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ESTABLISHMENT OF MAXIMUM VOLUNTARY COMPRESSIVE NECK TOLERANCE LEVELS

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Interim Report

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14. ABSTRACT

The primary objective of this study was to establish maximum human voluntary static tolerance levels of neck compressive loading to ensure the safe operation of a proposed Joint Strike Fighter (JSF) Head/Neck Restraint System (HNRS). A laboratory helmet-load apparatus was designed and used to safely apply compressive forces to the head/neck of 46 subjects' (26 female; 20 male). Nearly all subjects were able to sustain maximum forces of at least 120 lbs for 5 seconds, with several subjects tolerating maximum sustained forces of over 200 lbs. Neck circumference was the most significant variable across gender with larger neck circumferences correlating to higher sustained forces. Regression models, however, demonstrated low R^2 values due to high maximum voluntary load variability among subjects of similar weights. Such findings suggest that while compressive neck forces of 100 lbs could be safely tolerated by potential users of the HNRS, no single force setting will likely be ideal for all users.

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PREFACE

The laboratory tests and data analysis described in this report were accomplished by the Vulnerability Analysis Branch, Human Effectiveness Directorate of the Air Force Research Laboratory (711 HPW/RHPA) at Wright-Patterson Air Force Base, Ohio. The test facility for this study was a seated neck strength testing device located in the Neck Fatigue/Mass Properties laboratory in Bldg 824 at Wright-Patterson AFB. Funding was provided by the Joint Strike Fighter (JSF) Program Office. Engineering support was provided by General Dynamics AIS under contract F41624-97-D-6004 and Infoscitex under contract FA8650-09-D-6949. This study was approved by the Air Force Wright Site IRB under Protocol F-WR-2008-0023-H.

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JSF technical support and funding were provided by Ms. Dawn McGarvey, F-35 Pilot Systems Program Lead, through the JSF Program Office. The statistical analysis described in this report was performed with the assistance of Dr. Tim Webb of the Vulnerability Analysis Branch at the 711th Human Performance Wing and Dr. Raymond Hill of the Department of Operational Sciences at the Air Force Institute of Technology, Wright-Patterson AFB.

1.0 INTRODUCTION

The primary objective of this study was to establish maximum human voluntary static tolerance levels of neck compressive loading to ensure the safe operation of a proposed Joint Strike Fighter (JSF) Head/Neck Restraint System (HNRS). The HNRS has the potential to significantly decrease neck forces and head rotations experienced by small pilots during ejections. Obtaining the maximum neck load tolerance level will ensure the selection of optimal deployment tension levels for the HNRS such that the smaller crewmembers (< 150 lbs) can safely and comfortably utilize the system. The data collected during this test program were used to evaluate the feasibility of employing the HNRS system in conjunction with the JSF and other aircraft to reduce the neck loads experienced by small aircrew during high-speed ejections.

2.0 BACKGROUND

The new JSF F-35 aircraft will employ a Martin-Baker US16E ejection seat, which will be required to accommodate the full range of aircrew (103-245 lbs). However, preliminary rocket sled tests of this seat have shown that the neck forces and head rotations measured in small instrumented manikins are significantly higher than for their larger counterparts. To reduce these forces and rotations, a HNRS prototype was designed with the goal of offering neck protection to the small pilot population, specifically those crewmembers under 150 lbs. Females and small occupants have been shown to be more at risk of neck injury during ejection than large males (3,4,5) and were the target population for the JSF HNRS test program (2). While originally developed for use with the US16E ejection seat, the HNRS also has the potential to be used with other aircraft where neck injury to small occupants is a concern.

The HNRS is integrated into the pilot's flight equipment and consists of four straps tethered to the helmet with a specially designed harness inside the flight suit. The system is activated by an electrical signal initiated by the pull of the ejection seat handle to initiate an ejection from the aircraft. During the catapult, windblast, and parachute opening phases of ejection, the straps remain taut and act to impede the rotation of the head. Such tightening lowers the head accelerations and corresponding neck forces and torques normally associated with the different phases of the ejection. Although cadaver and other research have provided an understanding of vertebral breaking strength levels (6,7), maximum static voluntary neck compression load (MCVL) limits are not well known and are expected to fall well below these breaking strength levels. Establishing subject MCVL therefore elucidates these differences, allowing for the selection of safe and comfortable HNRS levels. This knowledge will ensure the proper and effective functioning of the HNRS system during future dynamic tests (2).

3.0 METHODS

A load measurement system was used to measure the compressive force on the subjects' head/neck, and a data acquisition system (DAS) in conjunction with a PC was used to collect the data. The system was similar to the extension load monitoring device used by Gallagher et al. (5) but adapted for vertical loading instead of horizontal loading. The concept for the device is shown in Figure 1, while the fully constructed device is shown in Figure 2.

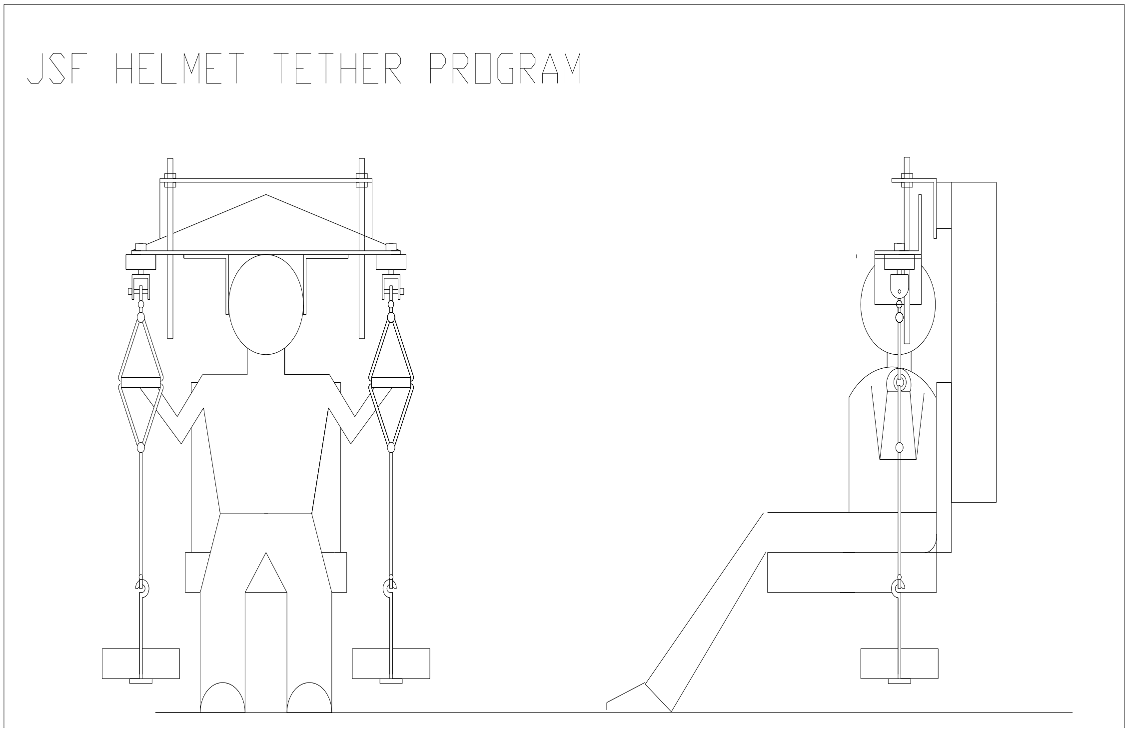

Figure 1. Neck strength test device initial design

Figure 2. Neck strength test device test fixture

Forty-six male and female subjects were recruited under an approved human use protocol (1). The subjects were seated during the measurements. The device consisted of a metal plate affixed to a modified Air Force 55/P helmet positioned on top of the subject's head and included a headrest to properly align the head and neck. Chains on the edges of the metal plate allowed for weights to be added, increasing the downward force on the subject's head and neck. Integrated into these chains were handles, allowing the subject to add additional force during the test by pulling downward. Guide rails were included to stabilize the top plate and the weights resulting in motion of the plate in one axis. A single-axis load cell, attached between the top of the helmet and the bottom of the plate, was used to measure the total force generated by the weight of the metal plate, the added weights, and the downward force generated by the subject.

Prior to beginning the test series, subjects were provided a series of neck stretching exercises (approximately 5-10 minutes). When the subject completed the exercises, he/she was seated in the head/neck load measurement device, and the metal plate/modified Air Force helmet combination was lowered onto the head. Weights were incrementally added to the base of the chains until the total weight reached approximately 2/3 of the subject's body weight (or until the subject experienced head or neck discomfort, or felt that he/she was approaching their load limit). This initial weight was necessary to allow the subjects to generate more force than they might be able to generate pulling just with their arms. The subjects were asked to perform up to three MCVL trials by pulling on the handles as hard as possible for eight seconds; a three minute interval existed between the trials. The load cell captured the force at the rate of 1000 samples per second over the eight second duration. At the end of the eight seconds, two spotters on either side of the subject immediately lifted the metal plate/helmet combination off the subject's head.

The highest MVL for each subject was used in the data analysis. The force data from each subject were recorded as well as subjective response data after the tests.

The electronic data were collected with a single axis load cell (Transducer Techniques model MLP-1K, 1000 lbs capacity, 22.58 μV/lb sensitivity) at the top of the flight helmet. The raw data were then amplified by a 500 V/v digital amplifier and then transferred to LabView software through a PCI card (National Instruments DAQ NI 5034E). The LabView program uses a sample rate of 1000 Hz for 13 seconds of data collection. Raw data are saved and then filtered using a low pass, 8-pole Butterworth filter at 120 Hz using the in-house software program AnalyzeTest.

4.0 RESULTS

4.1 Temporal results

A total of 26 female and 20 male subjects participated in the study. Figure 3 shows graphs of Force as a function of Time for the three trials for one subject. After the weights were fully loaded, the data collection began and a four second countdown timer started. The pulling phase of the test began at the four second mark and ended at the 12 second mark, as indicated by the rapid rise in force (when the subject initially pulled on the handles to generate more force) and then the rapid decline in force when the subject released the handles and the spotters raised the system off the subject's head.

4.2 Force Analysis

The duration of each test was eight seconds with force data collected at 1,000 samples/second, resulting in 8,000 data points. To determine the maximum force a subject could withstand for a certain length of time, a window averaging method was used. First, a 5 ms "window" was used to bracket the first 5 force data points, which were then averaged, resulting in the average force experienced over that time period. Next, the window was shifted by one millisecond so that data points 2-6 were averaged – resulting in the average force over that time period. The window was moved through the entire data set, creating a moving average. The maximum of this new set was then selected, representing the highest (averaged) force the subject willingly withstood for a 5 ms period. This same moving average was repeated for time periods of 10 ms, 30 ms, etc., up to 5000 ms, with the selected value for each representing the highest averaged force the subject voluntarily withstood for that time period (Table 1). This was performed for each of the three trials and plotted in Figure 4. As expected, the maximum force subjects could withstand decreased as time period lengthed. Table 1 displays the raw data.

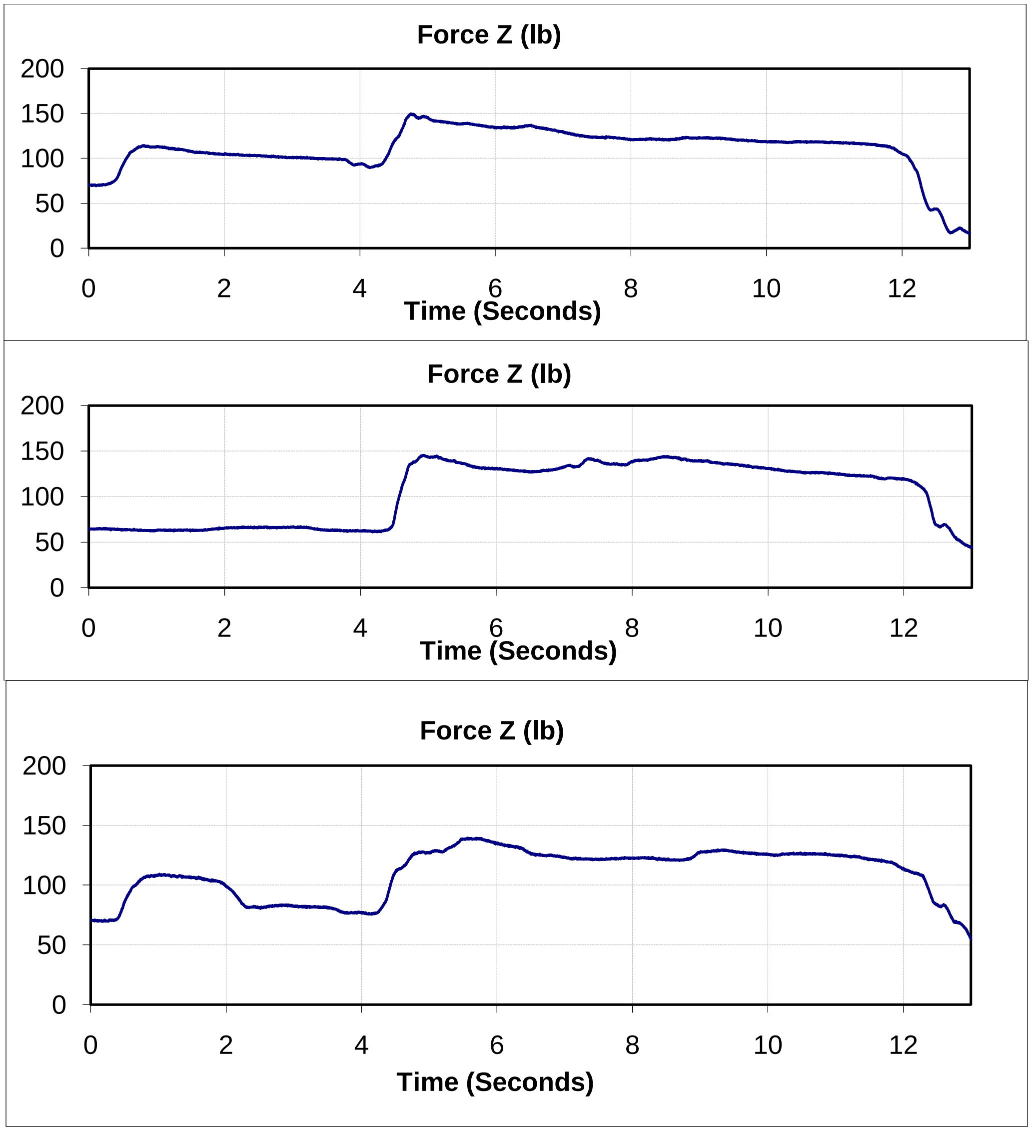

Figure 3. Real-time force data for the three trials of a single subject (Test 1014, Subject T21)

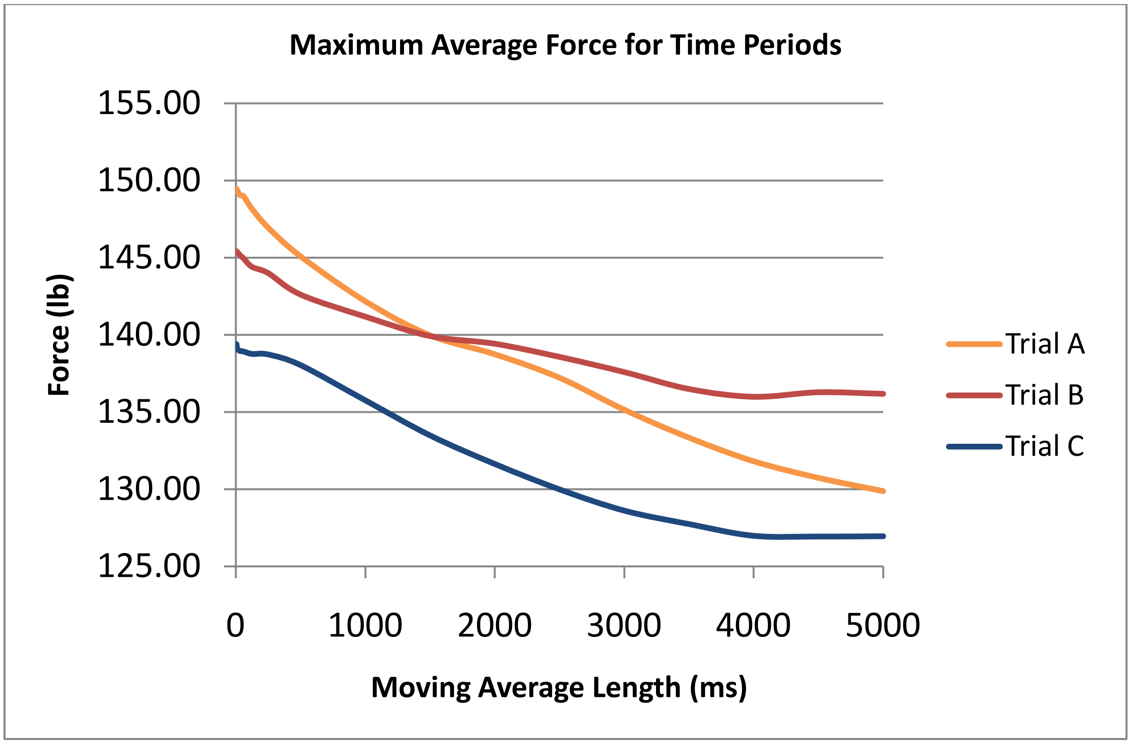

Figure 4. Maximum force levels for each time period during three trials of a single subject (Test 1014)

Table 1. Maximum average force data for each time interval during three trials of a single subject

Interval	Trial A	Trial B	Trial C
5	149.46	145.41	139.38
10	149.39	145.38	139.12
30	149.07	145.18	138.95
60	148.98	144.95	138.91
125	148.17	144.40	138.75
250	146.94	144.00	138.72
500	145.09	142.60	138.03
1000	142.17	141.17	135.75
1500	139.97	139.91	133.48
2000	138.74	139.42	131.63
2500	137.21	138.56	129.98
3000	135.14	137.58	128.61
3500	133.33	136.48	127.74
4000	131.80	135.98	126.98
4500	130.72	136.27	126.93
5000	129.86	136.17	126.95

Next, the trial with the highest force readings was selected for each subject. For most subjects, one trial consistently generated higher forces than the other two for all time periods, although no particular trial (out of three trials) showed a tendency to produce the highest forces. For a situation with similar force responses—as in Figure 4, the trial with the highest minimum was selected (i.e. the trial with the highest value at 5000 ms) – thus Trial B was selected. The rationale for this selection is that upon deployment, the HNRS may be engaged for a full five seconds. Thus, the maximum force a subject could withstand for five seconds is of interest to generate the maximum protection over the longest duration. The selected single plots for each subject were averaged for all subjects tested to create the mean maximum average force, plotted in Figure 5.

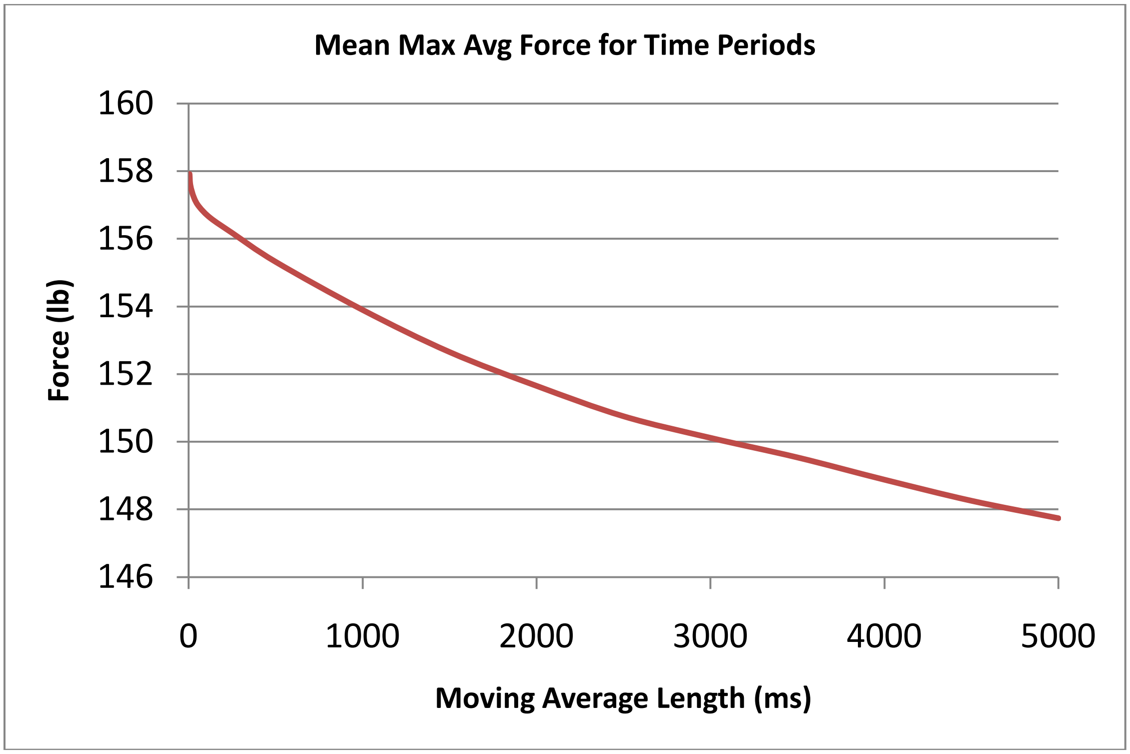

Figure 5. Mean maximum average force for all subjects

Figure 5 displays the maximum force the average subject in the study could voluntarily withstand. As time increases the force a subject can voluntarily withstand decreases. For comparison, Figure 6 shows the same mean line (the central curve) as in Figure 5, but includes plots of the two subjects with the lowest and highest maximum average (Max Avg) forces.

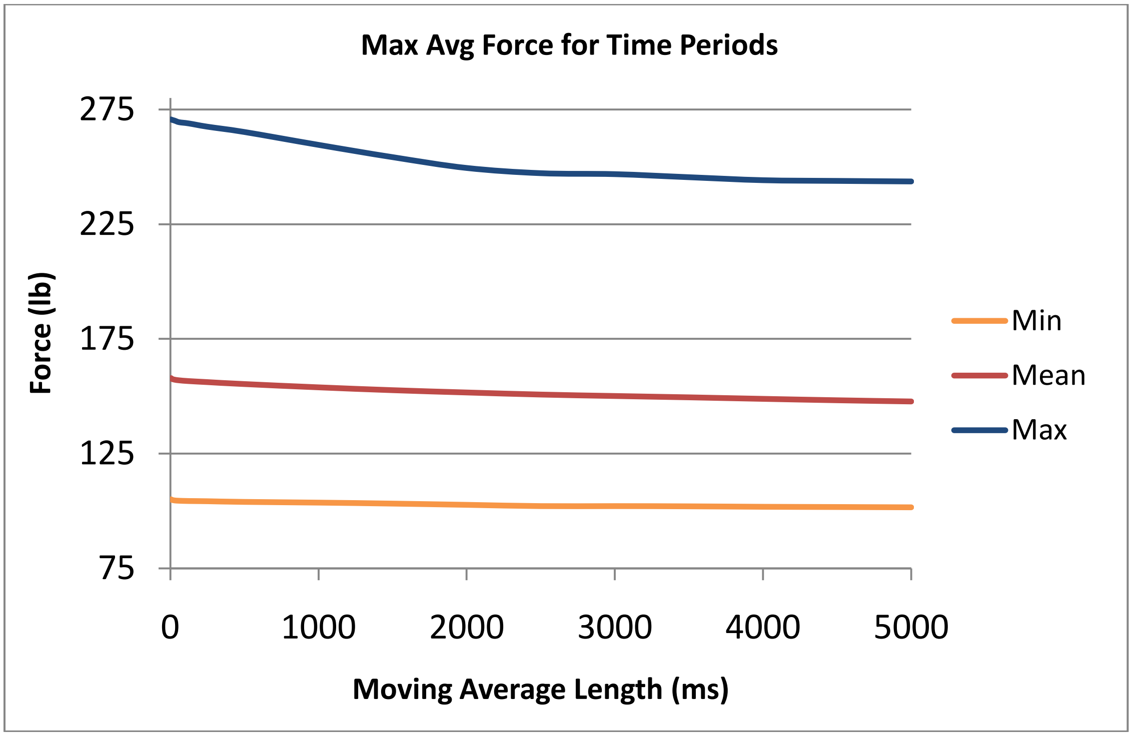

Figure 6. Two subjects (max and min) and the sample average

The subject that could withstand the least force (lowest/orange curve) was significantly lower in tolerance than the average, and the subject that could withstand the most (highest/blue curve) was significantly higher than the average. The full distribution of Max Avg Force curves for all subjects are plotted in Figure 7.

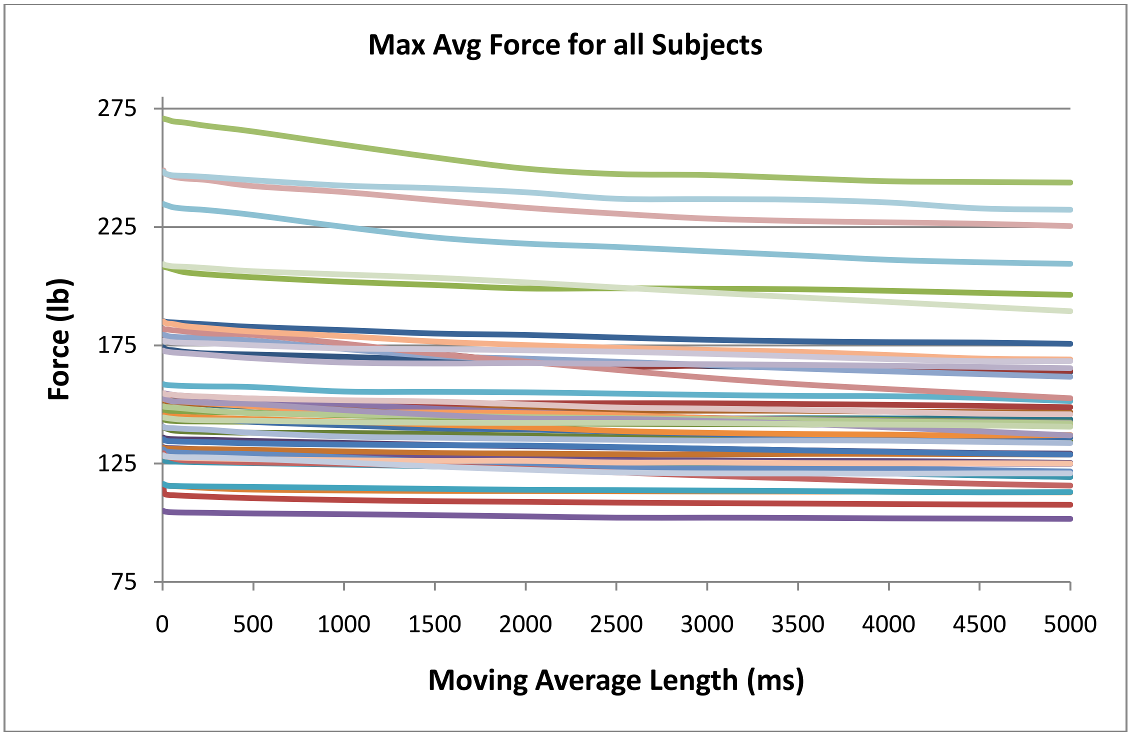

Figure 7. Max Avg Force for all subjects

Most subjects' neck forces ranged between 125 and 185 lbs over the full 5 seconds, with a few subjects above and below this level. When displayed on this force scale (see Figure 7), it is clear that most subjects' force tolerance does not significantly change over the duration of a test. Of note, the subjects that displayed more significant force tended to experience more degradation over time. Many of these subjects could be seen visibly straining to generate high forces.

The force tolerance of the subject population appeared to follow a skewed normal distribution, as shown in Figure 8 and Figure 9 which display the data in histogram format. Figure 8 and Figure 9 provide the distribution of the MCVL that subjects tolerated for 10 ms and 5,000 ms respectively. For example, as indicated in Figure 8, only one subject exerted a 10 ms MCVL between 100 and 110 lbs.

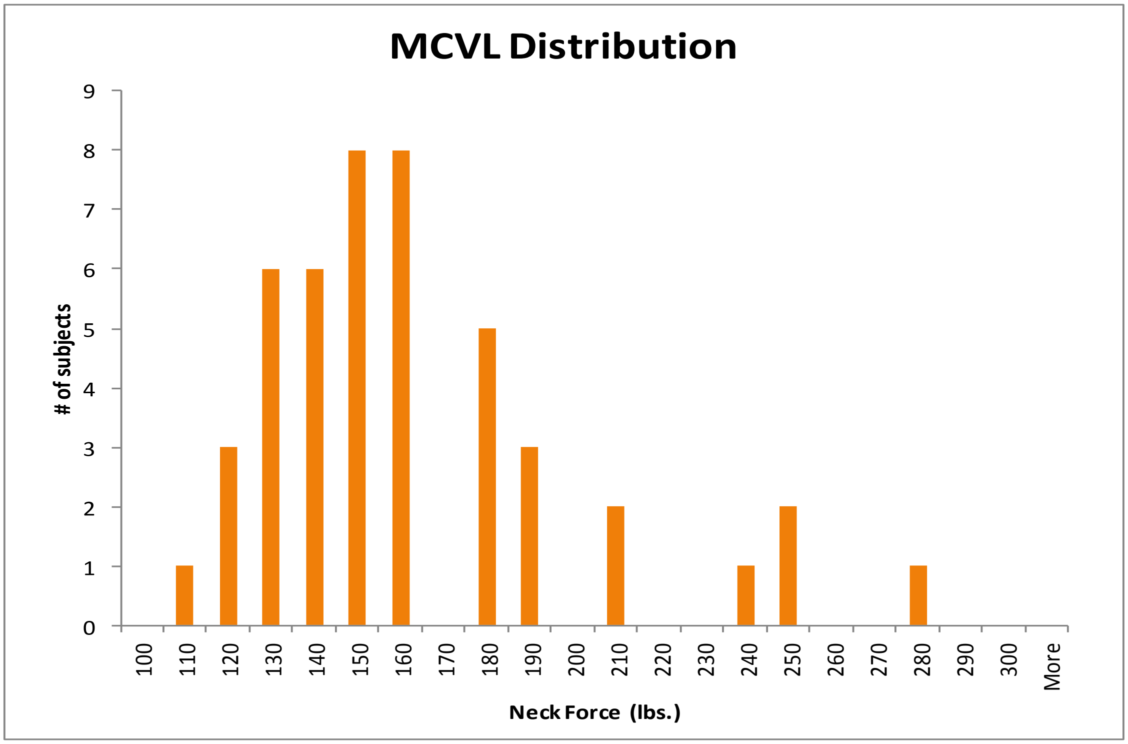

Figure 8. Individual 10 ms Maximum Average Force Distribution (with 10 lb. bins)

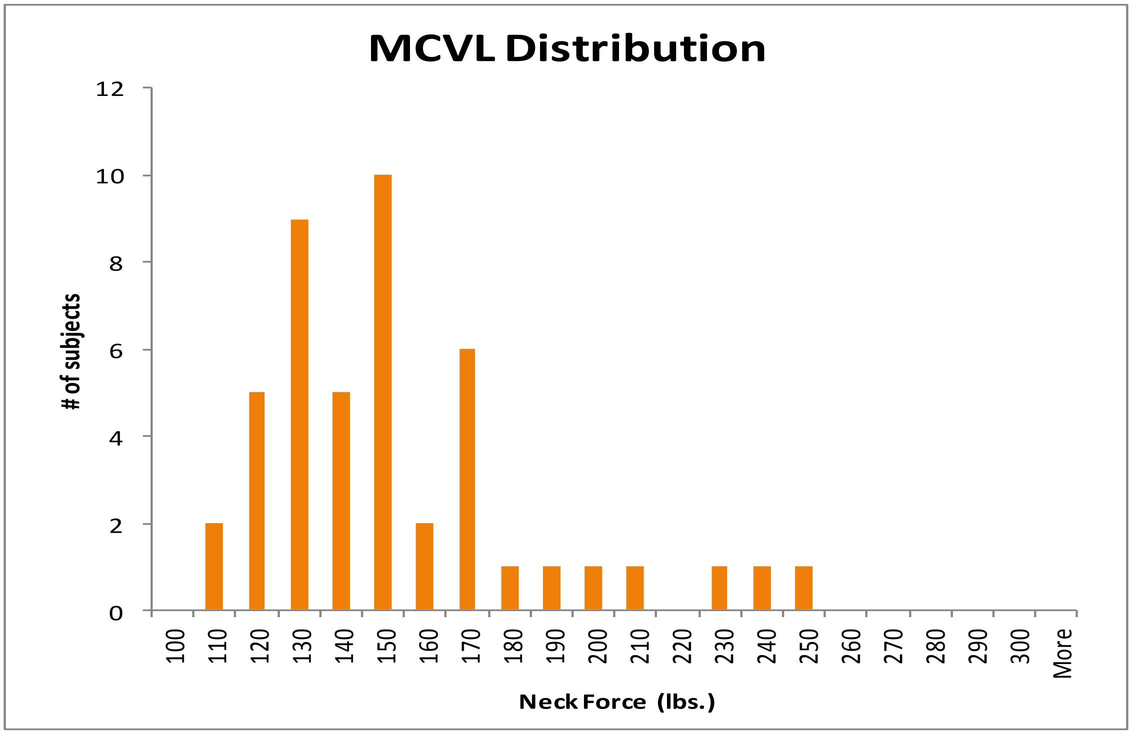

Figure 9. Individual 5000 ms Maximum Average Force Distribution (with 10 lb. bins)

4.3 Statistical Analysis

While all subjects were ≤ 150 lbs body weight (i.e. without boots/uniform, which are included in the measured weights), some subjects generated more than twice as much force as other subjects. Seven potential factors were indentified, plus gender. Subject pool anthropometry is shown in **Error! Reference source not found.**.

Table 2. Subject pool anthropometry

	Height (cm)	*Sit Height (cm)*	*Weight (lb)*	*Neck Circ (cm)*	*Waist Circ (cm)*	*Age*
Max	185.0	93.6	161.0	40.0	94.0	45
Min	148.0	76.5	120.0	30.5	65.0	19
Avg	169.0	87.4	141.0	34.0	78.0	25
Std	8.2	4.0	11.5	2.2	6.6	5

With n=46, consisting of 26 females and 20 males, regression analysis was performed to determine which factors were significant for the force responses. Figure 10 through Figure 16 display single factor plots of responses for force tolerance (maximum average force from 0-2500 ms).

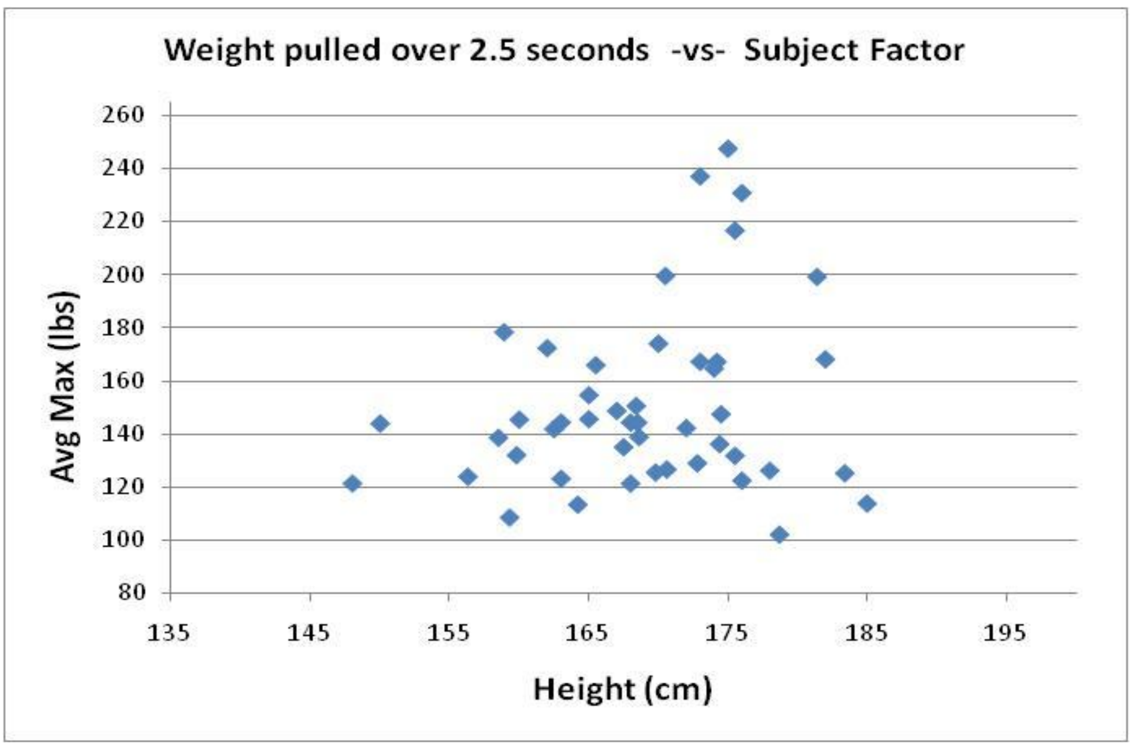

Figure 10. Response vs. height

Figure 10 indicates a trend for increasing maximum average force variance as a function of height.

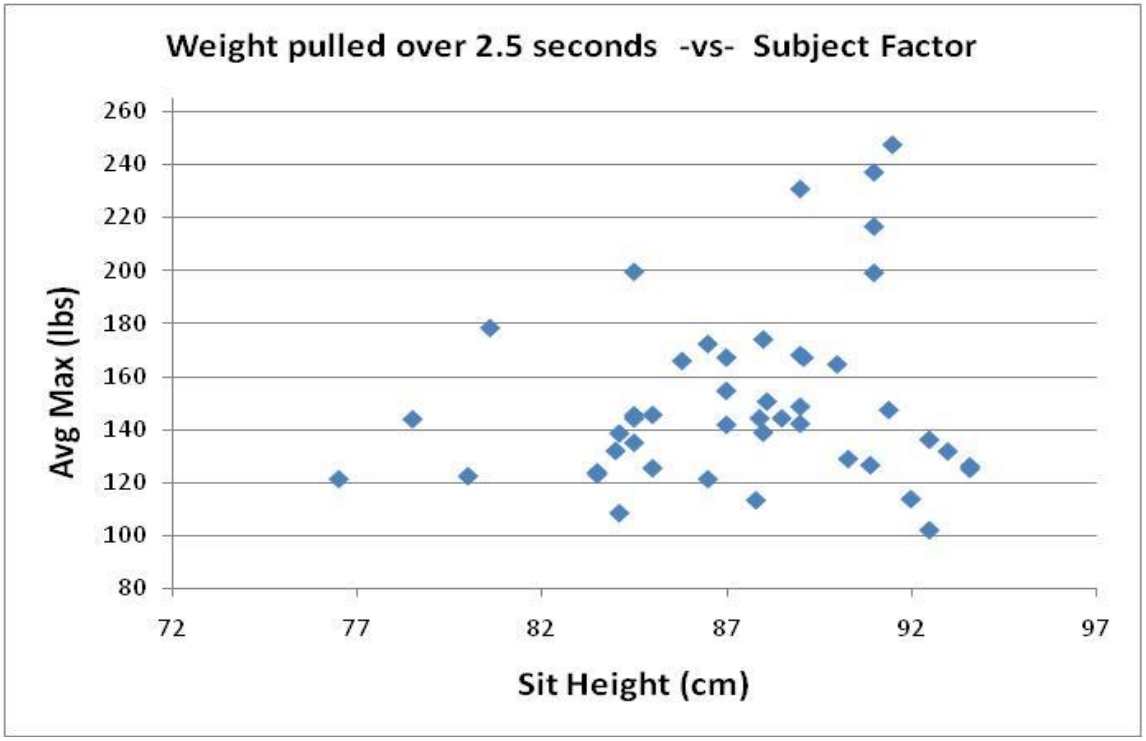

Figure 11. Response vs. sit height

Figure 11 indicates a trend for increasing maximum average force variance as a function of sitting height.

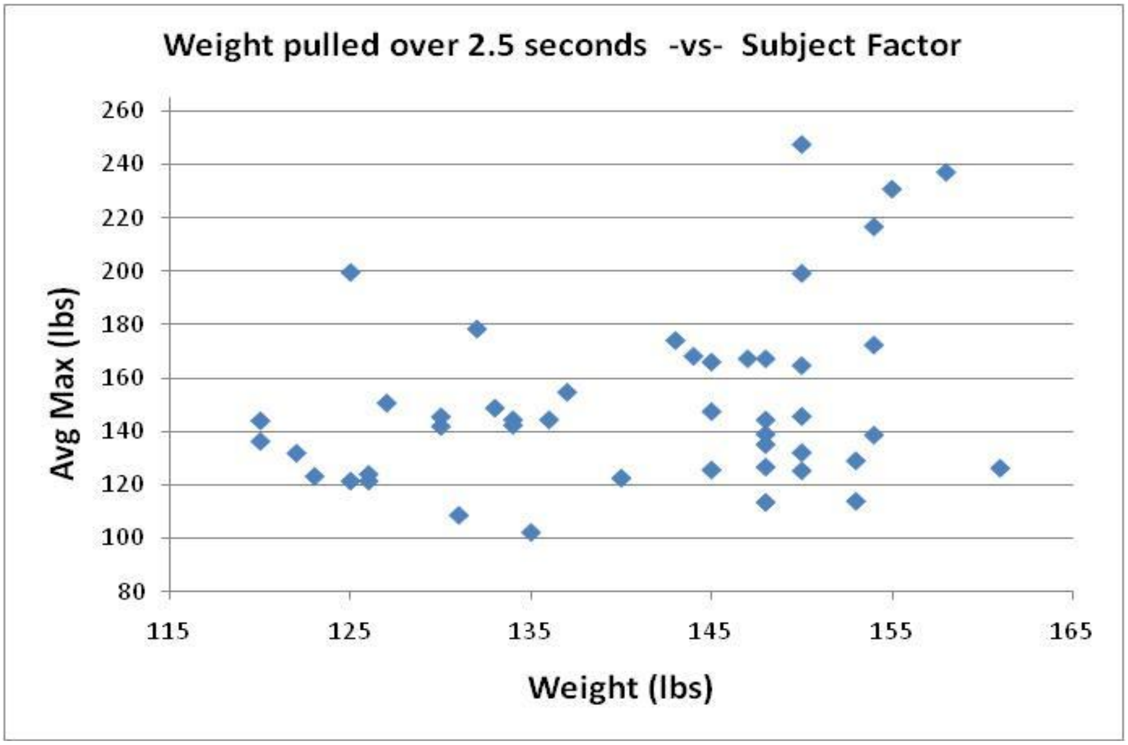

Figure 12. Response vs. weight

Figure 12 indicates a trend for slightly increasing maximum average force variance as a function of weight.

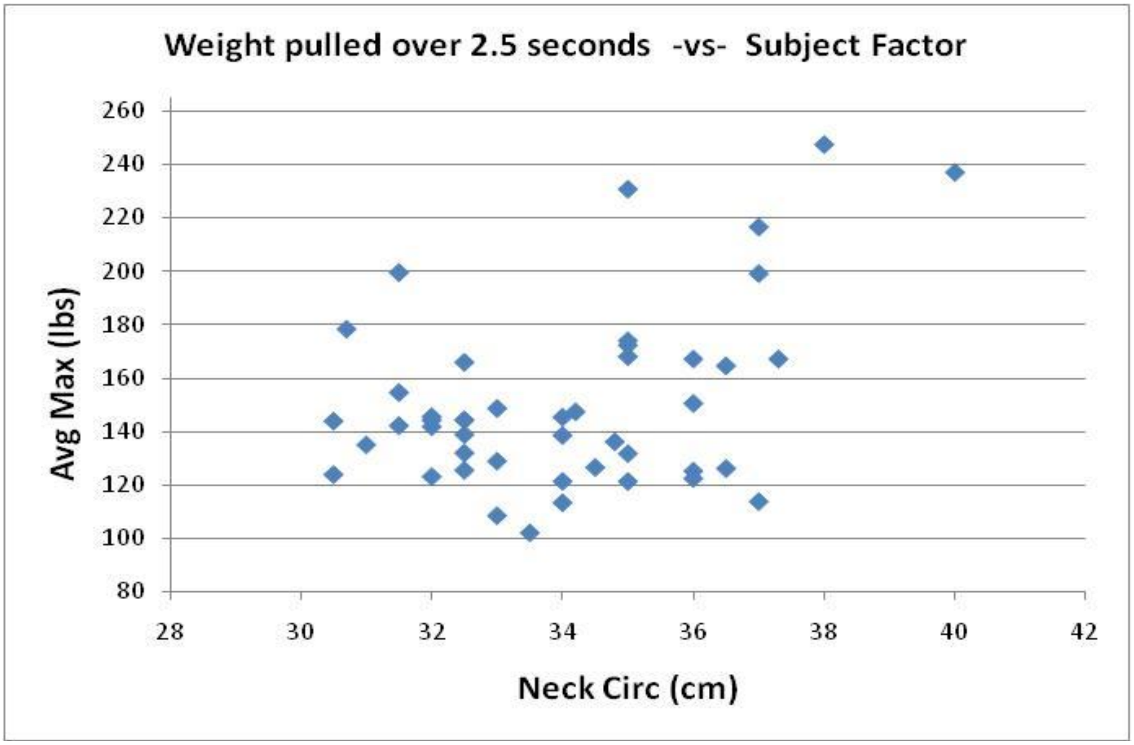

Figure 13. Response vs. neck circumference

Figure 13 suggests a positive linear trend between maximum average force and neck circumference (with individual variance).

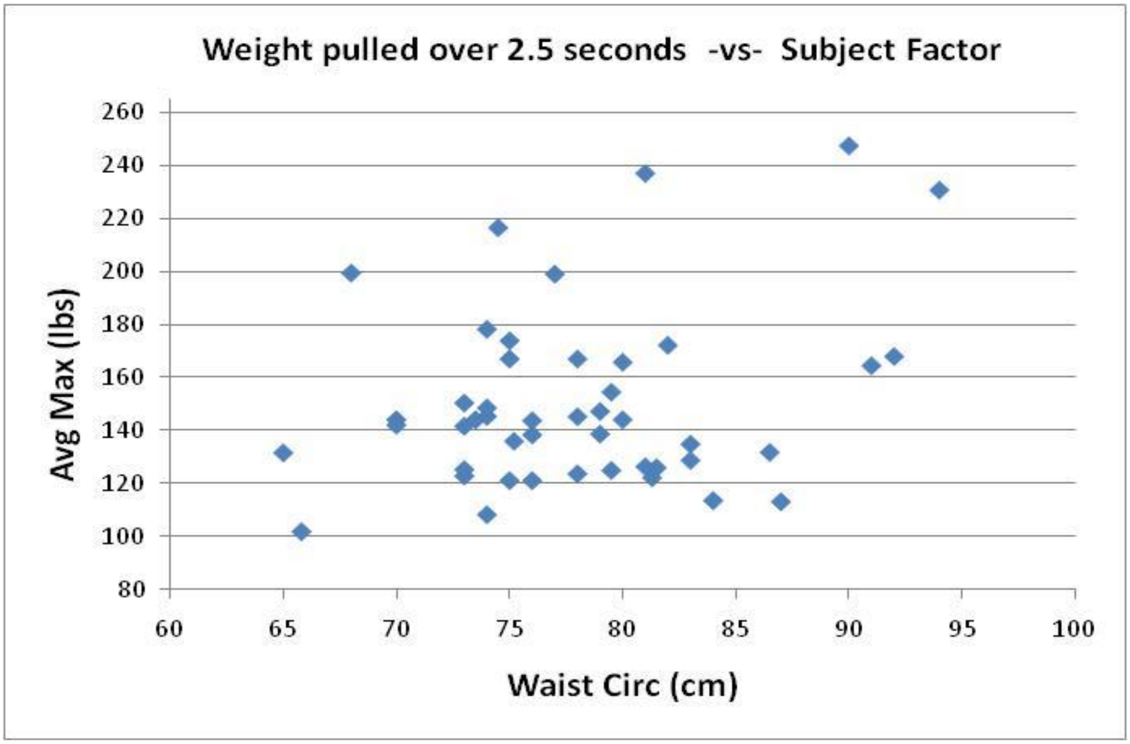

Figure 14. Response vs. waist circumference

Figure 14 suggests a positive linear trend between maximum average forceand waist circumference (with individual variance).

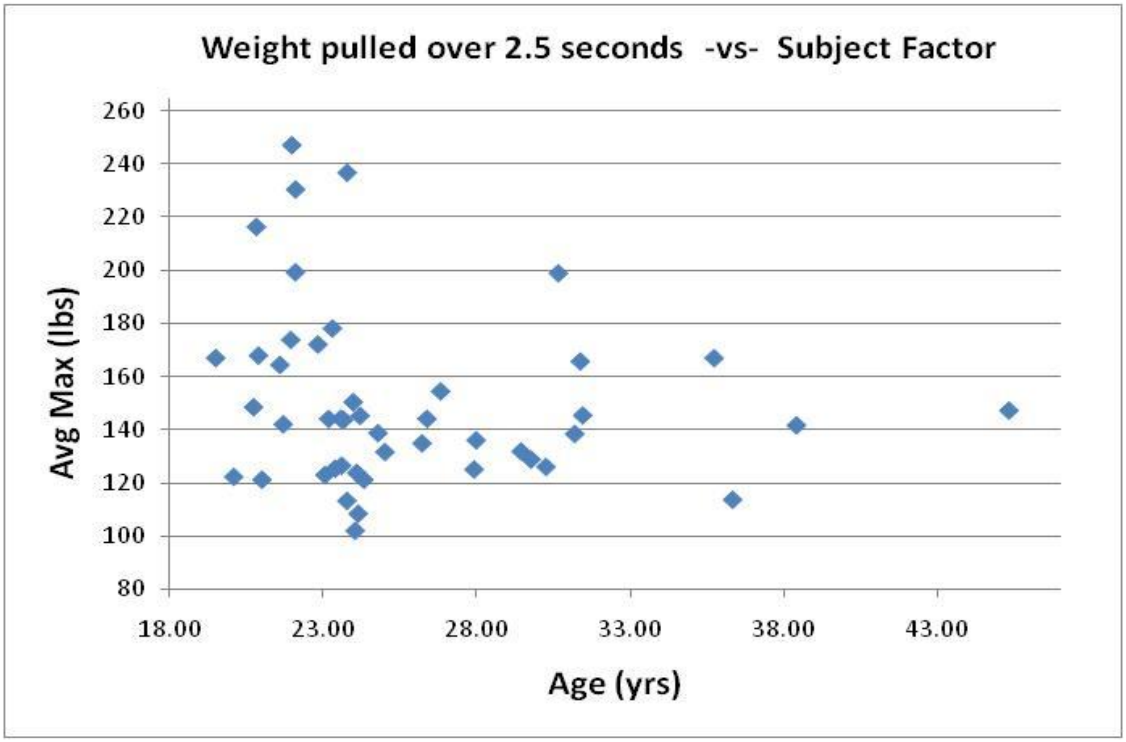

Figure 15. Response vs. age

Figure 15 indicates decreasing maximum average forcevariance as a function of age.

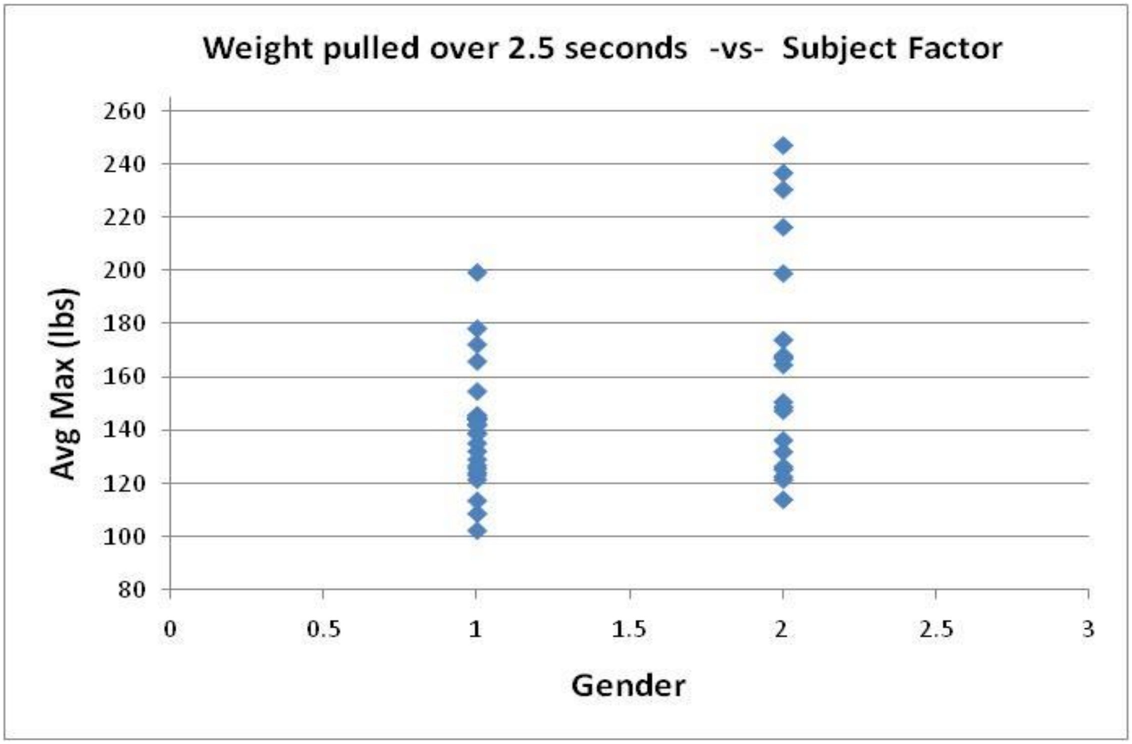

Figure 16. Response vs. gender (females = 1, males = 2)

Figure 16 indicates that maximum average force variance is higher for males with more males displaying loads above 200 lbs.

Multivariate analysis indicates a strong relationship between height and sitting height (r=0.79). This means a model does not need both variables, and including both could decrease the model fidelity. A moderately strong relationship also exists between weight and waist circumference (r=0.59) as this population was artificially limited through selection for weight under 150 lbs. None of the predictors (regressors) are highly correlated with the response. The strongest of these appears to be neck circumference.

Model development (separated by gender)

Females:

For each response (10 ms, 2500 ms, and 5000 ms), the final models are statistically the same – that is, the rate of amount pulled per unit of predictor level for 10/2500/5000 ms stay the same for each subject; only the intercept changes.

$y = f(neck\ circ, waist\ circ, neck\ circ * waist\ circ)$, with the interactions centered to reduce multicollinear relationships in the model. P-values for each factor are shown in Table 3.

Table 3. Female factor p-values

	p-value		
Factor	*10 ms*	*2500 ms*	*5000 ms*
Neck Circ	0.0567	0.0476	0.0528
Waist Circ	0.4935	0.5003	0.5409
Neck * Waist	0.0209	0.0139	0.0149

The $(neck\ circ * waist\ circ)$ interaction was the most significant in the female model. To maintain hierarchy, waist circumference is included in the model. Larger neck circumference and larger $(neck\ circ * waist\ circ)$ interaction correlated to higher forces generated.

Males:

For each response (10 ms, 2500 ms, and 5000 ms), the final models are statistically the same – that is, the rate of amount pulled per unit of predictor level for 10/2500/5000 ms stay the same for each subject; only the intercept changes.

$y = f(neck\ circ, waist\ circ, neck\ circ * neck\ circ, waist\ circ * waist\ circ)$, with all data centered to reduce multi-collinearity in the design matrix. P-values for each factor are shown in Table 4.

Table 4. Male factor p-values

	p-value		
Factor	*10 ms*	*2500 ms*	*5000 ms*
Neck Circ	0.0697	0.066	0.0711
Waist Circ	0.3191	0.3868	0.4392
Neck*Neck	0.1291	0.1043	0.0996
Waist*Waist	0.1034	0.1193	0.1383

Neck circumference is considered significant (though not at the 0.05 confidence level). The $(neck\ circ * neck\ circ)$ and $(waist\ circ * waist\ circ)$ terms can be considered significant at p = 0.10. To maintain hierarchy, waist circumference is included in the model. Larger neck circumference, larger $waist^2$ interaction, and larger $neck^2$ interaction correlated to higher forces generated.

Overall comments:

The regression models are generally not a good fit. The R^2 for the final female models (10 ms, 2500 ms, 5000 ms) were approximately 0.30. The R^2 for the final male models were approximately 0.60. There is no difference in model predictive ability using 10 ms, 2500 ms, or 5000 ms. The final regression models were all deemed adequate based on residual analyses. It is estimated that further subject testing would add neither confidence nor fidelity to the analysis.

Model summary

Females

$$y_{10ms} = 421.48 - 7.25 * neck\ circ - 0.56 * waist\ circ + 1.9(neck\ circ - 32.5)(waist\ circ - 76.62)$$

$$y_{2500ms} = 403.44 - 6.98 * neck\ circ - 0.51 * waist\ circ + 1.9(neck\ circ - 32.5)(waist\ circ - 76.62)$$

$$y_{5000ms} = 378.81 - 6.47 * neck\ circ - 0.44 * waist\ circ + 1.78(neck\ circ - 32.5)(waist\ circ - 76.62)$$

Statistically, all models are equivalent. The female model accounts for 28% of the variance in responses.

Males

$$y_{10ms} = -395.79 + 12.31 * neck\ circ + 1.32 * waist\ circ + 3.80(neck\ circ - 36)^2 + 0.23(waist\ circ - 79.8)^2$$

$$y_{2500ms} = -335.34 + 11.13 * neck\ circ + 1.01 * waist\ circ + 3.64(neck\ circ - 36)^2 + 0.199(waist\ circ - 79.8)^2$$

$$y_{5000ms} = -316.37 + 10.78 * neck\ circ + 0.89 * waist\ circ + 3.65(neck\ circ - 36)^2 + 0.19(waist\ circ - 79.8)^2$$

Statistically, all models are equivalent. The male model accounts for 59% of the variance in responses.

Height, weight, and age demonstrate no role in predicting the responses (y_{10ms}, y_{2500ms}, y_{5000ms}). Little to no correlation exists between these variables (height, weight, and age) and the responses. Each of the three response, however, are nearly perfectly correlated to one another. Therefore, any model based on 10 ms will be related to the other two models (at 2500 ms and 5000 ms) with only intercept differences.

4.4 Questionnaire Analysis

In addition to the above analysis, subjects completed a questionnaire that provided a general sense of subject discomfort in various body regions during the experiment. The questionnaire, which was divided into three sections, asked about discomfort in the head, neck, upper back, lower back and arms/shoulders regions. In the first section, subjects selected numerical values indicating the degree of "fatigue/weakness" in each body region. Similarly, subjects selected numerical values describing "pain/ache" in the same body regions. The last section of the questionnaire asked subjects to select numbers describing how much—if at all, "discomfort/pain" "prevented" subjects from "pulling more weight" in each body region.

Overall, most males and females selected low values (0-2) for arms/shoulders, upper back, and lower back regions for all sections of the questionnaire (see Appendix C). Higher values (3-6), or discomfort in general, were more frequently seen in the head and neck for both genders (see Table 5 below; note that four subjects did not take the questionnaire). In particular, 68% of males and 80% of females said that "discomfort/pain" in the neck was either "sometimes" or the "primary cause" in preventing them from pulling more weight during the experiment. For the head these values were 16% and 65% for males and females respectively. See Appendix B for a complete summary of subject responses.

Table 5. Percent of Head and Neck Questionnairre (Values 3-6)

	Head		**Neck**	
Gender	*"Fatigue/Weakness"*	*"Pain/Ache"*	*"Fatigue/Weakness"*	*"Pain/Ache"*
Males (N=19)	21%	31%	42%	64%
Females (N=20)	35%	7%	70%	40%

5.0 DISCUSSION

5.1 General observations

The subjects in this study produced a wide range of maximum voluntary compressive loads. As with any test that involves not only physical human response but conscious human effort, this range could be expected. Anecdotally, some subjects were seen to give significant effort in pulling on the handles to generate excess force beyond that provided by the weights, while others appeared to be hardly pulling at all. While all subjects were given the same instructions on how "hard" to pull, it is inevitable that some will try harder and others less. Not all variation in pulling action was due to effort – certainly, some subjects only had to pull slightly until they reached a loading they felt was their maximum comfort level.

However, with subject weights all under 150 lbs and most clustered around 140 lbs, to see several subjects produce forces twice as high as other subjects was unexpected. The wide distribution of maximum average forces shows that no single HNRS setting will likely provide ideal protection for all subjects while also minimizing potentially detrimental effects.

5.2 Statistical discussion

The regression models are generally not a good fit to the data. Of the seven factors examined in predicting the response, only a few provided any explanation of the response variance. For female subjects, neck-waist interactions showed the largest significance followed by neck circumference. Such a finding suggests that MCVL is not dependent on neck circumference alone but rather depends on the combined role of neck and other anthropometric factors. It is also possible that waist dimensions correlate to another factor that may interact with neck circumference. These effects, however, only account for 28% response variability, and thus have poor predictive capability for estimating an exact MCVL.

For male subjects, larger neck and waist circumference (and the squared terms for both of those factors) are also significant in indicating a higher MCVL. These factors account for more of the response variability (59%), but still are poor predictors of exact MCVL, as 41% of the variance comes from other unidentified sources (e.g. effort, more nuanced musculoskeletal structure indicators, etc.).

There is a large variation in the MCVL tolerated by all the subjects (approx 100-250 lbs), although most subjects are clustered in a range between 125 and 185 lbs. Overall, the average male produced slightly larger MCVLs than the average female. Of note, neither subject height nor weight are significant in predicting a response, which may be due the fact that all subjects were less than or equal to 150 lbs (there may not have been enough weight variability to see major changes). While the taller subjects and the heavier subjects produced the highest MCVLs, other subjects with similar heights and weights were just as likely to produce some of the lowest MCVLs. As height and weight increased, variance of subject response increased as well. Whenever conscious effort can affect the results, substantial variation is likely to occur. However, conscious effort will not be in effect when the HNRS activates upon emergency egress, and this difference should be taken into consideration when designing the actual system.

5.3 Questionnaire discussion

In general, subjects indicated higher discomfort questionnaire values for the head and neck compared to those for the arms/shoulders, upper back and lower back regions. As an example, one subject commented that most of the "pain/discomfort" was on the "back of [the] neck at the bottom near the shoulder" and that the "arms, head, and the rest weren't affected by the pulling". Though some subjects described discomfort in the head regions, sensation due to neck compression was the primary variable in determining each subject's MCVL. These findings are reasonable since the neck is more compressive compared to the fairly rigid skull when subjected to large external forces.

6.0 CONCLUSIONS

Nearly all subjects were able to sustain maximum forces of at least 120 lbs for 5 seconds with several subjects tolerating maximum sustained forces of over 200 lbs. Neck circumference is the most significant variable across gender with larger neck circumferences correlating to higher sustained forces. Regression models, however, demonstrated low R^2 values due to high maximum voluntary load variability among subjects of similar weights. Such findings suggest that while compressive neck forces of 100 lbs could be safely tolerated by potential users of the HNRS, no single force setting will likely be ideal for all users.

An important benefit of this research was the understanding of what range of force living subjects can tolerate before significant discomfort results. Previous research in this field concentrated on the pure biomechanical response of cadavers—determining the point of failure for muscles and bones. Clearly, this level is much higher than the results from this testing. The results from this test series provide insight in initial calibration levels for the HNRS as a minimum level that can be safely assumed based on the MCVL results from test subjects. This tolerance level is an important consideration since crew members experiencing levels greater that the MCVL would be less likely to control their head motion and execute the proper bracing and spinal alignment needed to avoid neck injury during the ejection sequence.

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APPENDIX A: Subject Anthropometry

	Factors							
Test#	ID#	Height (cm)	Sit Height (cm)	Weight (lbs)	Neck Circ (cm)	Waist Circ (cm)	Age	Gender
1002	Z-4	174.2	89.1	148	37.3	78	35	M
1003	W-17	156.3	83.5	126	30.5	78	24	F
1004	C-33	174.4	92.5	120	34.8	75.2	27	M
1005	B-53	175.5	93	122	35	65	25	M
1006	S-43	168	88.5	136	32.5	70	26	F
1007	H-29	174.5	91.4	145	34.2	79	45	M
1008	S-44	158.9	80.6	132	30.7	74	23	F
1009	O-8	165.5	85.8	145	32.5	80	31	F
1010	M-52	162.5	87	130	32	73	38	F
1011	K-15	170.6	90.9	148	34.5	81	23	F
1012	J-17	183.4	93.6	150	36	79.5	27	M
1013	G-23	172.8	90.3	153	33	83	29	F
1014	T-21	158.5	84.1	154	34	76	31	F
1015	Q-1	168.4	88.1	127	36	73	23	M
1016	Q-2	163	87.9	134	32.5	73.5	23	F
1017	H-30	178	93.6	161	36.5	81.5	30	M
1019	E-6	176	80	140	36	81.3	20	M
1020	A-13	164.2	87.8	148	34	87	23	F
1021	K-17	159.8	84	150	32.5	86.5	29	F
1022	B-54	159.3	84.1	131	33	74	24	F
1023	B-45	181.4	91	150	37	77	30	M
1024	F-12	178.7	92.5	135	33.5	65.8	24	F
1025	P-17	185	92	153	37	84	36	M
1026	M-53	168.6	88	148	32.5	79	24	F
1027	P-16	163	83.5	123	32	73	23	F
1028	A-14	148	76.5	126	34	75	21	F
1029	M-54	175	91.5	150	38	90	21	M
1030	S-45	160	84.5	130	34	78	24	F
1031	R-27	165	87	137	31.5	79.5	26	F
1032	S-46	165	85	150	32	74	31	F
1033	J-18	182	89	144	35	92	20	M
1034	J-19	174	90	150	36.5	91	21	M
1035	T-14	168.5	84.5	148	32	80	23	F
1036	G-22	150	78.5	120	30.5	76	23	F
1037	T-23	175.5	91	154	37	74.5	20	M
1038	C-34	170	88	143	35	75	21	M
1039	W-16	167.5	84.5	148	31	83	26	F
1040	N-1	176	89	155	35	94	22	M
1041	A-15	172	89	134	31.5	70	21	F
1042	T-24	173	87	147	36	75	19	M
1043	W-18	173	91	158	40	81	23	M
1044	D-19	169.8	85	145	32.5	73	23	F
1045	A-16	168	86.5	125	35	76	24	M
1046	E-7	167	89	133	33	74	20	M
1047	D-20	170.5	84.5	125	31.5	68	22	F
1048	V-5	162	86.5	154	35	82	22	F

APPENDIX B: Subject Questionnaire Ratings

For roughly the first half of the study subjects provided questionnaire ratings by filling out a paper based questionnaire. During the second half this questionnaire was converted into an electronic format that subjects completed after finishing the task. The details of these two questionnaire types (paper and electronic) are described below and identified as “paper version” and “electronic version” respectively in the tables following.

Paper Version Tables
Subjects who took the paper questionnaire could choose values ranging from 1-6 for the first two sections. In the last section, subjects could choose either “1”,“2”, “3” or “4” which meant “No”, “Some”, “Primary Cause” and “I do not remember” respectively. Subjects C-33, W-17, H-29, and Q-2 did not fill out a questionnaire.

Electronic Version Tables
Subjects who took the electronic questionnaire could choose values ranging from 0-6 for the first two sections. In the last section, subjects were asked to choose either “1”, “3” or “6” (respectively equivalent to “1”, “2”, and “3” in the paper version) which meant “Not at all”, “Somewhat” and “Most definitely the reason” respectively. A few subjects, however, failed to follow instructions and selected values outside instructed range. “m” indicates data that was either not collected or corrupted. Subjects K-15, S-45 and V-5 did not fill out a questionnaire.

		Males (paper version)					
	Body Region	**Z-4**	**B-53**	**S-44**	**J-17**	**Q-1**	**H-30**
Fatigue/Weakness	*Head*	4	1	1	2	3	4
	Neck	4	3	1	3	3	5
	Arms/Shoulders	1	2	1	2	3	2
	Upper Back	2	1	1	2	4	2
	Lower Back	2	2	1	2	1	1
Pain/Ache	*Head*	4	2	1	2	5	2
	Neck	4	5	3	4	4	5
	Arms/Shoulders	1	1	1	2	2	1
	Upper Back	3	2	4	3	3	3
	Lower Back	3	1	2	2	2	2
Discomfort Prevented Pulling?	*Head*	2	1	1	1	2	1
	Neck	2	3	2	3	1	2
	Arms/Shoulders	1	1	1	1	1	1
	Upper Back	1	1	3	2	1	1
	Lower Back	1	1	1	1	1	1

		Females (paper version)					
	Body Region	**S-43**	**O-8**	**M-52**	**G-23**	**T-21**	**K-17**
Fatigue/Weakness	*Head*	4	3	1	2	2	2
	Neck	4	3	2	3	4	2
	Arms/Shoulders	2	2	1	1	4	2
	Upper Back	2	1	1	1	1	1
	Lower Back	2	1	1	1	2	1
Pain/Ache	*Head*	3	2	1	3	2	2
	Neck	2	2	2	3	2	2
	Arms/Shoulders	2	1	1	1	4	1
	Upper Back	2	1	1	1	1	1
	Lower Back	2	1	2	1	2	1
Discomfort Prevented Pulling?	*Head*	2	1	1	2	3	3
	Neck	1	1	2	2	2	2
	Arms/Shoulders	1	1	1	1	3	1
	Upper Back	1	1	1	1	1	1
	Lower Back	1	1	1	1	2	1

	Males (electronic version)													
	Body Region	**E-6**	**B-45**	**P-17**	**M-54**	**J-18**	**J-19**	**T-24**	**W-18**	**A-16**	**E-7**	**T-23**	**C-34**	**N-1**
Fatigue/Weakness	Head	2	1	2	1	2	2	0	2	0	0	1	2	3
	Neck	2	2	4	1	3	2	2	1	2	1	4	2	1
	Arms/Shoulders	1	1	3	2	1	1	0	1	0	0	0	0	1
	Upper Back	1	1	2	1	1	3	2	1	0	0	0	1	2
	Lower Back	1	1	1	1	1	3	0	1	0	1	0	0	2
Pain/Ache	*Head*	2	1	2	1	3	3	0	3	0	0	1	0	3
	Neck	2	2	3	2	4	4	2	3	3	1	4	1	1
	Arms/Shoulders	1	1	1	1	1	1	0	0	0	1	1	0	1
	Upper Back	1	1	1	1	1	3	2	0	0	1	3	0	1
	Lower Back	1	1	0	1	1	3	0	0	0	1	0	0	2
Discomfort Prevented Pulling?	*Head*	1	1	1	1	1	1	1	1	0	0	1	1	4
	Neck	1	3	6	1	6	6	6	1	3	1	6	3	2
	Arms/Shoulders	1	1	1	1	0	1	1	1	0	1	1	1	1
	Upper Back	1	1	1	1	0	3	3	1	0	1	3	1	1
	Lower Back	m	m	m	m	m	m	m	m	m	m	m	m	m

		Females (electronic version)													
	Body Region	**A-13**	**B-54**	**F-12**	**M-53**	**P-16**	**A-14**	**W-16**	**A-15**	**D-19**	**D-20**	**G-22**	**R-27**	**S-46**	**T-14**
Fatigue/Weakness	*Head*	1	0	4	3	1	2	1	3	3	1	1	3	1	1
	Neck	5	5	5	2	1	4	4	3	4	2	4	3	3	2
	Arms/Shoulders	0	0	3	0	1	1	0	2	4	0	1	1	0	0
	Upper Back	1	0	3	0	1	3	2	1	4	1	1	1	2	1
	Lower Back	0	0	1	0	1	1	0	2	4	0	0	0	0	0
Pain/Ache	*Head*	1	5	4	1	2	0	4	4	4	0	0	1	2	2
	Neck	3	5	4	1	2	0	5	5	5	2	1	1	3	1
	Arms/Shoulders	1	0	3	0	1	0	0	2	3	0	0	1	0	1
	Upper Back	1	0	2	0	1	0	1	2	4	1	0	0	0	1
	Lower Back	0	0	0	0	1	0	0	1	2	0	0	0	0	0
Discomfort Prevented Pulling?	*Head*	2	0	3	6	3	1	3	3	3	1	1	3	3	5
	Neck	4	3	3	1	3	1	6	3	6	3	3	3	6	3
	Arms/Shoulders	0	1	1	1	1	1	1	1	1	1	1	1	0	1
	Upper Back	0	1	1	1	1	1	1	1	3	1	0	1	0	1
	Lower Back	m	m	m	m	m	m	m	m	m	m	m	m	m	m