS OF THE AMPLITUDE AND FREQUENCY OF THE EMG

Neck muscle EMG was recorded during the pre-exercise MVC's and during the post-exercise contractions (either 70% MVC to fatigue, or the 0, 1, 3 and 7 minute MVC). The EMG recordings were analyzed in the bioinstrumentation laboratory of Wright State University on an Intel 8080A based microprocessor. The EMG was sampled over 1.5 second periods at a sampling frequency of 2048 samples per second. The EMG amplitude was then calculated from the 1.5 second sample as the full wave RMS amplitude of the EMG. Next the digitalized EMG was broken into 6 data blocks of 512 samples each (a total of 3072 samples or 1.5 seconds of EMG). A 512 point Fourier transform was then applied to each of the data blocks to calculate the amplitude of the harmonic components from a fundamental frequency of 4 hertz through the first 120 harmonics. Each harmonic component of these 6 Fourier power spectra was then averaged together to obtain the average Fourier power spectra over the 1.5 second sampling period. From this power spectrum, the average of center-frequency could be calculated.

All EMG RMS amplitude data was normalized by the RMS amplitude of the pre-exercise MVC EMG. EMG center-frequency data (70% MVC to fatigue post-exercise contraction) was normalized by the center-frequency calculated at the beginning of the fatiguing contraction. Normalization allowed inter-individual comparisons.

CARDIOVASCULAR RESPONSES

A resting blood pressure (systolic over diastolic) was recorded in all subjects at rest, and as often as possible during the 70% MVC fatiguing contractions during the post-exercise contractions (either lateral or forward directions). Heart rate was continuously recorded on a strip chart-recorder during blood pressure measurements. The systolic and diastolic blood pressure recordings, the time at which they occurred, and the heart rate at those times were processed as a function of the total endurance time of the fatiguing contraction.

STATISTICAL ANALYSIS OF DATA

Calculation of means, standard deviations, and related T-tests were done on an Intel 8080A Microprocessor. The level of significance was chosen at $P < 0.05$.

RESULTS

The results may be summarized in four categories:

ENDURANCE TIME

Table 4 indicates the endurance times (70% MVC neck contraction held to fatigue) for the two contraction modes, three weights and five C.G. configurations. For the forward contraction mode, there is no significant difference between the endurance times and the fifteen head loading configurations. However, for the lateral contraction mode, a number of interesting observations can be made. With a forward-low C.G., the endurance times for 5.0 lb. and 9.0 lb. helmet weights are significantly reduced as compared to the 3.2 lb. helmet weight ($p < 0.5$). For the lateral-right low C.G., a clear pattern is seen in which the endurance times for 5.0 lb. and 9.0 lb. helmet weights are reduced (compared to the 3.2 lb. helmet weight), but this pattern is only at the 90% confidence level. Finally, for the aftward-low C.G., there is a tendency for the endurance time to be increased with the 9.0 lb. helmet weight as compared to the 3.2 lb. and 5.0 lb. helmet weight. However, this is only a trend as there is not statistical significance due to the large standard deviation at 9.0 lbs. With a center-high or center-low C.G., there are no clear correlations between endurance times and helmet weight. These results and their significance to the military operational environment are discussed at some length in the next section of this report.

EMG RESPONSE

The EMG response consisting of the RMS amplitude change and center frequency change are shown for the forward contraction mode at 3.2 lbs. (Table 5), 5.0 lbs. (Table 6), 9.0 lbs. (Table 7) and also for the lateral contraction mode at 3.2 lbs. (Table 8), 5.0 lbs. (Table 9), 9.0 lbs. (Table 10). On the average, there is a 78% increase in the RMS amplitude and a 21% decrease in the center frequency for the forward contraction mode with the fifteen head loading configurations (Tables 5, 6, and 7). For the lateral contraction mode, there is an average 44% increase in the RMS amplitude of the EMG and an average 20% decrease in the center frequency for the fifteen head loading configurations (Tables 8, 9, and 10). These results are entirely consistent with those of Petrofsky (1980) for handgrip muscles, indicating that the subjects were indeed performing fatiguing contractions.

CARDIOVASCULAR RESPONSES

For the forward contraction mode utilizing predominantly the sternocleidomastoid muscles (Phillips and Petrofsky, 1981d), there is an average 25% increase in the systolic blood pressure, an average 40% increase in the diastolic blood pressure, and an average 16% increase in the heart rate for all fifteen headloading configurations (Tables 11, 12 and 13). For the lateral contraction mode using predominantly the trapezius and splenius muscles as well as the sternocleidomastoid muscles (Phillips and Petrofsky, 1981d), there is an average 26% increase in the systolic blood pressure, an average 40% increase in the diastolic blood pressure, and an average 22% increase in the heart rate for all fifteen headloading configurations (Tables 14, 15 and 16).

STRENGTH-RECOVERY RESPONSE

The strength-recovery response as measured by the RMS amplitude of the EMG is shown for both the forward and lateral contraction modes at 3.2 lbs. (Table 17), 5.0 lbs. (Table 18) and 9.0 lbs. (Table 19).

The RMS amplitude of the EMG as an index of isometric strength-recovery appears to be highly variable for both contraction modes, helment C.G. and helmet weight. Consequently, no consistent pattern was observed with respect to the neck muscles studied.

DISCUSSION AND CONCLUSIONS

This study has involved a comprehensive analysis of the neck muscles and their response to systematic variations of head loading configurations. This section discusses the results and the conclusions reached.

ENDURANCE TIME

At the standard helmet weight (3.2 lbs.), loading with a forward-low C.G. or lateral-right-low C.G. is associated with large endurance times for the lateral contraction mode (compared to the forward contraction mode). This is probably due (in part) because lateral neck contractions (as shown by Phillips and Petrofsky, 1981d) utilize both posterior and lateral neck muscle groups as contrasted to forward neck muscle contractions which utilize almost exclusively the lateral neck muscles (while very little contribution is made by the posterior neck muscles). However, as more helmet weight is added (5.0 lbs. and 9.0 lbs.), there is a significant reduction in endurance times for the lateral contraction mode (Table 4). This is a significant observation since loading with night vision goggles tends to shift the helmet C.G. forward (and low), and C.G. loading with "heads up" avionics devices tends to shift the helmet C.G. laterally (right-ward and low). In essence, the additional weight loading (at these C.G. locations) negates the high endurance times seen without the additional loading (3.2 lbs.). The precise mechanism for this phenomenon is not clear, but somehow (at standard helmet weight of 3.2 lbs.) laterally contracting neck muscles must optimally "trade-off" (i.e., alternate and/or redistribute) the load among the sternocleidomastoid, trapezius and splenius muscles of the neck. Again, for unknown reasons, additional weight loading (5.0 lbs. and 9.0 lbs.) at these C.G. positions somehow negates this "optimal trade off" arrangement, significantly reducing endurance times. Although precise mechanisms for neck muscle endurance are not known, various possibilities have been discussed in our previous report (Phillips and Petrofsky, 1981d).

A very interesting "trend" in the data of Table 4, is that the endurance time for aftward-low C.G. loading at 9.0 lbs. is greatly increased (for the lateral contraction mode). Actually, endurance time at this weight and C.G. combination tends to approach the high endurance times noted for both the 3.2 lb. with forward-low C.G. and the 3.2 lb. with right-lateral-low C.G. Functionally, this would imply that the "optimal tradeoff" arrangement (whatever its precise mechanism) is being reestablished.

Despite the preliminary nature of these observations, some interesting conclusions may be inferred. First, physiologically optimal helmet loading (at least at large weight levels) may indeed be on the back of the helmet, an area which is not currently being utilized in conventional helmet designs. Future engineering design of equipment intended to be attached to the helmet should consider "redistributing" part of the system (preferably the heavier ports) to the back of the helmet. Second, additional loading could be applied to the back of the helmet when wearing equipment attached to other parts of the helmet. This might tend to "counteract" the deleterious effects of shifting the helmet C.G. too far forward or lateral. Third, a combination of these first two approaches might prove most physiologically beneficial. In this situation one might envision some part of the externally attached equipment mounted on the back of the helmet <u>and</u> some amount of internal loading (preferential weighting) of the helmet shell and/or liner itself toward its backside.

These conclusions must be viewed as preliminary since additional headgear loading configurations remain to be studied in the third year of the project. Also if a population larger than our group of 6 subjects could be studied (at some time in the future) the statistical significance between endurance times and the various headgear loading combinations might be more clearly determined.

EMG RESPONSE

This study confirms our previous report (Phillips and Petrofsky, 1982a) that characteristic changes in the EMG are associated with isometric neck muscle fatigue (an average 60% increase in the RMS amplitude of the EMG and an average 20% decrease in the center frequency of the EMG). For the first time, these characteristic variations are seen to occur over a wide range of helmet loading configurations. The characteristic EMG changes provide a non-invasive, quantitative and objective measurement which indicate that the subjects do perform fatiguing contractions.

CARDIOVASCULAR RESPONSES

This study confirms our previous report (Phillips and Petrofsky, 1982d) that characteristic changes in cardiovascular parameters are associated with isometric neck muscle fatigue (an average 25% increase in systolic blood pressure, an average 40% increase in diastolic blood pressure and our average 20% increase in heart rate). For the first time, these characteristic variations are also seen to occur over a wide range of helmet loading configurations. The fact that diastolic pressures are proportionately more elevated than systolic pressures, would indicate that peripheral arterial vasoconstriction is probably the predominate mechanism. Consequently, helicopter crew members whose neck muscles are subjected to any significant isometric loading by headgear configurations should maintain a high level of cardiovascular fitness.

STRENGTH-RECOVERY RESPONSE

With both contraction modes, various helmet C.G. configurations and helmet weights, the RMS value of the EMG post-exercise appears to be highly variable (for brief MVC's at 0, 1, 3 and 7 minutes post-exercise). This is probably due to a complex interplay of altered muscular blood flow (i.e., post-exercise hyperemia) and muscle temperature (i.e., post-exercise muscle cooling) which alter the characteristic EMG amplitude. Absolute strength of the neck muscles (post-exercise) is probably a better way to quantitate fatigue recovery (Phillips and Petrofsky, 1981d).

CONCLUDING REMARKS

In conclusion, a great deal has been learned from this study. More information is anticipated from a continuation of this study (currently pending) in which nine additional headgear loading configurations will be studied in order to provide an adequate data bank necessary for a definitive mathematical model. The model will predict neck muscle strength-endurance for any headgear loading configuration (within the boundary conditions).

TABLE 1

GENERAL CHARACTERISTIC OF THE SUBJECTS (n = 6)

Subject	Age (yrs.)	Height (cm)	Weight (kg.)	Neck Circ. (cur)
1	22	180	77	37
2	28	175	85	37
3	22	193	79	38
4	20	188	73	37
5	20	185	70	36
6	19	168	61	36

TABLE 2

SPECIFIC C.G. LOCATIONS FOR WHICH THE HELMET SIMULATOR IS CALIBRATED

C.G. Location Description*	Displacement (cm)**		
	X	Y	Z
Central			
Maximum Height	0	0	8.0
Medium Height	0	0	4.0
Low Height	0	0	0
Forward			
Maximum Height	5.0	0	8.0
Medium Height	5.0	0	4.0
Low Height	5.0	0	0
Aftward			
Maximum Height	-2.5	0	8.0
Medium Height	-2.5	0	4.0
Low Height	-2.5	0	0
Central			
Left, Maximum Height	0	2.5	8.0
Left, Medium Height	0	2.5	4.0
Left, Low Height	0	2.5	0
Central			
Right, Maximum Height	0	-2.5	8.0
Right, Medium Height	0	-2.5	4.0
Right, Low Height	0	-2.5	0
Forward			
Left, Maximum Height	4.3	1.8	8.0
Left, Medium Height	4.3	1.8	4.0
Left, Low Height	4.3	1.8	0
Forward			
Right, Maximum Height	4.3	-1.8	8.0
Right, Medium Height	4.3	-1.8	4.0
Right, Low Height	4.3	-1.8	0

* C.G. locations for total weights of less than 4 lb may differ from values shown in this table.

** Displacement from head and neck c.g. (axis directions as defined in Figure 1).

TABLE 3

FIFTEEN HEADGEAR COMBINATIONS EVALUATED

C.G.-Weight Description	Weight (lbs)	X	Displacement Y	(cm)* Z
CL				
Center-Low-3	3.2	0	0	0
Center-Low-5	5.0	0	0	0
Center-Low-9	9.0	0	0	0
CH				
Center-High-3	3.2	0	0	8.0
Center-High-5	5.0	0	0	8.0
Center-High-9	9.0	0	0	8.0
FL				
Forward-Low-3	3.2	5.0	0	0
Forward-Low-5	5.0	5.0	0	0
Forward-Low-9	9.0	5.0	0	0
LRL				
Lat-Right-Low-3	3.2	0	-2.5	0
Lat-Right-Low-5	5.0	0	-2.5	0
Lat-Right-Low-9	9.0	0	-2.5	0
AL				
Afterward-Low-3	3.2	-2.5	0	0
Afterward-Low-5	5.0	-2.5	0	0
Afterward-Low-9	9.0	-2.5	0	0

* Displacement from the head/neck center-of-gravity: axis directions as per Fig. 1, and displacement distances as per Table 2.

TABLE 4

ENDURANCE TIME (seconds)

A. Forward Contraction:

Wt. / *C.G.	3.2 lbs.	5.0 lbs.	9.0 lbs.
FL	86 ± 49	65 ± 26	55 ± 24
AL	86 ± 34	64 ± 19	83 ± 20
CH	71 ± 49	81 ± 59	73 ± 55
LRL	75 ± 57	66 ± 21	96 ± 61
CL	98 ± 34	74 ± 43	68 ± 34

B. Lateral Contraction:

Wt. / *C.G.	3.2 lbs.	5.0 lbs.	9.0 lbs.
FL	157 ± 56	89 ± 42**	62 ± 35***
AL	88 ± 35	73 ± 47	129 ± 69
CH	82 ± 56	72 ± 35	61 ± 39
LRL	156 ± 59	81 ± 40 ●	71 ± 35 ●●
CL	106 ± 88	83 ± 33	89 ± 38

*See Table 3.

** $p < .05$ compared to 3.2 lb. weight

*** $p < .05$ compared to 3.2 lb. weight

● $p < .10$ compared to 3.2 lb. weight

●● $p < .10$ compared to 3.2 lb. weight

TABLE 5

EMG RESPONSE, FORWARD CONTRACTION (3.2 lbs.)

Percent Endurance Time	FORWARD LOW (n=4)		AFTWARD LOW (n=5)		CENTER HIGH (n=6)	
	Amplitude	Center Freq.	Amplitude	Center Freq.	Amplitude	Center Freq.
Resting	.62 ± .10	1.00 -	.47 ± .13	1.00 -	.54 ± .16	1.00 -
20	.68 ± .15	.97 ± .02	.64 ± .20	.95 ± .05	.63 ± .20	.92 ± .06
40	.77 ± .16	.93 ± .05	.68 ± .26	.91 ± .04	.70 ± .23	.86 ± .04
60	.84 ± .20	.89 ± .06	.72 ± .26	.88 ± .06	.81 ± .21	.84 ± .04
80	.95 ± .20	.88 ± .09	.84 ± .23	.83 ± .08	.88 ± .24	.81 ± .03
100	1.06 ± .20	.79 ± .11	1.01 ± .18	.79 ± .08	1.02 ± .19	.78 ± .05

Percent Endurance Time	LATERAL RIGHT LOW (n=5)		CENTER LOW (n=4)	
	Amplitude	Center Freq.	Amplitude	Center Freq.
Resting	.62 ± .12	1.00 -	.62 ± .12	1.00 -
20	.69 ± .13	.95 ± .03	.58 ± .12	.96 ± .04
40	.73 ± .07	.89 ± .03	.63 ± .18	.84 ± .07
60	.81 ± .17	.86 ± .05	.65 ± .20	.82 ± .09
80	1.02 ± .10	.82 ± .03	.80 ± .09	.78 ± .12
100	1.12 ± .15	.77 ± .04	.91 ± .11	.74 ± .08

TABLE 6

EMG RESPONSE, FORWARD CONTRACTION (5.0 lbs.)

Percent Endurance Time	FORWARD LOW (n=6)		AFTWARD LOW (n=5)		CENTER HIGH (n=6)	
	Amplitude	Center Freq.	Amplitude	Center Freq.	Amplitude	Center Freq.
Resting	.51 ± .07	1.00 -	.50 ± .13	1.00 -	.60 ± .11	1.00 -
20	.60 ± .13	.94 ± .01	.64 ± .11	.93 ± .06	.67 ± .12	.90 ± .10
40	.66 ± .20	.90 ± .06	.69 ± .11	.89 ± .08	.77 ± .10	.87 ± .08
60	.78 ± .17	.85 ± .08	.72 ± .14	.86 ± .08	.90 ± .15	.82 ± .07
80	.88 ± .20	.80 ± .08	.85 ± .16	.83 ± .08	.92 ± .95	.80 ± .08
100	1.04 ± .18	.76 ± .06	.99 ± .11	.79 ± .09	1.05 ± .13	.75 ± .09

Percent Endurance Time	LATERAL RIGHT LOW (n=5)		CENTER LOW (n=5)	
	Amplitude	Center Freq.	Amplitude	Center Freq.
Resting	.57 ± .14	1.00 -	.60 ± .22	1.00 -
20	.70 ± .15	.98 ± .04	.69 ± .22	.93 ± .06
40	.75 ± .18	.93 ± .05	.77 ± .22	.90 ± .05
60	.84 ± .20	.87 ± .06	.84 ± .21	.85 ± .10
80	.95 ± .23	.84 ± .07	.89 ± .19	.91 ± .09
100	1.06 ± .33	.79 ± .11	1.02 ± .16	.78 ± .08

TABLE 7

EMG RESPONSE, FORWARD CONTRACTION (9.0 lbs.)

Percent Endurance Time	FORWARD LOW (n=6)		AFTWARD LOW (n=4)		CENTER HIGH (n=6)	
	Amplitude	Center Freq.	Amplitude	Center Freq.	Amplitude	Center Freq.
Resting	.54 ± .10	1.00 -	.64 ± .07	1.00 -	.51 ± .09	1.00 -
20	.64 ± .07	.97 ± .04	.69 ± .09	.94 ± .05	.57 ± .11	.92 ± .04
40	.69 ± .10	.90 ± .04	.74 ± .11	.91 ± .09	.59 ± .10	.89 ± .06
60	.77 ± .11	.89 ± .06	.75 ± .04	.89 ± .09	.72 ± .13	.86 ± .06
80	.88 ± .16	.85 ± .07	.82 ± .07	.85 ± .09	.79 ± .10	.80 ± .08
100	.98 ± .14	.83 ± .09	.85 ± .09	.82 ± .12	.90 ± .14	.78 ± .12

Percent Endurance Time	LATERAL RIGHT LOW (n=5)		CENTER LOW (n=5)	
	Amplitude	Center Freq.	Amplitude	Center Freq.
Resting	.52 ± .21	1.00 -	.61 ± .14	1.00 -
20	.56 ± .21	.97 ± .08	.63 ± .11	.95 ± .02
40	.61 ± .24	.93 ± .09	.71 ± .10	.93 ± .04
60	.69 ± .21	.88 ± .10	.89 ± .04	.92 ± .05
80	.77 ± .19	.86 ± .09	.90 ± .10	.88 ± .06
100	.98 ± .13	.83 ± .08	1.06 ± .08	.81 ± .04

TABLE 8

EMG RESPONSE, LATERAL CONTRACTION (3.2 lbs.)

Percent Endurance Time	FORWARD LOW (n=6) Amplitude	FORWARD LOW (n=6) Center Freq.	AFTWARD LOW (n=6) Amplitude	AFTWARD LOW (n=6) Center Freq.	CENTER HIGH (n=5) Amplitude	CENTER HIGH (n=5) Center Freq.
Resting	.54 ± .10	1.00 -	.64 ± .15	1.00 -	.63 ± .08	1.00 -
20	.73 ± .21	.93 ± .07	.71 ± .12	.95 ± .03	.65 ± .12	.96 ± .04
40	.61 ± .13	.90 ± .05	.77 ± .08	.90 ± .05	.75 ± .08	.89 ± .05
60	.63 ± .10	.87 ± .07	.83 ± .10	.88 ± .05	.78 ± .09	.81 ± .06
80	.66 ± .05	.90 ± .05	.91 ± .05	.85 ± .06	.85 ± .10	.85 ± .05
100	.85 ± .13	.82 ± .06	.92 ± .12	.80 ± .05	.95 ± .12	.80 ± .07

Percent Endurance Time	LATERAL RIGHT LOW (n=5) Amplitude	LATERAL RIGHT LOW (n=5) Center Freq.	CENTER LOW (n=6) Amplitude	CENTER LOW (n=6) Center Freq.
Resting	.57 ± .08	1.00 -	.62 ± .20	1.00 -
20	.63 ± .06	.94 ± .06	.70 ± .21	.96 ± .06
40	.65 ± .06	.88 ± .08	.76 ± .19	.92 ± .09
60	.68 ± .06	.83 ± .08	.76 ± .20	.92 ± .08
80	.74 ± .08	.79 ± .08	.84 ± .14	.86 ± .09
100	.83 ± .14	.73 ± .06	.96 ± .16	.81 ± .12

TABLE 9

EMG RESPONSE, LATERAL CONTRACTION (5.0 lbs.)

Percent Endurance Time	FORWARD LOW (n=6)		AFTWARD LOW (n=5)		CENTER HIGH (n=5)	
	Amplitude	Center Freq.	Amplitude	Center Freq.	Amplitude	Center Freq.
Resting	.55 ± .04	1.00 -	.70 ± .21	1.00 -	.67 ± .13	1.00 -
20	.63 ± .09	.92 ± .04	.76 ± .31	.95 ± .08	.64 ± .16	.95 ± .12
40	.66 ± .10	.88 ± .06	.84 ± .33	.91 ± .08	.64 ± .13	.88 ± .09
60	.72 ± .12	.83 ± .04	.88 ± .26	.88 ± .10	.77 ± .15	.86 ± .12
80	.79 ± .10	.78 ± .03	.95 ± .29	.86 ± .11	.85 ± .12	.80 ± .11
100	.89 ± .12	.76 ± .05	.93 ± .18	.81 ± .09	.97 ± .11	.81 ± .11

Percent Endurance Time	LATERAL RIGHT LOW (n=5)		CENTER LOW (n=5)	
	Amplitude	Center Freq.	Amplitude	Center Freq.
Resting	.60 ± .11	1.00 -	.64 ± .20	1.00 -
20	.70 ± .09	.94 ± .02	.65 ± .10	.95 ± .04
40	.73 ± .08	.90 ± .04	.60 ± .05	.91 ± .06
60	.72 ± .13	.88 ± .04	.61 ± .09	.88 ± .07
80	.77 ± .14	.86 ± .03	.78 ± .10	.79 ± .09
100	.89 ± .14	.82 ± .06	.78 ± .04	.78 ± .09

TABLE 10

EMG RESPONSE, LATERAL CONTRACTION (9.0 lbs.)

Percent Endurance Time	FORWARD LOW (n=6) Amplitude	FORWARD LOW (n=6) Center Freq.	AFTWARD LOW (n=5) Amplitude	AFTWARD LOW (n=5) Center Freq.	CENTER HIGH (n=5) Amplitude	CENTER HIGH (n=5) Center Freq.
Resting	.62 ± .09	1.00 -	.62 ± .07	1.00 -	.65 ± .11	1.00 -
20	.65 ± .05	.94 ± .02	.68 ± .08	.96 ± .06	.71 ± .10	.97 ± .03
40	.71 ± .10	.91 ± .07	.72 ± .11	.93 ± .09	.72 ± .09	.95 ± .07
60	.84 ± .13	.92 ± .04	.74 ± .03	.39 ± .08	.67 ± .11	.88 ± .10
80	.92 ± .13	.83 ± .11	.82 ± .06	.85 ± .08	.82 ± .09	.87 ± .12
100	1.04 ± .13	.78 ± .09	.85 ± .09	.85 ± .13	.90 ± .13	.86 ± .09

Percent Endurance Time	LATERAL RIGHT LOW (n=6) Amplitude	LATERAL RIGHT LOW (n=6) Center Freq.	CENTER LOW (n=4) Amplitude	CENTER LOW (n=4) Center Freq.
Resting	.71 ± .17	1.00 -	.68 ± .18	1.00 -
20	.68 ± .11	.95 ± .02	.68 ± .14	.96 ± .02
40	.73 ± .13	.90 ± .05	.79 ± .12	.88 ± .05
60	.79 ± .10	.87 ± .03	.80 ± .21	.84 ± .05
80	.83 ± .11	.85 ± .05	.85 ± .28	.83 ± .05
100	.92 ± .11	.78 ± .03	.91 ± .25	.79 ± .07

TABLE 11

CARDIOVASCULAR RESPONSE, FORWARD CONTRACTION (3.2 lbs.)

Percent Endurance Time	FORWARD LOW (n=4)			AFTWARD LOW (n=5)			CENTER HIGH (n=6)		
	Syst. B.P.	Diast B.P.	H.R.	Syst. B.P.	Diast B.P.	H.R.	Syst. B.P.	Diast B.P.	H.R.
Resting	126 ± 19	92 ± 18	72 ± 7	116 ± 5	84 ± 7	80 ± 6	119 ± 6	85 ± 6	85 ± 13
20	128 ± 21	94 ± 17	83 ± 12	124 ± 8	92 ± 9	86 ± 7	125 ± 9	92 ± 8	98 ± 8
40	132 ± 23	98 ± 19	84 ± 11	133 ± 13	99 ± 12	90 ± 9	114 ± 13	100 ± 12	97 ± 7
60	135 ± 26	103 ± 20	81 ± 12	141 ± 17	106 ± 14	86 ± 16	144 ± 16	106 ± 15	100 ± 11
80	139 ± 30	107 ± 23	83 ± 10	149 ± 22	113 ± 17	86 ± 14	151 ± 23	113 ± 19	105 ± 9
100	143 ± 43	111 ± 25	85 ± 13	157 ± 27	121 ± 20	91 ± 16	159 ± 27	120 ± 22	104 ± 10

Percent Endurance Time	LATERAL RIGHT LOW (n=5)			CENTER LOW (n=4)		
	Syst. B.P.	Diast B.P.	H.R.	Syst. B.P.	Diast B.P.	H.R.
Resting	119 ± 4	82 ± 4	80 ± 14	126 ± 11	83 ± 8	79 ± 13
20	126 ± 6	90 ± 3	88 ± 7	133 ± 11	88 ± 7	81 ± 11
40	130 ± 5	100 ± 7	92 ± 8	137 ± 10	95 ± 7	89 ± 9
60	141 ± 15	109 ± 12	92 ± 8	141 ± 10	103 ± 8	89 ± 10
80	148 ± 19	119 ± 18	86 ± 15	145 ± 9	111 ± 10	92 ± 10
100	156 ± 24	124 ± 19	84 ± 11	149 ± 9	118 ± 13	94 ± 17

TABLE 12

CARDIOVASCULAR RESPONSE, FORWARD CONTRACTION (5.0 lbs.)

Percent Endurance Time	FORWARD LOW (n=6)			AFTWARD LOW (n=5)			CENTER HIGH (n=6)		
	Syst. B.P.	Diast B.P.	H.R.	Syst. B.P.	Diast B.P.	H.R.	Syst. B.P.	Diast B.P.	H.R.
Resting	113 ± 15	81 ± 10	83 ± 9	117 ± 10	84 ± 5	89 ± 23	121 ± 19	84 ± 11	72 ± 7
20	116 ± 14	87 ± 7	91 ± 13	123 ± 10	91 ± 6	88 ± 16	126 ± 18	90 ± 10	86 ± 14
40	123 ± 16	94 ± 6	87 ± 13	129 ± 13	97 ± 9	89 ± 16	132 ± 18	97 ± 10	85 ± 16
60	129 ± 17	99 ± 5	93 ± 13	134 ± 16	103 ± 12	89 ± 18	139 ± 19	104 ± 11	88 ± 19
80	133 ± 19	104 ± 6	104 ± 6	140 ± 21	110 ± 16	94 ± 16	146 ± 19	111 ± 11	90 ± 20
100	138 ± 21	110 ± 8	88 ± 13	146 ± 25	116 ± 19	91 ± 19	152 ± 21	118 ± 21	100 ± 19

Percent Endurance Time	LATERAL RIGHT LOW (n=5)			CENTER LOW (n=5)		
	Syst. B.P.	Diast B.P.	H.R.	Syst. B.P.	Diast B.P.	H.R.
Resting	116 ± 9	77 ± 6	88 ± 19	116 ± 14	82 ± 7	72 ± 12
20	119 ± 9	82 ± 5	92 ± 3	115 ± 13	87 ± 8	85 ± 10
40	124 ± 10	87 ± 6	92 ± 9	129 ± 11	93 ± 11	86 ± 9
60	128 ± 19	82 ± 7	94 ± 6	136 ± 18	96 ± 16	88 ± 12
80	132 ± 11	97 ± 9	92 ± 18	142 ± 21	103 ± 19	85 ± 15
100	136 ± 12	102 ± 10	94 ± 22	149 ± 23	109 ± 23	84 ± 15

TABLE 13

CARDIOVASCULAR RESPONSE, FORWARD CONTRACTION (9.0 lbs.)

Percent Endurance	FORWARD LOW (n=6)			AFTWARD LOW (n=5)			CENTER HIGH (n=6)		
Time	Syst. B.P.	Diast B.P.	H.R.	Syst. B.P.	Diast B.P.	H.R.	Syst. B.P.	Diast B.P.	H.R.
Resting	124 ± 17	84 ± 10	82 ± 8	125 ± 16	85 ± 9	78 ± 14	120 ± 12	88 ± 11	77 ± 11
20	127 ± 16	90 ± 12	87 ± 10	129 ± 15	91 ± 10	83 ± 3	127 ± 10	91 ± 9	94 ± 14
40	133 ± 15	98 ± 14	93 ± 14	134 ± 18	97 ± 11	84 ± 10	133 ± 11	95 ± 11	92 ± 13
60	139 ± 15	105 ± 16	101 ± 13	139 ± 21	102 ± 13	84 ± 18	140 ± 13	99 ± 13	97 ± 15
80	145 ± 15	112 ± 19	97 ± 15	143 ± 25	107± 14	87 ± 16	146 ± 17	194 ± 16	98 ± 17
100	151 ± 17	131 ± 28	103 ± 28	148 ± 30	113± 16	89 ± 23	153 ± 21	108 ± 19	99 ± 20

Percent Endurance	LATERAL RIGHT LOW (n=5)			CENTER LOW (n=5)		
Time	Syst. B.P.	Diast B.P.	H.R.	Syst. B.P.	Diast B.P	H.R.
Resting	118 ± 10	83 ± 9	80 ± 6	116 ± 11	78 ± 6	78 ± 8
20	127 ± 10	91 ± 8	86 ± 7	122 ± 15	87 ± 9	84 ± 14
40	136 ± 11	100 ± 10	88 ± 10	127 ± 17	94 ± 12	82 ± 17
60	144 ± 12	108 ± 11	94 ± 7	132 ± 19	104 ± 13	85 ± 16
80	152 ± 13	117 ± 13	87 ± 10	137 ± 21	112 ± 16	85 ± 20
100	160 ± 15	125 ± 15	103 ± 23	143 ± 24	120 ± 20	87 ± 11

TABLE 14

CARDIOVASCULAR RESPONSE, LATERAL CONTRACTION (3.2 lbs.)

Percent Endurance Time	FORWARD LOW (n=6)			AFTWARD LOW (n=5)			CENTER HIGH (n=6)		
	Syst. B.P.	Diast B.P.	H.R.	Syst. B.P.	Diast B.P.	H.R.	Syst. B.P.	Diast B.P.	H.R.
Resting	119 ± 13	83 ± 12	83 ± 7	122 ± 16	83 ± 13	80 ± 5	113 ± 17	83 ± 17	74 ± 10
20	128 ± 17	94 ± 16	90 ± 5	129 ± 15	91 ± 12	88 ± 6	120 ± 16	87 ± 15	85 ± 9
40	135 ± 23	101 ± 18	95 ± 9	136 ± 15	98 ± 11	94 ± 6	125 ± 18	93 ± 19	85 ± 15
60	138 ± 21	109 ± 21	97 ± 12	143 + 16	106 ± 11	95 ± 7	131 ± 21	99 ± 25	96 ± 19
80	142 ± 24	115 ± 26	97 ± 17	150 ± 16	113 ± 12	100 ± 8	136 ± 25	105 ± 31	104 ± 38
100	147 ± 27	124 ± 28	99 ± 17	157 ± 19	120 ± 14	97 ± 8	142 ± 29	111 ± 38	100 ± 35

Percent Endurance Time	LATERAL RIGHT LOW (n=5)			CENTER LOW (n=5)		
	Syst. B.P.	Diast B.P.	H.R.	Syst. B.P.	Diast B.P.	H.R.
Resting	122 ± 10	85 ± 9	83 ± 17	114 ± 15	83 ± 10	78 ± 7
20	131 ± 11	92 ± 9	92 ± 7	126 ± 12	91 ± 12	89 ± 11
40	136 ± 12	98 ± 9	92 ± 8	132 ± 13	97 ± 13	91 ± 5
60	142 ± 13	104 ± 10	95 ± 8	139 ± 14	102 ± 13	93 ± 6
80	148 ± 14	109 ± 11	95 ± 12	146 ± 15	108 ± 15	91 ± 15
100	154 ± 16	115 ± 13	96 ± 11	155 ± 17	114 ± 15	96 ± 11

TABLE 15

CARDIOVASCULAR RESPONSE, LATERAL CONTRACTION (5.0 lbs.)

Percent Endurance Time	FORWARD LOW (n=6)			AFTWARD LOW (n=5)			CENTER HIGH (n=6)		
	Syst. B.P.	Diast B.P.	H.R.	Syst. B.P.	Diast B.P.	H.R.	Syst. B.P.	Diast B.P.	H.R.
Resting	114 ± 11	81 ± 13	81 ± 18	123 ± 16	78 ± 18	80 ± 11	118 ± 12	82 ± 9	83 ± 11
20	117 ± 23	90 ± 10	93 ± 15	131 ± 17	90 ± 12	96 ± 13	124 ± 11	87 ± 11	97 ± 11
40	132 ± 12	98 ± 7	95 ± 8	137 ± 20	97 ± 17	95 ± 13	129 ± 11	94 ± 12	101 ± 7
60	140 ± 11	106 ± 6	90 ± 15	143 ± 24	104 ± 22	94 ± 13	134 ± 11	100 ± 13	102 ± 9
80	148 ± 12	115 ± 5	95 ± 18	150 ± 27	111 ± 26	99 ± 13	140 ± 11	107 ± 14	101 ± 12
100	155 ± 12	123 ± 6	95 ± 14	155 ± 31	118 ± 31	101 ± 11	145 ± 12	114 ± 16	96 ± 17

Percent Endurance Time	LATERAL RIGHT LOW (n=5)			CENTER LOW (n=5)		
	Syst. B.P.	Diast B.P.	H.R.	Syst. B.P.	Diast B.P.	H.R.
Resting	122 ± 13	84 ± 14	84 ± 12	124 ± 16	86 ± 8	79 ± 10
20	130 ± 15	91 ± 14	96 ± 15	129 ± 15	90 ± 8	92 ± 7
40	137 ± 18	98 ± 15	99 ± 14	134 ± 13	94 ± 9	95 ± 11
60	144 ± 20	104 ± 17	97 ± 9	139 ± 12	101 ± 11	99 ± 16
80	151 ± 23	111 ± 19	103 ± 11	144 ± 13	106 ± 13	98 ± 17
100	158 ± 26	117 ± 21	99 ± 7	149 ± 16	111 ± 14	104 ± 16

TABLE 16

CARDIOVASCULAR RESPONSE, LATERAL CONTRACTION (9.0 lbs.)

Percent Endurance Time	FORWARD LOW (n=6)			AFTWARD LOW (n=5)			CENTER HIGH (n=6)		
	Syst. B.P.	Diast B.P.	H.R.	Syst. B.P.	Diast B.P.	H.R.	Syst. B.P.	Diast B.P.	H.R.
Resting	123 ± 12	81 ± 10	81 ± 9	122 ± 13	87 ± 10	78 ± 15	120 ± 15	89 ± 11	82 ± 10
20	132 ± 11	90 ± 10	102 ± 7	129 ± 9	94 ± 8	84 ± 9	124 ± 17	95 ± 10	97 ± 14
40	138 ± 12	100 ± 11	101 ± 6	134 ± 9	100 ± 9	86 ± 12	129 ± 19	100 ± 9	95 ± 14
60	146 ± 12	109 ± 13	105 ± 8	139 ± 10	106 ± 10	90 ± 14	135 ± 21	105 ± 9	96 ± 17
80	153 ± 13	118 ± 16	108 ± 9	144 ± 12	111 ± 12	88 ± 14	140 ± 23	110 ± 9	95 ± 14
100	161 ± 15	127 ± 19	97 ± 19	149 ± 15	117 ± 14	90 ± 14	145 ± 25	115 ± 11	98 ± 11

Percent Endurance Time	LATERAL RIGHT LOW (n=5)			CENTER LOW (n=5)		
	Syst. B.P.	Diast B.P.	H.R.	Syst. B.P.	Diast B.P.	H.R.
Resting	126 ± 18	87 ± 13	76 ± 8	125 ± 10	85 ± 8	71 ± 6
20	132 ± 17	93 ± 12	94 ± 15	132 ± 11	94 ± 10	89 ± 9
40	137 ± 17	98 ± 13	92 ± 11	138 ± 14	98 ± 12	92 ± 6
60	142 ± 19	104 ± 15	99 ± 16	144 ± 17	103 ± 14	95 ± 3
80	147 ± 21	110 ± 16	101 ± 10	150 ± 20	108 ± 16	89 ± 6
100	153 ± 24	116 ± 18	104 ± 19	156 ± 23	112 ± 19	90 ± 5

TABLE 17

STRENGTH-RECOVERY RESPONSE (EMG Amplitude), 3.2 lbs.

A. Forward Contraction:

Time Interval	CENTER LOW (n=6)	CENTER HIGH (n=5)	LATERAL RIGHT LOW (n=5)	FORWARD LOW (n=5)	AFTWARD LOW (n=4)
Pre-Exercise	1.00 -	1.00 -	1.00 -	1.00 -	1.00 -
0 min. post	.96 ± .24	.84 ± .13	.68 ± .16	.93 ± .26	.71 ± .07
1 min. post	.79 ± .21	.77 ± .17	.73 ± .13	.90 ± .17	.74 ± .11
3 min. post	.88 ± .16	.85 ± .24	.68 ± .09	.92 ± .25	.71 ± .12
7 min. post	1.01 ± .59	.80 ± .23	.71 ± .13	.86 ± .29	.76 ± .14

B. Lateral Contraction:

Time Interval	CENTER LOW (n=6)	CENTER HIGH (n=5)	LATERAL RIGHT LOW (n=5)	FORWARD LOW (n=5)	AFTWARD LOW (n=4)
Pre-Exercise	1.00 -	1.00 -	1.00 -	1.00 -	1.00 -
0 min. post	1.04 ± .20	.75 ± .30	1.13 ± .39	.81 ± .20	.65 ± .19
1 min. post	.75 ± .20	.65 ± .17	.75 ± .30	.67 ± .28	.71 ± .09
3 min. post	1.11 ± .33	.69 ± .19	1.04 ± .39	.87 ± .40	.69 ± .12
7 min. post	.83 ± .16	.69 ± .21	.85 ± .20	.72 ± .23	.67 ± .29

TABLE 18

STRENGTH-RECOVERY RESPONSE (EMG Amplitude), 5.0 lbs.

A. Forward Contraction:

Time Interval	CENTER LOW (n=6)	CENTER HIGH (n=6)	LATERAL RIGHT LOW (n=6)	FORWARD LOW (n=6)	AFTWARD LOW (n=6)
Pre-Exercise	1.00 -	1.00 -	1.00 -	1.00 -	1.00 -
0 min. post	.79 ± .18	.73 ± .22	.72 ± .23	.82 ± .19	.96 ± .28
1 min. post	.89 ± .37	.75 ± .26	.66 ± .12	.82 ± .18	.86 ± .21
3 min. post	.81 ± .18	.76 ± .29	.71 ± .15	.77 ± .28	.72 ± .36
7 min. post	.87 ± .29	.69 ± .23	.87 ± .21	.86 ± .23	.74 ± .22

B. Lateral Contraction:

Time Interval	CENTER LOW (n=5)	CENTER HIGH (n=6)	LATERAL RIGHT LOW (n=4)	FORWARD LOW (n=4)	AFTWARD LOW (n=6)
Pre-Exercise	1.00 -	1.00 -	1.00 -	1.00 -	1.00 -
0 min. post	1.01 ± .21	.72 ± .22	1.04 ± .60	.75 ± .38	.71 ± .18
1 min. post	.93 ± .23	.64 ± .35	1.24 ± .71	.72 ± .13	.82 ± .41
3 min. post	.80 ± .15	.95 ± .73	.68 ± .16	.66 ± .18	.60 ± .23
7 min. post	.94 ± .22	.62 ± .17	.73 ± .15	.65 ± .14	.70 ± .27

TABLE 19

STRENGTH-RECOVERY RESPONSE (EMG Amplitude), 9.0 lbs.

A. Forward Contraction:

Time Interval	CENTER LOW (n=6)	CENTER HIGH (n=5)	LATERAL RIGHT LOW (n=6)	FORWARD LOW (n=6)	AFTWARD LOW (n=5)
Pre-Exercise	1.00 -	1.00 -	1.00 -	1.00 -	1.00 -
0 min. post	1.10 ± .48	.89 ± .21	.75 ± .17	.74 ± .35	.90 ± .17
1 min. post	.99 ± .35	.81 ± .17	.85 ± .32	.78 ± .17	.84 ± .19
3 min. post	.97 ± .30	.71 ± .16	.80 ± .13	.84 ± .08	.84 ± .18
7 min. post	.85 ± .37	.98 ± .44	.80 ± .10	.97 ± .13	.94 ± .30

B. Lateral Contraction:

Time Interval	CENTER LOW (n=5)	CENTER HIGH (n=5)	LATERAL RIGHT LOW (n=4)	FORWARD LOW (n=5)	AFTWARD LOW (n=4)
Pre-Exercise	1.00 -	1.00 -	1.00 -	1.00 -	1.00 -
0 min. post	.92 ± .34	.90 ± .31	.65 ± .14	.83 ± .16	.96 ± .10
1 min. post	.90 ± .50	.74 ± .24	.60 ± .07	.76 ± .16	.93 ± .25
3 min. post	.86 ± .26	.76 ± .14	.77 ± .13	.74 ± .16	.78 ± .04
7 min. post	.86 ± .20	.69 ± .27	.63 ± .15	.75 ± .30	.77 ± .09

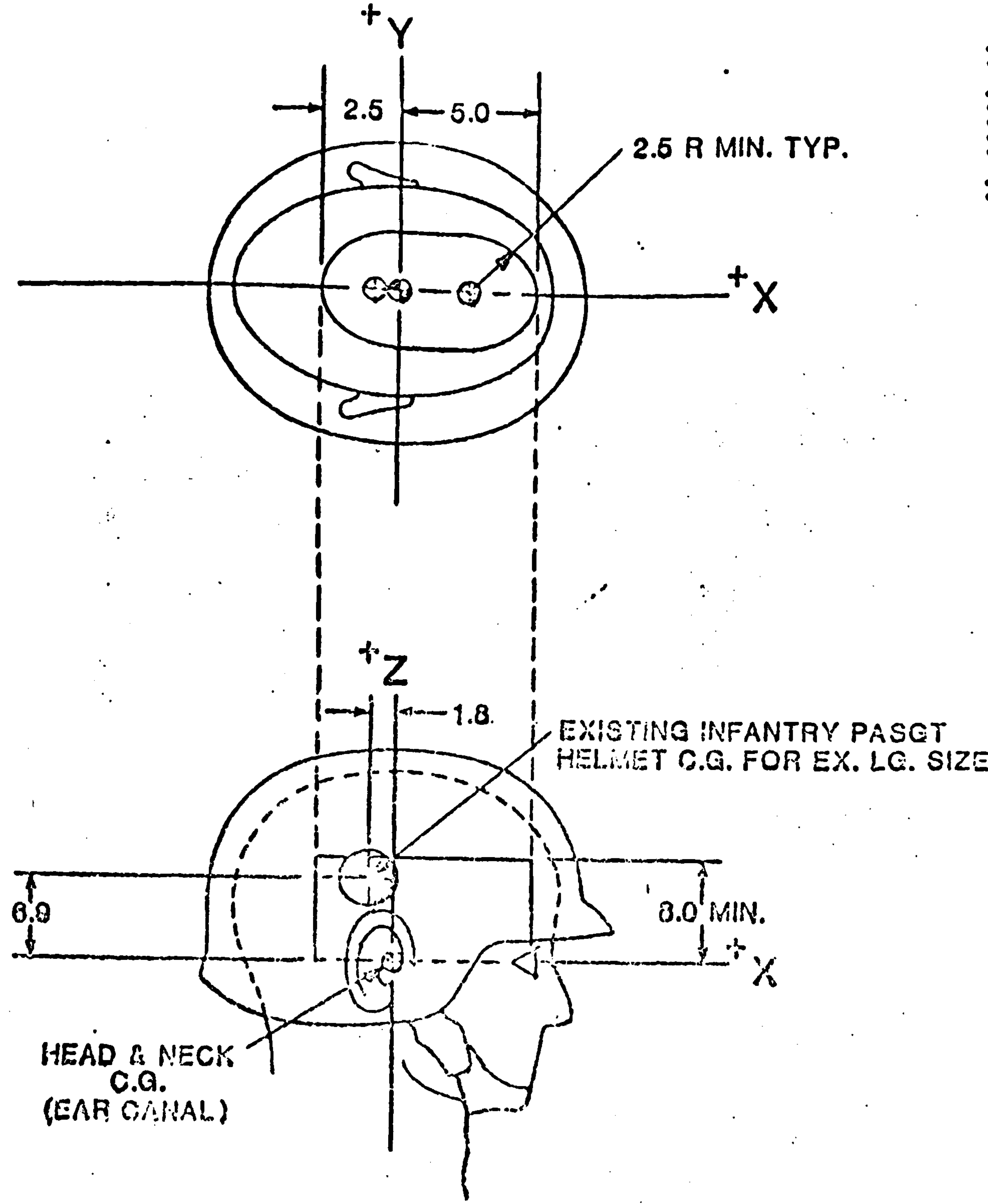

Figure 1. C.G. variation required for test helmet(s)
(all dimensions in centimeters)

REFERENCES CITED

Bigland, B. and O.C.J. Lippold. 1954. Motor unit activity in the voluntary contraction of human muscle. J. Physiol. 125: 322.

DeVries, H.A. 1968. Method of evaluation of muscle fatigue and endurance from electromyographic curves. Am. J. Phys. Med. 47: 125-135.

Eason, R. 1960. Electromyographic study of local and generalized muscular impairment. J. Appl. Physiol. 15: 479-482.

Edwards, R.G. and O.C.J. Lippold. 1956. The relation between force and the integrated electrical activity in fatigued muscle. J. Physiol. 132: 667-681.

Lippold, O.C.J., J.W.T. Redfearn, and J. Vuco. 1960. The electromyography of fatigue. Ergonomics 3: 121-131.

Lloyd, A.J. 1971. Surface electromyography during sustained isometric contractions. J. Appl. Physiol. 30: 713-719.

Messier, R.H., J. Duffy, H.M. Litchman, P.R. Paslay, J.F. Soechting, and P.S. Steward. 1971. The electromyogram as a measure of tension in the human biceps and triceps. Int. J. Mech. Sci. 13: 585-598.

Milner-Brown, H.S. and R.B. Stein. 1975. The relation between the surface electromyogram and muscular force. J. Physiol. 246: 549.

Petrofsky, J.S. 1980. Computer analysis of the surface EMG during isometric exercise. Comput. Biol. Med. 10: 83-95.

Petrofsky, J.S. and C.A. Phillips. 1982. The Strength-Endurance Relationship in Skeletal Muscle: Its Application to Helmet Design. Aviat. Space Environ. Med. 53: 365-369.

Phillips, C.A. and J.S. Petrofsky. 1981a. The Strength-Endurance Relationship of the Neck Muscles: A Physiological Basis for Helmet Design. Proc. Aerospace Med. Assoc. 81: 217-218.

Phillips, C.A. and J.S. Petrofsky. 1981b. Physiological Criteria for Helmet Design. Federation Proc. 40: 497.

Phillips, C.A. and J.S. Petrofsky. 1981c. A Quantitative Evaluation of Neck Muscle Performance. The Physiologist 24: 66.

Phillips, C.A. and J.S. Petrofsky. 1981d. Influence of U.S. Army Headgear Parameters on Neck Muscle Loading and Fatigue. Annual Report. Army contract DAMD17-80-C-0089. U.S. Army Medical Research and Development Command (in press).

Phillips, C.A. and J.S. Petrofsky, 1982a. Quantitative Electromyography: Response of The Neck Muscles to Conventional Helmet Loading. Aviat. Space Environ. Med. (in press).

Phillips, C.A. and J.S. Petrofsky, 1982b. Electromyographic Changes in the Lateral and Posterior Neck Muscles associated with Conventional Helmet loading. Proc. Aerospace Med. Assoc. 82: 59-60.

Phillips, C.A. and J.S. Petrofsky, 1982c. Validation Study of the UCGW Helmet Simulator. Proc. 35th ACEMB. 24: 15.

Phillips, C.A. and J.S. Petrofsky, 1982d. Cardiovascular Response to Neck Muscle Exertion. The Physiologist. 25: 202.

Rohmert, W. 1968. Rechts-links-Vergleich bei isometretishen Armmuskeltraining mit verschidenem traningsreiz bei achtjahvgin Kinder. Int. Z. angew. Physiol. 26: 363.

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