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Comparing the Effects of USAF Helmets on Neck Kinematics and Fatigue

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14. ABSTRACT
Joint Helmet Mounted Cuing System (JHMCS) helmets have a mounted display to show mission critical information; however, this added functionality comes at the cost of increased weight and shifted center of gravity compared to standard HGU-55/P helmets, which may lead to increased neck pain and injury. This study compared changes in cervical neck range of motion, strength, and subjective discomfort when wearing a JHMCS helmet compared to an HGU-55/P helmet. Forty subjects volunteered for two days of testing where one helmet was worn on each day. Subjects performed six neck motions while maximum joint angles and functional neck strength were recorded. Subjects also answered a subjective discomfort questionnaire. These testing procedures were repeated three times per day: without a helmet, with a helmet, and after wearing a helmet for one hour. As expected, results showed decreases in all range of motion measures after putting on either helmet. However, wearing a helmet for one hour did not consistently alter range of motion further, with a few exceptions. JHMCS helmets caused decreases in neck strength for right and left rotations and right lateral flexion after one hour; however, these decreases counteracted the increase seen after initially putting on the helmet (bringing values back to baseline). Levels of fatigue and discomfort increased after wearing either helmet for one hour, and JHMCS helmets had significantly greater discomfort in the head region after one hour compared to HGU-55/P helmets. Future work may conduct similar testing under high G conditions to more closely replicate operational use.

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1.0 SUMMARY

Joint Helmet Mounted Cuing System (JHMCS) helmets have a mounted display to show mission critical information; however, this added functionality comes at the cost of increased weight and shifted center of gravity compared to standard HGU-55/P helmets, which may lead to increased neck pain and injury. This study compared changes in cervical neck range of motion, strength, and subjective discomfort when wearing a JHMCS helmet compared to an HGU-55/P helmet. Forty subjects volunteered for two days of testing where one helmet was worn on each day. Subjects performed six neck motions while maximum joint angles and functional neck strength were recorded. Subjects also answered a subjective discomfort questionnaire. These testing procedures were repeated three times per day: without a helmet, with a helmet, and after wearing a helmet for one hour. As expected, results showed decreases in all range of motion measures after putting on either helmet. However, wearing a helmet for one hour did not consistently alter range of motion further, with a few exceptions. JHMCS helmets caused decreases in neck strength for right and left rotations and right lateral flexion after one hour; however, these decreases counteracted the increase seen after initially putting on the helmet (bringing values back to baseline). Levels of fatigue and discomfort increased after wearing either helmet for one hour, and JHMCS helmets had significantly greater discomfort in the head region after one hour compared to HGU-55/P helmets. Future work may conduct similar testing under high G conditions to more closely replicate operational use.

2.0 BACKGROUND

2.1 Introduction

As military fighter aircraft continue to advance in speed and capabilities, prevention and treatment of neck pain is becoming increasingly more important and necessary to mission success and pilot sustainability. Neck pain is a recurring problem in fighter pilots leading to "duties not including flying" (DNIF) status and long-term health effects. Surveys of fighter pilots often convey frequent instances of neck pain, including a retrospective survey of fighter pilots showing 72% experienced neck pain and 35% experienced back pain.[1] Another survey of F-16 pilots detailed an 18.9% one-year prevalence of neck pain.[2] Additionally, reports have detailed instances of cervical disk bulging in fighter pilots,[3] among other injuries such as cervical compression fractures, herniated discs, and interspinous ligament tears.[4]

Research has examined several factors which may lead to neck pain in pilots; however, exact causes of neck pain have been difficult to pinpoint and are likely multi-faceted.[2] A major consideration for neck pain in pilots is the high G flight environment. Maximum G exposure has been related to reports of neck pain,[1,5] and 74% of surveyed F/A-18 pilots reported neck pain with high $+G_z$ exposure.[6] Additionally, repeated high G flight caused significant muscle fatigue, particularly in the neck area,[7] and decreased isometric strength after high G flight has been measured in the back, neck, and lateral neck muscles.[7]

Besides high G exposure, pilots must also wear specialized helmets and equipment, which add additional weight and may limit range of motion. For example, a study examining centrifuge training under 3-7 $+G_z$ found increased neck muscle strain when wearing a helmet with mounted night vision goggles versus wearing a helmet without night vision goggles.[8] Similar to mounted night vision goggles, helmet mounted displays (HMD) are growing in popularity due to their added functionality and ability to enhance situational awareness. One such design is the Joint Helmet Mounted Cuing System (JHMCS) helmet, which uses a modified HGU-55/P helmet with a detachable display module. This display module projects mission critical information onto the helmet visor, allowing pilots to move their head to look at a target and engage weapon systems without looking away. While this technology provides excellent functionality, the added display module increases the overall weight of the helmet and shifts the center of gravity forward compared to HGU-55/P helmets. Due to these mass properties, JHMCS helmets place asymmetrical forces on the cervical spine, and constant contraction of neck muscles is required to keep the head level, even in a 1G environment.[9] Previous research in a 1G environment showed a lighter helmet with a forward center of gravity (similar to the JHMCS helmet) was significantly more uncomfortable than a heavier helmet with a central center of gravity.[10] Thus, JHMCS helmets may put pilots at an increased risk of neck pain and injury.

The Air Force Research Laboratory recommends helmets be under five pounds with a center of gravity within a given "Knox box".[*] Although the JHMCS helmet meets these guidelines, pilots still report increased incidence of neck pain when wearing JHMCS helmets. In a survey of F-16 97% experienced neck pain after flying; however, this study did not break down differences in neck pain between pilots wearing the JHMCS helmet or not.[11] Additionally, F-15C pilots reported that neck pain was significantly worse with JHMCS use compared to helmets without the JHMCS display.[12] Therefore, a need exists to further study JHMCS helmets to identify causes of pain such that future HMD helmets can be improved or helmet recommendations can be modified. To address this need, the current study assessed the functional effects of wear of a standard HGU-55/P helmet compared to a JHMCS helmet.

2.2 Purpose and Hypotheses

The objective of this study was to assess changes in cervical neck range of motion, neck strength, and subjective discomfort caused by HGU-55/P and JHMCS style helmets. Three time points of testing were no helmet (baseline), helmet less than 10 minutes, and helmet after one hour. The effect of putting on a helmet (ΔHelmet) and wearing a helmet for one hour (ΔFatigue) were examined for both helmet styles. The following hypotheses guided this study:

H1: Subjects wearing either helmet for less than 10 minutes will have decreased cervical neck range of motion, decreased neck strength, and more discomfort compared to the same subjects when not wearing a helmet (baseline).

$$\text{No Helmet} - \text{Helmet less than 10 minutes} = \Delta\text{Helmet}$$
$$\Delta\text{HGU-55/P} > 0 \text{ and } \Delta\text{JHMCS Helmet} > 0$$

H2: Subjects wearing either helmet for one hour will have decreased cervical neck range of motion, decreased neck strength, and more discomfort compared to the same subjects wearing a helmet for less than ten minutes.

[*] Knox F.S., Buhrman J.R., Perry C.E., and Kaleps I. (1991). "Interim Head/Neck Criterion," (non-published consultation report), Air Force Research Laboratory, Wright-Patterson AFB, OH.

Helmet less than 10 minutes – Helmet for one hour = ΔFatigue
ΔFatigue HGU-55/P > 0 and ΔFatigue JHMCS > 0

H3: Subjects wearing a JHMCS helmet for less than 10 minutes will have larger decreases (relative to not wearing the helmet) in cervical neck range of motion and neck strength and larger increases in discomfort compared to the same subjects wearing an HGU-55/P helmet at the same timepoints.
For range of motion and strength: Δ↓JHMCS Helmet > Δ↓HGU-55/P Helmet
For discomfort: Δ↑JHMCS Helmet > Δ↑HGU-55/P Helmet

H4: Subjects wearing a JHMCS helmet for one hour will have larger decreases (relative to wearing the helmet for less than 10 minutes) in cervical neck range of motion and neck strength and larger increases in discomfort compared to the same subjects wearing an HGU-55/P helmet at the same timepoints.
For range of motion and strength: Δ↓Fatigue JHMCS > Δ↓Fatigue HGU-55/P
For discomfort: Δ↑Fatigue JHMCS > Δ↑Fatigue HGU-55/P

A visual depiction of the study effects and each hypothesis comparison is shown in Figure 1.

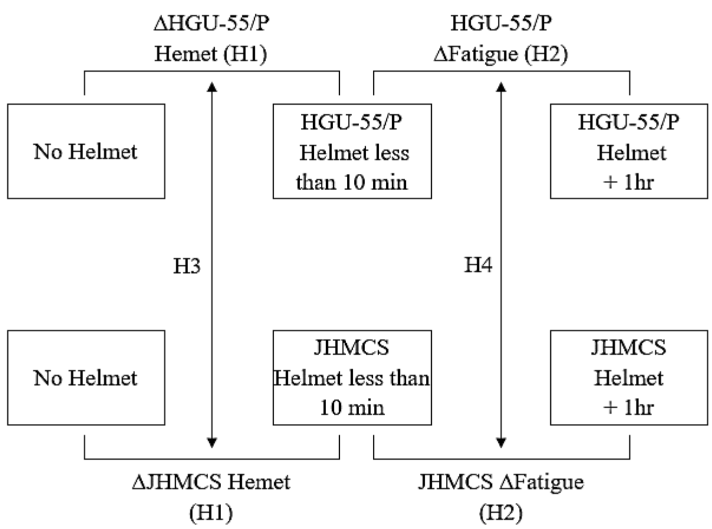


Figure 1: Visual Summary of Comparisons for each Hypothesis

3.0 METHODS

This study was conducted in accordance with the Wright-Patterson Air Force Base Institutional Review Board approved protocol number FWR20190054H.

3.1 Study Population

A person was eligible for participation in the study if the following three inclusion criteria were met: age 18-45 years old, no spinal injuries in the prior year, and no pacemakers or other magnetic sensitivities. Based on an a priori power analysis using $\alpha = 0.05$, power = 0.80, and assuming an effect size of 0.50, the required sample size was 33 subjects. A recruitment goal of 40 subjects was established to account for attrition where subjects failed to complete testing.

3.2 Research Design

This study included a combination of cervical neck range of motion, neck strength, and subjective neck discomfort measurements to compare an HGU-55/P and JHMCS helmets. The study used a repeated measures crossover design with two independent variables: time and helmet type. The three time points were no helmet (baseline), helmet less than 10 minutes, and helmet after one hour. The two helmet conditions were HGU-55/P and JHMCS.

3.3 Helmets

Three sizes of Gentex HGU-55/P helmets and three sizes of JHMCS helmets were used in this study (i.e., medium, large, and extra-large; see Appendix A, Table A-1 for part numbers). An MBU-20/P oxygen mask was used for all subjects (size large wide), weighing 0.4 lbs., with the intake/outtake hoses removed. JHMCS helmets were an average of 1.62 lbs. heavier than HGU-55/P helmets. Helmet mass properties and center of gravity are shown in Appendix A.

3.4 Measurement Instruments

Range of Motion: Subjects were instructed to perform six neck motions with maximal effort. Maximum range of motion (degrees) was measured using a cervical range of motion (CROM) device (Performance Attainment Associates, Lindstrom, MN). The CROM device is often used as the "gold-standard" device for cervical range of motion studies.[13,14,15] The CROM device has similar accuracy to a marker-based motion capture system,[16] and has demonstrated high reliability with intra-class correlation coefficients between 0.74-0.98.[16,17,18] Additionally, minimal detectable change for the CROM device is between 3.6-10.7 degrees.[16,17,18]

The CROM device is intended to be worn similar to a pair of glasses while an investigator reads appropriate range of motion from three inclinometers. In this study, the CROM could not be used as intended while wearing a helmet. To measure range of motion while wearing a helmet, a CROM device was modified to remove the arms and attach directly to the helmet (Figure 2, next page). Orientation of the modified CROM device was compensated for by taking starting measurements from the inclinometers while the neck was in a neutral position and subtracting these offsets from each subsequent range of motion measurement.

Figure 2: Modified CROM Device on Helmet

Strength: For each neck motion, subjects were instructed to push with maximal effort against an investigator holding a handheld dynamometer (microFET2, Hoggan Scientific, LLC., Salt Lake City, UT). Maximum force (lbf) was recorded for each motion. The microFET2 device has been used in prior research to detect changes in neck strength[19] and has good correlation to the "gold-standard" Biodex system.[20] Additionally, the microFET2 has demonstrated high intra-rater reliability with intra-class correlation coefficients between 0.87-0.97 and intra-session minimal detectable changes between 5.86-10.41 lbf when measuring neck strength.[19]

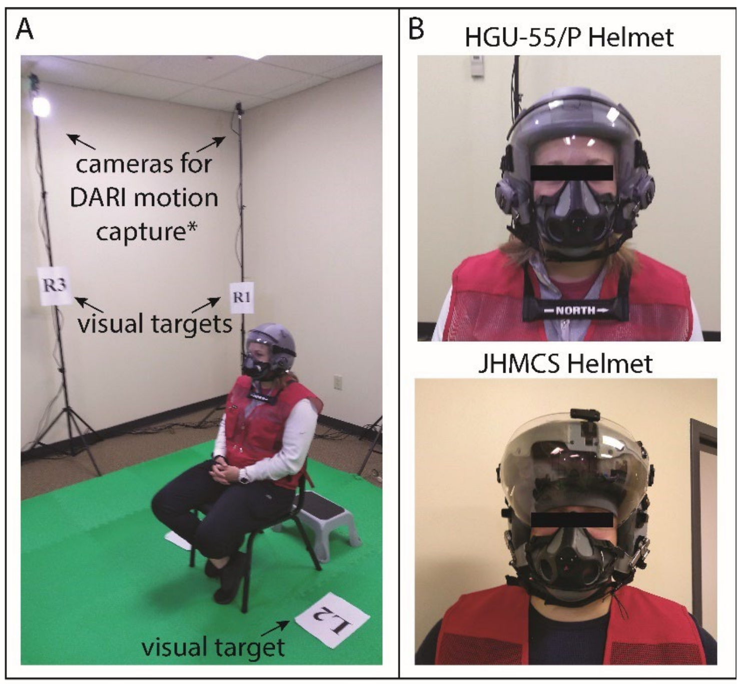
Subjective Discomfort: To assess subjective discomfort, a questionnaire was created by investigators which included three yes/no questions about level of difficulty for the motions, whether the subject felt fatigued, and whether the helmet was uncomfortable (Appendix B). The questionnaire also includes a Likert scale for discomfort in six different body regions. This same scale and body region identification was used in prior helmet research.[10]

3.5 Procedures

Each subject volunteered for two days of testing. On Day 1, subjects were assigned an identification number which was randomly associated with Group A or Group B. Subjects in Group A used the HGU-55/P helmet for testing on Day 1 and the JHMCS helmet for testing on Day 2. Conversely, subjects in Group B used the JHMCS helmet for testing on Day 1 and the HGU-55/P helmet for testing on Day 2. After being assigned an identification number on Day 1, subjects reviewed the informed consent document and completed a pretesting background questionnaire.

Testing occurred at three time points: no helmet (baseline), within 10 minutes after putting on the helmet, and after wearing the helmet for one hour. To begin testing, subjects wore a vest and were fitted with the CROM device per manufacturer guidelines. The vest provided chest pockets to hold the JHMCS helmet cable, when needed. Subjects were asked to sit in a rigid chair reclined at 10 degrees throughout testing (Figure 3A, next page). While seated, subjects performed the following six cervical neck movements while maximum range of motion was measured via the CROM device: flexion, extension, right rotation, left rotation, right lateral flexion, and left lateral flexion. To measure functional neck strength, subjects repeated these six movements while pushing with maximal force against an investigator with a microFET2 handheld dynamometer. After these tests, subjects answered a subjective discomfort questionnaire regarding their current physical state. This completed baseline testing with no helmet.

Each subject's head length and width were then measured using spreading calipers, and a helmet size was determined via Gentex HGU-55/P helmet manual specifications.[*] Subjects then put on a washable cap and the helmet for that day (Figure 3B, next page). A modified CROM device was then attached to the helmet (Figure 2), and a timer was started. Once the helmet was secure and the subject was comfortable, the above testing procedure was repeated with the helmet on (range of motion, strength, and questionnaire). This completed testing for wearing the helmet less than 10 minutes. After testing, the helmet visor was flipped down and an oxygen mask was worn to ensure stability. The mask intake/outtake connections were removed to allow subjects to breath freely (Figure 3B).



*DARI motion capture was used simultaneously to compare CROM inclinometer measured joint angles with motion capture measured joint angles. These results are included in a separate report.

Figure 3: Data Collection Set-up

After the second round of testing, subjects remained seated and wore the helmet until the timer reached one hour. While waiting, subjects were allowed to watch television from a computer located at eye level. Subjects performed a flight awareness check every 15 minutes to simulate actual helmet use and to standardize the amount of fatigue in each subject. A series of nine visual targets were placed around the subject's chair (Figure 3A), and subjects were instructed to look

[*]Operation and Maintenance Instructions with Illustrated Parts Breakdown: Lightweight HGU-55/P Helmet Assembly. Section 2-2.1: Determining Helmet Size. Gentex Corporation, 2011. https://shop.gentexcorp.com/content/TP0351-Commercial55.pdf.

at each target for five seconds each. After one hour, subjects performed the testing procedure again (i.e., range of motion, strength, and questionnaire). This completed testing for wearing the helmet for one hour. Immediately after testing, all equipment was sanitized with 70% alcohol.

All testing outlined above was repeated on Day 2, scheduled no less than 72 hours after initial testing. Day 2 testing was identical to Day 1, except the opposite helmet was worn.

3.6 Statistical Analysis

A significance level of 0.05 was set for all tests in the study. Subject demographics were tested for normality using a Shapiro-Wilk normality test in SPSS (IBM Corp., Version 25.0, Armonk, NY). Similarly, a Shapiro-Wilk normality test was also performed in SPSS to check if calculated differences in each measure (ΔHelmet and ΔFatigue) were normally distributed. If a measure was normally distributed, a paired t-test was then performed using SPSS. If a measure was not normally distributed, a related samples Wilcoxon signed rank test was performed using SPSS. Even though hypotheses indicate an expected direction in results (i.e. decreased range of motion, decreased neck strength, and increased discomfort), all analyses were performed using two-tailed tests. This is the most conservative approach and does not ignore the possibility that a difference exists in the opposite direction than hypothesized. All results for the appropriate test for each variable are found in the tables of Appendix C. Cohen's d_z effect size for repeated measures was also calculated for each result using the corresponding mean and standard deviation of the difference in each comparison (G*Power, University of Dusseldorf, Version 3.1.9.2, Dusseldorf, Germany).

4.0 RESULTS

4.1 Study Population

A total of 40 subjects were enrolled in the study (Table 1). All subject demographics were normally distributed except for the age of female subjects. Average time between testing days was 15 ± 13 days (min = 3, max = 45).

Table 1: Subject Demographics

Gender	**Number of Subjects**	**Age** (years)	**Height** (inches)	**Weight** (pounds)	**Head Length** (inches)	**Head Width** (inches)
Male	25	28.84 ± 7.12	70.84 ± 3.69	190.44 ± 38.08	7.90 ± 0.34	6.19 ± 0.25
Female	15	27.93 ± 8.15[†]	66.33 ± 3.75	153.27 ± 22.17	7.43 ± 0.20	5.88 ± 0.28

All values are mean ± standard deviation.
[†]Female age was non-normally distributed. Median age = 25 years. Interquartile range = 14 years.

4.2 Hypothesis Testing

Cervical neck range of motion and functional neck strength results are summarized in Figures 3 and 4, respectively (following pages). Subjective discomfort results are summarized in Figures 5 and 6. All results are also summarized in tabular format in Appendix C.

Hypothesis 1:
Hypothesis 1 predicted that subjects wearing either helmet for less than 10 minutes will have decreased cervical neck range of motion, decreased neck strength, and more discomfort compared to the same subjects when not wearing a helmet (baseline).

Range of Motion: The hypothesis was supported for both HGU-55/P and JHMCS helmets, where subjects had significantly decreased cervical neck range of motion for all movements after putting on either helmet ($p \leq 0.010$, $|d_z| \geq 0.428$, Figure 4, Table C-1 and C-3).

Strength: The hypothesis was partially supported for the HGU-55/P helmet and not supported for the JHMCS helmet. For subjects wearing the HGU-55/P helmet, only right rotation strength was significantly less after putting on the helmet ($p = 0.044$, $|d_z| = 0.329$, Figure 5C, Table C-1). However, left rotation neck strength was unchanged ($p = 0.468$, Figure 5D, Table C-1). The hypothesis was not supported for subjects wearing the JHMCS helmet, where only significant increases in right and left lateral flexion strength were seen after putting on the helmet (right: $p = 0.020$, $|d_z| = 0.384$; left: $p = 0.013$, $|d_z| = 0.410$; Figure 5E and 5F, Table C-3), rather than the expected decrease.

Subjective Discomfort: The hypothesis was not supported for HGU-55/P helmets and was partially supported for JHMCS helmets. Subjects reported no significant changes in fatigue or discomfort after putting on the HGU-55/P helmet ($p \geq 0.083$, Figure 6 and 7, Table C-2), but significantly higher levels of discomfort were reported after putting on the JHMCS helmet in the upper and lower neck regions (upper: $p = 0.046$, $|d_z| = 0.329$; lower: $p = 0.008$; $|d_z| = 0.455$, Figure 7B and 7C, Table C-4), though overall changes after putting on the helmet remained small.

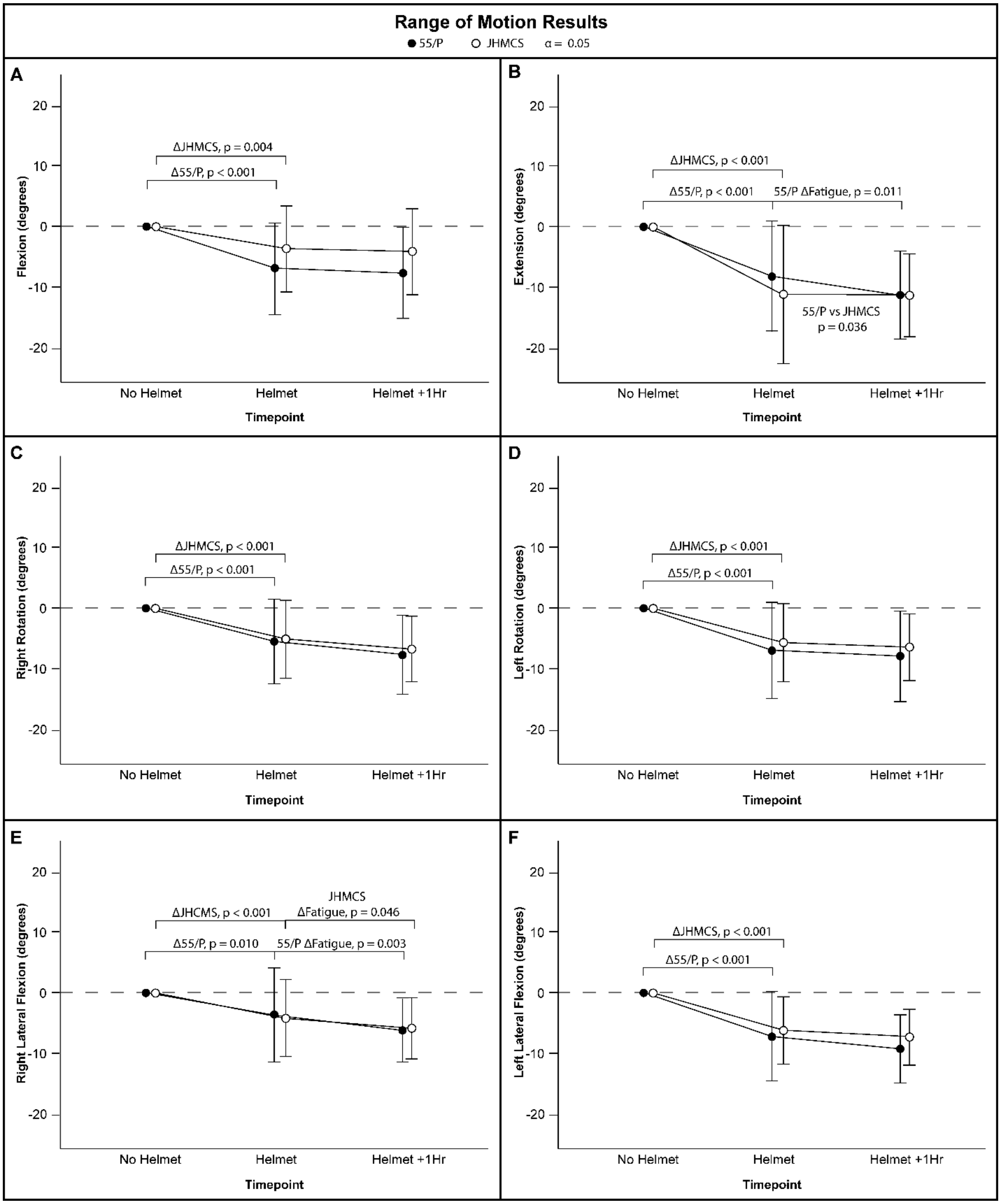


Figure 4: Cervical Neck Range of Motion Results

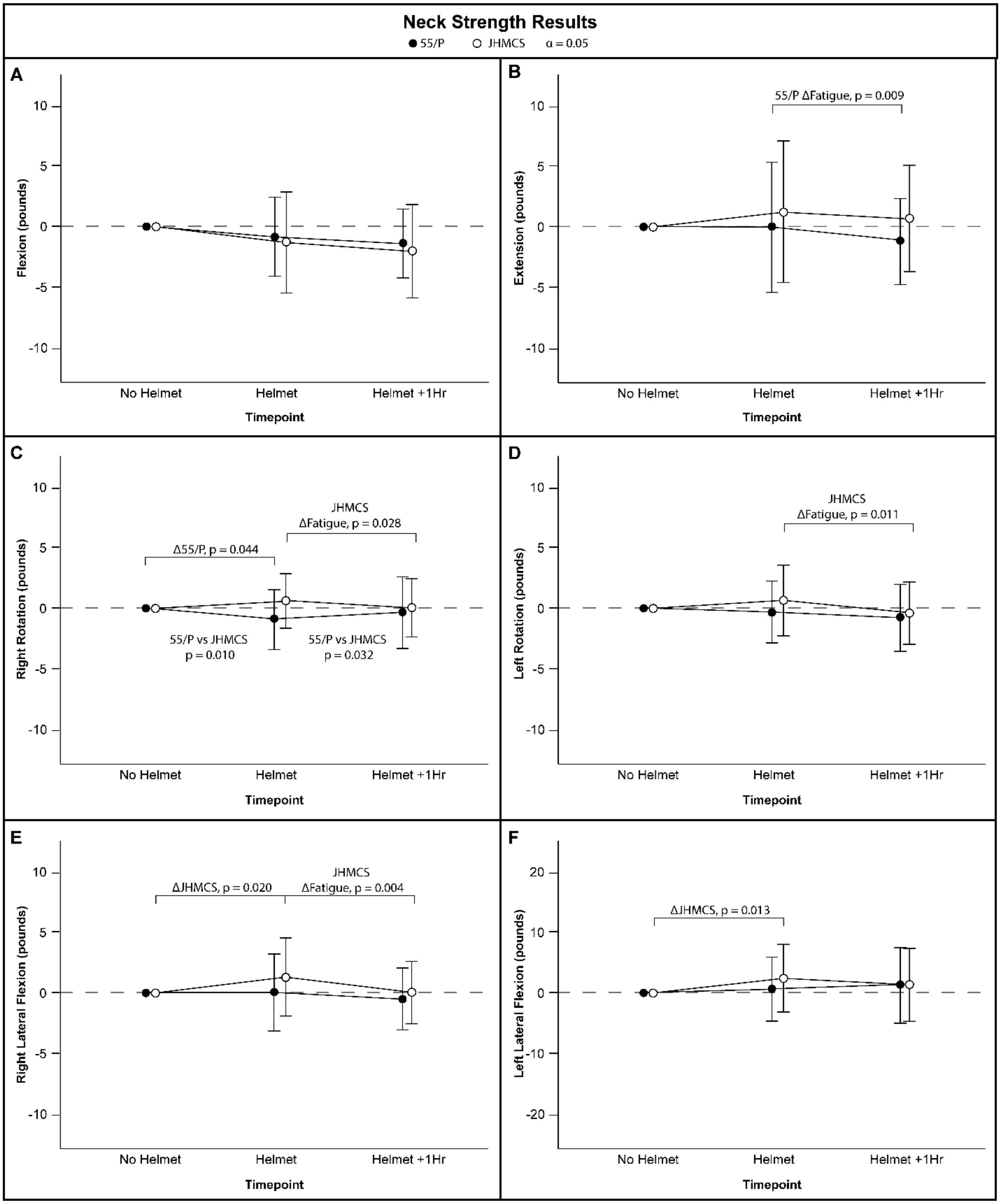


Figure 5: Cervical Neck Strength Results

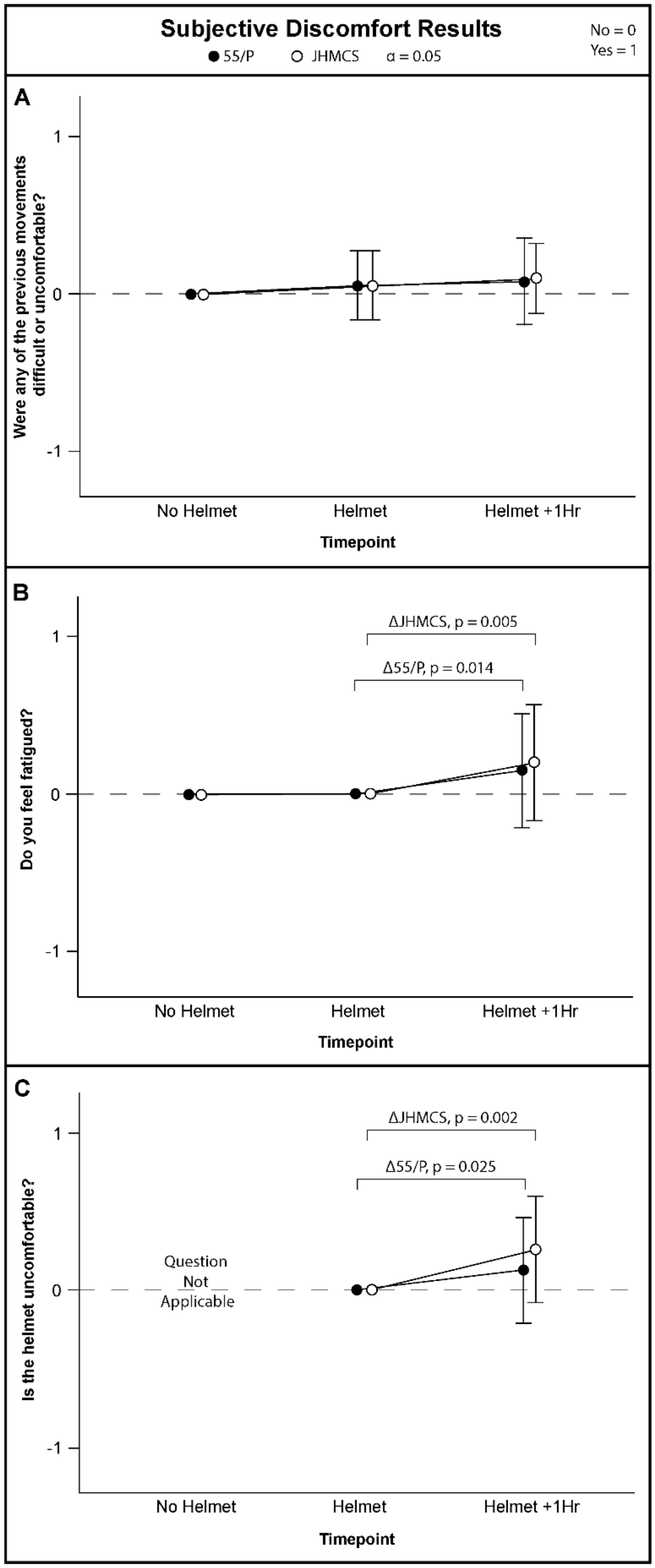


Figure 6: Subjective Discomfort Results

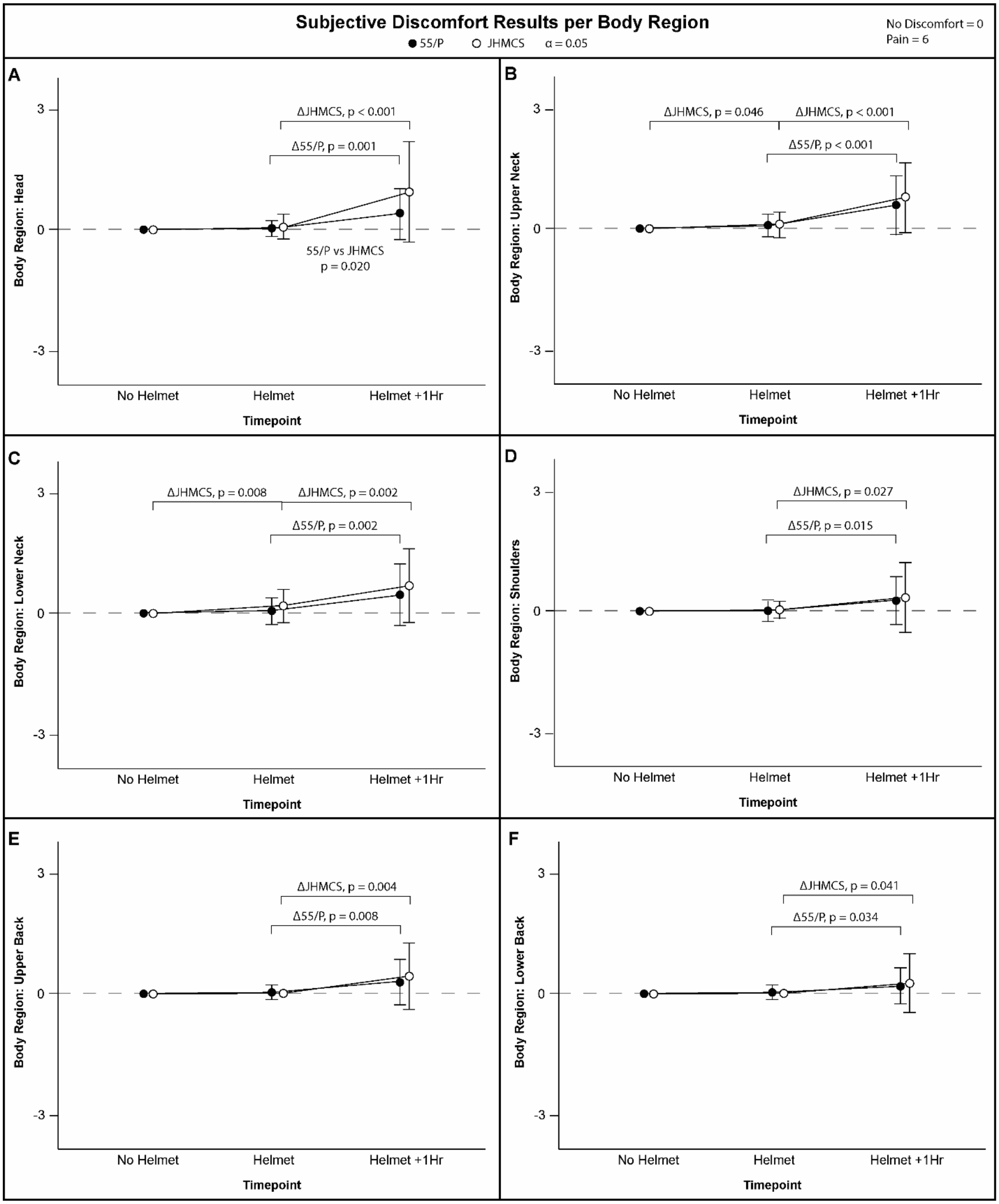


Figure 7: Subjective Discomfort Results per Body Region

Hypothesis 2:

Hypothesis 2 predicted that subjects wearing either helmet for one hour will have decreased cervical neck range of motion, decreased neck strength, and more discomfort compared to the same subjects wearing a helmet for less than ten minutes.

Range of Motion: The hypothesis was partially supported for both HGU-55/P and JHMCS helmets as expected decreases after wearing the helmet for one hour were only seen in some movements. Subjects wearing the HGU-55/P helmet had further significant decreases in extension range of motion ($p = 0.011$, $|d_z| = 0.423$, Figure 4B, Table C-5) and right lateral flexion range of motion ($p = 0.003$, $|d_z| = 0.498$, Figure 4E, Table C-5). Left lateral flexion showed similar trends, though not statistically significant ($p = 0.074$, Figure 4F). For the JHMCS helmet, there was a further significant decrease in right lateral flexion range of motion ($p = 0.046$, $|d_z| = 0.326$, Figure 4E, Table C-7). Again, left lateral flexion showed similar trends though not statistically significant ($p = 0.130$).

Strength: The hypothesis was partially supported for both HGU-55/P and JHMCS helmets, as expected decreases in neck strength were only seen in some movements. For the HGU-55/P helmet, only neck strength during extension was significantly less after wearing the helmet for one hour ($p = 0.009$, $|d_z| = 0.345$, Figure 5B, Table C-5). For the JHMCS helmet, there were significant decreases in right and left rotation strength (right: $p = 0.028$, $|d_z| = 0.245$; left: $p = 0.011$, $|d_z| = 0.421$; Figure 5C and 5D, Table C-7) and right lateral flexion strength ($p = 0.004$, $|d_z| = 0.481$, Figure 5E, Table C-7).

Subjective Discomfort: The hypothesis was supported for both helmets for all subjective discomfort questions except "were any of the previous movement difficult or uncomfortable?" (HGU-55/P: $p = 0.564$; | JHMCS: $p = 0.157$; Figure 6A, Table C-6 and C-8). Subjects reported significantly more fatigue (HGU-55/P: $p = 0.014$, $|d_z| = 0.414$; JHMCS: $p = 0.005$, $|d_z| = 0.494$; Figure 6B, Table C-6 and C-8) and higher levels of discomfort (HGU-55/P: $p = 0.025$, $|d_z| = 0.373$; JHMCS: $p = 0.002$, $|d_z| = 0.579$; Figure 6C, Table C-6 and C-8) after wearing both helmets for one hour. Additionally, both helmets had significantly more discomfort or pain in each body region after wearing the helmets for one hour ($p \leq 0.041$, $|d_z| \geq 0.337$, Figure 7, Table C-6 and C-8).

Hypothesis 3:

Hypothesis 3 predicated that subjects wearing a JHMCS helmet for less than 10 minutes will have larger decreases (relative to not wearing the helmet) in cervical neck range of motion and neck strength and larger increases in discomfort compared to the same subjects wearing an HGU-55/P helmet at the same time points.

Range of Motion: The hypothesis was not supported. No significant range of motion differences were seen between putting on the HGU-55/P helmet or JHMCS helmet ($p \geq 0.126$, Figure 4, Table C-9).

Strength: The hypothesis was not supported. While Hypothesis 3 predicted larger decreases in JHMCS helmets compared to HGU-55/P helmets, the opposite was seen for right rotation neck strength. JHMCS helmets saw a slight increase in neck strength during right rotation while the HGU-55/P helmet saw a slight decrease ($p = 0.010$, $|d_z| = 0.428$, Figure 5C, Table C-9). A similar trend in left rotation was not significant ($p = 0.066$, Figure 5D, Table C-9).

Subjective Discomfort: The hypothesis was not supported as no significant fatigue or comfort rating differences were seen between putting on the HGU-55/P helmet or JHMCS helmet ($p \geq 0.132$, Figure 6 and 7, Table C-10).

Hypothesis 4:
Hypothesis 4 predicted that subjects wearing a JHMCS helmet for one hour will have larger decreases (relative to wearing the helmet for less than 10 minutes) in cervical neck range of motion and neck strength and larger increases in discomfort compared to the same subjects wearing an HGU-55/P helmet at the same time points.

Range of Motion: The hypothesis was not supported. While Hypothesis 4 predicted larger decreases in JHMCS helmets compared to HGU-55/P helmets, the opposite was seen for extension range of motion. Subjects wearing HGU-55/P helmets had significantly greater decreases in extension range of motion after wearing the helmet for one hour compared to wearing the JHMCS helmet for one hour ($p = 0.036$, $|d_z| = 0.343$, Figure 4B, Table C-11). Looking at Figure 4B, JHMCS extension range of motion decreased a large amount after putting on the helmet, but did not decrease further after one hour. Subjects wearing the HGU-55/P helmet had a smaller decrease in extension range of motion when putting on the helmet which decreased significantly further after one hour.

Strength: The hypothesis was partially supported as JHMCS helmet strength during right rotation decreased more than in HGU-55/P helmets after one hour ($p = 0.032$, $|d_z| = 0.286$, Figure 5C, Table C-11). However, the HGU-55/P and JHMCS helmets seemed to counter changes seen when initially putting the helmets on (Hypothesis 3) as both helmets shifted back to baseline after one hour. These shifts were opposing and found to be significantly different between the two helmet styles. This same trend was seen in left rotation and right lateral flexion, although these were not statistically significant ($p \leq 0.262$, Figure 5D and 5E, Table C-11).

Subjective Discomfort: The hypothesis was partially supported as only JHMCS helmets had significantly greater increases in head region discomfort after wearing the helmet for one hour compared to the HGU-55/P helmet ($p = 0.020$, $|d_z| = 0.343$, Figure 7A, Table C-12).

5.0 DISCUSSION

5.1 Overview of the Study

As expected through Hypothesis 1, range of motion was decreased in all measures after putting on either helmet. However, neck strength did not consistently decrease after putting on a helmet. Here, only decreases in right rotation neck strength when wearing the HGU-55/P helmet were seen, along with increases in right and left lateral flexion strength when wearing the JHMCS helmet. Additionally, Hypothesis 1 predicted increases in discomfort when wearing either helmet; however, there were only significantly higher levels of discomfort in the upper and lower neck regions with the JHMCS helmet.

Hypothesis 2 predicted further decreases in all range of motion measures after wearing either helmet for one hour; however, decreases in range of motion were only seen in neck extension for the HGU-55/P helmet and in right lateral flexion for both helmets. Additionally, Hypothesis 2 predicted further decreases in all neck strength measures after wearing either helmet for one hour; however, only subjects wearing the HGU-55/P helmet had further decreases in neck strength during extension, and subjects wearing the JHMCS helmet saw decreases in neck strength during right and left rotation and right lateral flexion. As expected through Hypothesis 2, subjects had increased levels of discomfort after wearing either helmet for one hour for most questions and all body regions.

Hypothesis 3 predicted larger decreases in measures from baseline to putting on the helmet when wearing the JHMCS helmet relative to the HGU-55/P helmet. However, no differences between helmets were seen in range of motion or subjective discomfort results. The only difference in neck strength comparisons was in right rotation neck strength, which had the opposite effect than expected. Wearing the JHMCS helmet was associated with increases in neck strength while wearing the HGU-55/P was associated with decreases in neck strength.

Lastly, Hypothesis 4 predicted larger decreases in measures from putting on the helmet to one hour when wearing the JHMCS helmet relative to the HGU-55/P helmet. However, the opposite effect was seen in extension range of motion where HGU-55/P helmets had greater decreases than JHMCS helmets after one hour. An expected difference was seen with JHMCS helmets having larger decreases in right rotation neck strength compared to HGU-55/P helmets. Additionally, subjective discomfort results showed only a significantly greater discomfort in the head region after one hour of wearing JHMCS helmets compared to HGU-55/P helmets.

5.2 Comments on Unexpected Findings

Although expected decreases in range of motion were seen after putting on either helmet, range of motion was not consistently decreased further after one hour. While prior research has linked changes in range of motion to neck pain,[21,22] subjects in the current study were not in pain immediately after putting on the helmets. Thus, decreases in range of motion after putting on the helmets may be solely due to the helmet itself. However, further range of motion changes were expected after one hour, especially with the onset of fatigue and pain. Again, subjects did not consistently report severe neck pain (only one person ever rated pain above 4 on the Likert scale, Appendix B). Thus, further range of motion changes may not be expected at one hour since pain was not severe.

Additionally, Hypotheses 3 and 4 predicted larger decreases in range of motion from wearing a JHMCS helmet compared to an HGU-55/P helmet. Unexpectedly, range of motion for right and left rotation and right and left lateral flexion tracked closely between the two helmets and decreased over time. It is hypothesized that longer time periods over one hour may lead to further decreases in range of motion, especially as fatigue and pain increase over time. However, repeated measures may also play a role, as seen in prior work reporting reduced lateral flexion after a second measurement.[21]

Contrary to what was predicted, neck strength did not consistently decrease after putting on the helmet or after one hour. Additionally, when comparing the two helmets after initially putting them on, the only difference was in right rotation neck strength, which had the opposite effect than expected. Here, wearing the JHMCS helmet was associated with increases in neck strength while wearing HGU-55/P helmet was associated with decreases in neck strength. This unexpected strength increase when wearing the JHMCS helmet may be due to feeling more protected or by leaning into the movement more with the additional weight of the helmet. However, in each movement, neck strength tended to return to baseline after one hour, potentially because subjects became adjusted to the helmet.

After one hour, wearing the JHMCS helmet was associated with larger decreases in right rotation neck strength compared to wearing the HGU-55/P helmet (as expected), reversing the finding between the first two time points described above. Therefore, meaningful and lasting changes in neck strength were not found. Prior research showed nearly identical neck strength in extension before and after wearing an aviator's helmet for eight hours, along with increased muscle fatigue in the splenius capitus muscles.[10] The same prior study did not see differences in neck strength caused by mock helmets of varying weight and center of gravity,[10] thus matching the results of the current study. Other work has related chronic neck pain with significantly lower neck strength in flexion, extension, and rotational strength.[23] However, the current study only induced mild discomfort or acute neck pain; thus, changes in neck strength may not have been expected.

Putting on either helmet was expected to increase initial discomfort; however, this was not seen. Prior research noted significant discomfort after two hours of wearing a helmet.[10] Thus, discomfort may be reliant on time, rather than the helmet itself, and longer times may amplify discomfort. Additionally, there were no significant differences in subjective discomfort between HGU-55/P and JHMCS helmets at any time point, with the exception of increased discomfort in the head region after one hour. These results can be compared to prior work showing neck and back discomfort from wearing a helmet with a forward shifted center of gravity for eight hours; however, this study also noted that increased helmet weight did not correlate to increases in subject discomfort. [10] Thus, center of gravity shifts may affect discomfort more than weight but potentially only at longer durations.

As expected, wearing the JHMCS helmet was associated with increased discomfort after putting on the helmet, but only in the upper and lower neck body regions. After one hour, all body regions had significantly higher discomfort ratings for both helmets. Prior survey reports have shown pilots experience more neck pain after wearing a JHMCS helmet,[12] which was expected in Hypotheses 3 and 4. However, the current study only showed increased discomfort in the head region after one hour when wearing the JHMCS helmet compared to the HGU-55/P helmet. Over longer periods of time, additional differences between the two helmets may be seen. Additionally, JHMCS helmets may cause increased pain and fatigue when under additional G forces.

All unexpected results noted above may be best summarized by the fatigue effect not being present after only one hour, and correspondingly, discomfort levels were not high enough after one hour to drastically impact functional neck measures further. While actual fighter pilot sorties range from 1-2 hours, this time wearing the helmet is also under high G forces, which may impact fatigue and pain, and in turn then impact range of motion and neck strength.

Lastly, a nonsignificant but unexpected result was seen where flexion range of motion decreased more when wearing an HGU-55/P helmet compared to a JHMCS helmet (Figure 4A). Subjects may have felt unsure of their movements when wearing a helmet for the first time, and may have been more cautious when moving their heads (big decrease in flexion for HGU-55/P). However, the forward shifted center of gravity in JHMCS helmets may have served to pull the head down closer to the true maximal flexion (lesser decrease in flexion for JHMCS compared to baseline). Additionally, range of motion for extension was reduced sooner in the JHMCS helmet compared to the HGU-55/P helmet (Figure 4B). Subjects may have been hesitant to go into full extension because the added weight pulling in the opposite direction made them uneasy.

5.3 Comments on Operational Relevance

All range of motion measures significantly decreased after putting on a helmet, implying that a pilot's ability to move their neck may be significantly impaired when wearing a helmet. However, it is important to note that even though these changes were statistically significant, all significant changes were relatively small, with magnitudes ranging from 1.63-11.13 degrees ($|d_z|$ ranged from 0.343-1.084). Minimal detectable changes for the CROM device is between 3.6-10.7 degrees;[16,17,18] thus, these changes in cervical range of motion were relatively small compared to the measuring consistency of the device. Therefore, while these findings were statistically significant, they may not be as operationally significant as initially implied.

Similarly, even though some neck strength measures were statistically significant, the mean magnitude of significant changes ranged from 0.57-1.24 lbs ($|d_z|$ ranged from 0.245-0.481). These mean changes were small, especially when considering that the reported minimal detectable changes for measuring neck strength with the MicroFET2 device is between 5.86-10.41 lbf [19]. Therefore, these changes in neck strength may be statistically significant, but changes were small and may not be operationally significant or significant in relation to the measuring consistency of the device.

There were large increases in the proportion of "yes" responses to the question "do you feel fatigued?" when wearing both helmets after one hour (15% increase in HGU-55/P and 20% increase in JHMCS, Figure 6B). Write-in responses largely conveyed subjects were not accustomed to using these neck muscles, especially for maximal strength measures. They also were not used to the heaviness of the helmets. Actual pilots, who are accustomed to wearing helmets for long periods of time, may not report as high fatigue levels from helmet wear.

Similarly, there were large increases in "yes" responses to the question "is the helmet uncomfortable?" when wearing both helmets after one hour (12.5% increase in HGU-55/P and 27.2% increase in JHMCS, Figure 6C). More discomfort was noted when wearing the JHMCS helmet, but this effect was not significant. However, the write-in responses related to this question showed the HGU-55/P and JHMCS helmets largely received complaints from helmet fit (i.e. ear cups rubbing, mask uncomfortable, and pressure on head), while the JHCMS helmet received additional complaints about tightness and forehead pain. Forehead pain complaints were demonstrated in the data by an increase in discomfort levels for the head body region after one hour (Figure 7A), where the JHMCS helmet had significantly higher discomfort ratings compared to the HGU-55/P helmet after one hour. These reports of discomfort in JHMCS helmets may agree with prior surveys of JHMCS related neck pain[11,12] and have operational significance to fighter pilots.

Overall, there were more instances of significant changes in neck range of motion as opposed to functional neck strength. Additionally, subjects reported higher fatigue and discomfort responses for all body regions after wearing the helmets for one hour. Therefore, fatigue and pain may affect range of motion more than functional neck strength. These findings may be supported by prior work showing no significant differences in neck muscle strength and positioning between healthy F-16 pilots and those with neck pain; however, those with neck pain had limited range of motion in the sagittal and transverse plane.[24] Limited range of motion may be detrimental to fighter pilots who need to move heads to look at targets (as suggested with JHMCS functionality) and perform “check six” awareness checks.[11]

5.4 Methodological Limitations

A possible limit on accuracy may exist from the CROM inclinometers being marked in increments of 2 degrees; however, the CROM device has been studied previously to accurately measure range of motion with minimal detectable changes between 3.6-10.7 degrees.[18,19] Another possible limitation is that the CROM device could not be used per manufacturer’s instructions while wearing a helmet, and a modified CROM device was used with helmets (Figure 2). Therefore, there exists possibility that the modified CROM device does not measure exactly as intended. Orientation of the modified CROM device was compensated for by taking starting measurements while the subject’s neck was in a neutral position and subtracting these offsets from each measurement.

Additionally, this study was performed in a 1 G environment, whereas pilots wear helmets under high G forces. Larger effects may be seen if the same study was performed while under higher G forces. Additionally, the rigid chair used in this study had a back rest reclined to 10 degrees, whereas traditional pilot ejection seats are reclined 13-30 degrees depending on the aircraft. Lastly, proper fitting helmets per operational standards could not be guaranteed in this study since all sizes of each piece of equipment were not available (i.e., different liners, different earcups, different mask sizes, etc.). Improper fit could have affected subjective discomfort results.

5.5 Recommendations for Future Work

This study should serve as an initial foundation for future studies quantifying changes in neck range of motion, neck strength, and subjective discomfort after wearing helmets in a higher G environment, such as during actual sorties or simulated exposures in a centrifuge. Prior work showed relations between neck pain and frequency of G exposure[5], so repeated sorties or centrifuge sessions may be recommended.

6.0 CONCLUSION

Wearing HGU-55/P or JHMCS helmets decreased range of motion, but no further effect was seen after one hour. Neck strength was not consistently affected by helmet or time. However, subjects reported significantly more fatigue and discomfort from both helmets after one hour, which may operationally affect airmen. Larger differences in these measures would be expected under high G forces and when wearing a helmet for longer periods of time, which future research may examine.

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8.0 LIST OF ACRONYMS

CROM	cervical range of motion
DARI	Dynamic Athletic Research Institute
DNIF	duties not including flying
HGU	head gear unit
HMD	helmet mounted display
JHMCS	joint helmet mounted cuing system
SD	standard deviation
USAF	United States Air Force

APPENDIX A

LIST OF FIGURES

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Helmet part numbers are shown in Table A-1 below.

Table A-1: Helmet Manufacturer Information and Part Numbers

Size	Style	Manufacturer of Helmet	Part Number of Helmet	Manufacturer of Display Module	Part Number of Display Module
Medium	HGU-55/P	Gentex	8475-01-446-1786	N/A	N/A
Large	HGU-55/P	Gentex	8475-01-446-2438	N/A	N/A
X-Large	HGU-55/P	Gentex	8475-01-446-2436	N/A	N/A
Medium	Legacy JHMCS	VSI	620540-03-00	Rockwell+	09344 135015-59B
Large	Legacy JHMCS	Kaiser Electronics#	135315-16		
X-Large	Legacy JHMCS	VSI	620510-01-05	Rockwell	09344 135015-59B

The large JHMCS style helmet from was further identified as “JHMCS HDU Mockup”.

+ The same display module was swapped between the medium and large size helmets when needed.

Helmet mass properties were measured on a large ADAM manikin head with known mass properties to determine the center of gravity shift induced by each helmet set-up. Center of gravity data was recorded with respect to the manikin's anatomical coordinate system (Figure A-1).

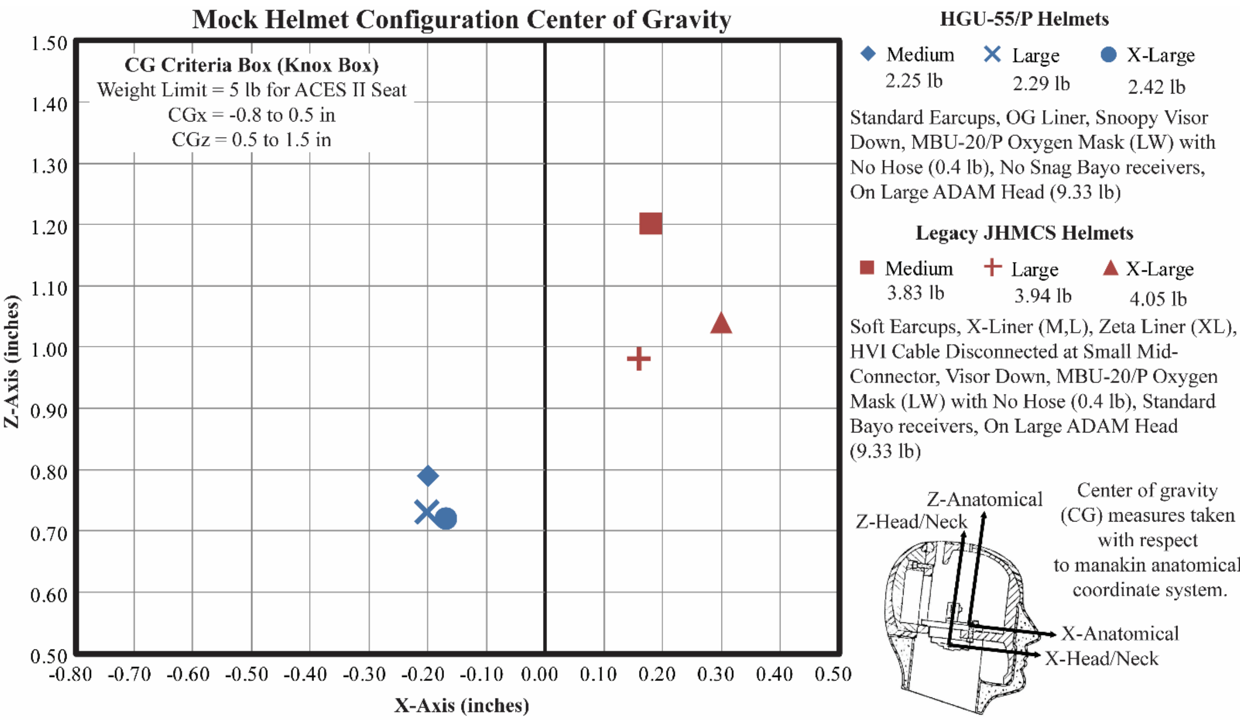


Figure A-1: Helmet Center of Gravity Measures

APPENDIX B

The following questionnaire was given at each testing point on each testing day:

Please answer Yes or No for the following questions:

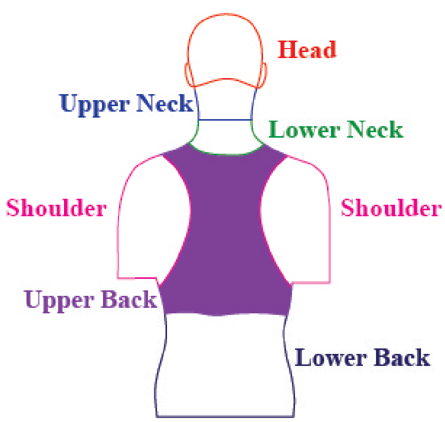
1. Were any of the previous movements difficult or uncomfortable? Yes No
2. Do you feel fatigued? Yes No
3. Is the helmet uncomfortable? N/A Yes No

Please describe any Yes answers: ____

____

According to the scale below, select a number that corresponds to your current physical state for each of the regions shown in the image below. Please record answers in the provided table.

0	1	2	3	4	5	6
No Discomfort		Discomfort		Soreness		Pain



Region	Current Rating
Head	
Upper Neck	
Lower Neck	
Shoulders	
Upper Back	
Lower Back	

If any rating is greater than 3, please answer the following questions:

Is your pain/discomfort (circle one): Constant Movement Induced

Please explain: ____

Do you have any other symptoms, such as numbness, weakness, tenderness, etc? Yes No

If Yes, describe: ____

APPENDIX C

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Table C-1: Results Table for Continuous Data in Hypothesis 1: HGU-55/P

		Shapiro-Wilk Normality Test	**Paired *t*-test** (Used if data normally distributed.)					**Related Samples Wilcoxon Signed Rank Test** (Used if not normally distributed.)	**Cohen's *d* Effect Size** (d_z for Repeated Measures)
	Hypothesis 1 HGU-55/P (No Helmet vs Helmet less than 10 min)	**Sig**	**Mean of the Difference** (NoHelmet-Helmet)	**SD of the Difference** (NoHelmet-Helmet)	***t***	**df**	**Sig** (2-tailed)	**Sig**	d_z
Range of Motion (deg)	Flexion	0.691	6.650	7.509	5.601	39	< 0.001	-	0.886
	Extension	0.032	8.200	9.126	5.683	39	-	< 0.001	0.899
	Right Rotation	0.452	5.250	7.027	4.726	39	< 0.001	-	0.747
	Left Rotation	0.025	6.750	7.814	5.463	39	-	< 0.001	0.864
	Right Lateral Flexion	0.472	3.275	7.649	2.708	39	< 0.001	-	0.428
	Left Lateral Flexion	0.486	6.950	7.380	5.956	39	< 0.001	-	0.942

Table C-1: Continued

		Shapiro-Wilk Normality Test	Paired *t*-test (Used if data normally distributed.)					Related Samples Wilcoxon Signed Rank Test (Used if not normally distributed.)	Cohen's *d* Effect Size (d_z for Repeated Measures)
	Hypothesis 1 HGU-55/P (No Helmet vs Helmet less than 10 min)	**Sig**	**Mean of the Difference** (NoHelmet-Helmet)	**SD of the Difference** (NoHelmet-Helmet)	***t***	**df**	**Sig** (2-tailed)	**Sig**	d_z
Neck Strength (lbf)	Flexion	0.307	0.885	3.248	1.723	39	0.093	-	0.272
	Extension	0.292	0.028	5.364	0.032	39	0.974	-	0.005
	Right Rotation	0.382	0.805	2.446	2.082	39	0.044	-	0.329
	Left Rotation	0.131	0.295	2.545	0.733	39	0.468	-	0.116
	Right Lateral Flexion	0.217	-0.020	3.176	-0.040	39	0.968	-	-0.006
	Left Lateral Flexion	0.894	-0.285	2.678	-0.673	39	0.505	-	-0.106

Table C-2: Results Table for Ordinal Data in Hypothesis 1: HGU-55/P

	Paired *t*-test (All data not normally distributed. Used for descriptive numbers.)				Related Samples Wilcoxon Signed Rank Test	Cohen's *d* Effect Size (d_z for Repeated Measures)
Hypothesis 1 HGU-55/P (No Helmet vs Helmet less than 10 min)	**Mean of the Difference** (NoHelmet-Helmet)	**SD of the Difference** (NoHelmet-Helmet)	***t***	**df**	**Sig**	d_z
Were any of the previous movements difficult or uncomfortable?	-0.050	0.221	-1.433	39	0.157	-0.226
Do you feel fatigued?	Exact – no change					
Head	-0.025	0.158	-1.000	39	0.317	-0.158
UpperNeck	-0.075	0.267	-1.778	39	0.083	-0.281
LowerNeck	-0.050	0.316	-1.000	39	0.317	-0.158
Shoulders	0.000	0.226	0.000	39	1.000	0
UpperBack	-0.025	0.158	-1.000	39	0.317	-0.158

LowerBack	-0.025	0.158	-1.000	39	0.317	-0.158

Table C-3: Results Table for Continuous Data in Hypothesis 1: JHMCS

		Shapiro-Wilk Normality Test	**Paired *t*-test** (Used if data normally distributed.)					**Related Samples Wilcoxon Signed Rank Test** (Used if not normally distributed.)	**Cohen's *d* Effect Size** (d_z for Repeated Measures)
	Hypothesis 1 JHMCS (No Helmet vs Helmet less than 10 min)	**Sig**	**Mean of the Difference** (NoHelmet-Helmet)	**SD of the Difference** (NoHelmet-Helmet)	***t***	**df**	**Sig** (2-tailed)	**Sig**	d_z
Range of Motion (deg)	Flexion	0.300	3.425	7.063	3.067	39	0.004	-	0.485
	Extension	0.294	11.125	11.335	6.208	39	< 0.001	-	0.981
	Right Rotation	0.007	4.838	6.504	4.524	36	-	< 0.001	0.744
	Left Rotation	0.785	5.425	6.425	5.340	39	< 0.001	-	0.844
	Right Lateral Flexion	0.337	3.925	6.298	3.942	39	< 0.001	-	0.623
	Left Lateral Flexion	0.111	5.925	5.465	6.857	39	< 0.001	-	1.084
Neck Strength (lbf)	Flexion	0.310	1.298	4.122	1.991	39	0.054	-	0.315
	Extension	0.800	-1.155	5.837	-1.251	39	0.218	-	-0.198
	Right Rotation	0.569	-0.680	2.223	-1.935	39	0.060	-	-0.306
	Left Rotation	0.009	-0.708	2.906	-1.540	39	-	0.137	-0.243
	Right Lateral Flexion	0.970	-1.235	3.215	-2.430	39	0.020	-	-0.384
	Left Lateral Flexion	0.400	-1.153	2.813	-2.591	39	0.013	-	-0.410

Table C-4: Results Table for Ordinal Data in Hypothesis 1: JHMCS

	Paired *t*-test (All data not normally distributed. Used for descriptive numbers.)				**Related Samples Wilcoxon Signed Rank Test**	**Cohen's *d* Effect Size** (d_z for Repeated Measures)
Hypothesis 1 JHMCS (No Helmet vs Helmet less than 10 min)	**Mean of the Difference** (NoHelmet-Helmet)	**SD of the Difference** (NoHelmet-Helmet)	***t***	**df**	**Sig**	d_z
Were any of the previous movements difficult or uncomfortable?	-0.050	0.221	-1.433	39	0.157	-0.226
Do you feel fatigued?	Exact – no change					
Head	-0.050	0.316	-1.000	39	0.317	-0.158
UpperNeck	-0.100	0.304	-2.082	39	0.046	-0.329
LowerNeck	-0.175	0.385	-2.876	39	0.008	-0.455
Shoulders	-0.025	0.158	-1.000	39	0.317	-0.158
UpperBack	Exact – no change					
LowerBack	Exact – no change					

Table C-5: Results Table for Continuous Data in Hypothesis 2: HGU-55/P

		Shapiro-Wilk Normality Test	**Paired *t*-test** (Used if data normally distributed.)					**Related Samples Wilcoxon Signed Rank Test** (Used if not normally distributed.)	**Cohen's *d* Effect Size** (d_z for Repeated Measures)
	Hypothesis 2 HGU-55/P (Helmet less than 10 min vs Helmet for one hour)	**Sig**	**Mean of the Difference** (Helmet-Helmet1Hr)	**SD of the Difference** (Helmet-Helmet1Hr)	***t***	**df**	**Sig** (2-tailed)	**Sig**	d_z
Range of Motion (deg)	Flexion	0.568	0.825	7.521	0.694	39	0.492	-	0.110
	Extension	0.685	3.050	7.218	2.672	39	0.011	-	0.423
	Right Rotation	0.011	2.231	6.587	2.115	38	-	0.056	0.339
	Left Rotation	0.182	0.900	7.595	0.749	39	0.458	-	0.118
	Right Lateral Flexion	0.102	2.625	5.266	3.153	39	0.003	-	0.498
	Left Lateral Flexion	0.007	2.000	5.616	2.252	39	-	0.074	0.356
Neck Strength (lbf)	Flexion	0.881	0.508	2.771	1.158	39	0.254	-	0.183
	Extension	0.042	1.165	3.381	2.179	39	-	0.009	0.345
	Right Rotation	0.338	-0.535	2.896	-1.169	39	0.250	-	-0.185
	Left Rotation	0.923	0.385	2.723	0.894	39	0.377	-	0.141
	Right Lateral Flexion	0.566	0.583	2.533	1.454	39	0.154	-	0.230
	Left Lateral Flexion	0.124	0.568	3.026	1.186	39	0.243	-	0.188

Table C-6: Results Table for Ordinal Data in Hypothesis 2: HGU-55/P

	Paired *t*-test (All data not normally distributed. Used for descriptive numbers.)				**Related Samples Wilcoxon Signed Rank Test**	**Cohen's *d* Effect Size** (d_z for Repeated Measures)
Hypothesis 2 HGU-55/P (Helmet less than 10 min vs Helmet for one hour)	**Mean of the Difference** (Helmet-Helmet1Hr)	**SD of the Difference** (Helmet-Helmet1Hr)	***t***	**df**	**Sig**	d_z
Were any of the previous movements difficult or uncomfortable?	-0.025	0.276	-0.572	39	0.564	-0.091
Do you feel fatigued?	-0.150	0.362	-2.623	39	0.014	-0.414
Is the helmet uncomfortable?	-0.125	0.335	-2.360	39	0.025	-0.373
Head	-0.375	0.628	-3.777	39	0.001	-0.597
UpperNeck	-0.500	0.716	-4.416	39	< 0.001	-0.698
LowerNeck	-0.400	0.744	-3.399	39	0.002	-0.538
Shoulders	-0.250	0.588	-2.687	39	0.015	-0.425
UpperBack	-0.250	0.543	-2.912	39	0.008	-0.460
LowerBack	-0.150	0.427	-2.223	39	0.034	-0.351

Table C-7: Results Table for Continuous Data in Hypothesis 2: JHMCS

		Shapiro-Wilk Normality Test	**Paired *t*-test** (Used if data normally distributed.)					**Related Samples Wilcoxon Signed Rank Test** (Used if not normally distributed.)	**Cohen's *d* Effect Size** (d_z for Repeated Measures)
	Hypothesis 2 JHMCS (Helmet less than 10 min vs Helmet for one hour)	**Sig**	**Mean of the Difference** (Helmet-Helmet1Hr)	**SD of the Difference** (Helmet-Helmet1Hr)	***t***	**df**	**Sig** (2-tailed)	**Sig**	d_z
Range of Motion (deg)	Flexion	0.022	0.475	7.042	0.427	39	-	0.470	0.067
	Extension	0.374	0.175	6.838	0.162	39	0.872	-	0.026
	Right Rotation	0.289	1.676	5.313	1.919	36	0.063	-	0.315
	Left Rotation	0.724	0.750	5.546	0.855	39	0.398	-	0.135
	Right Lateral Flexion	0.225	1.625	4.986	2.061	39	0.046	-	0.326
	Left Lateral Flexion	0.423	1.075	4.399	1.545	39	0.130	-	0.244
Neck Strength (lbf)	Flexion	0.817	0.743	3.864	1.215	39	0.232	-	0.192
	Extension	0.167	0.508	4.384	0.732	39	0.468	-	0.116
	Right Rotation	0.001	0.573	2.340	1.547	39	-	0.028	0.245
	Left Rotation	0.764	1.055	2.506	2.662	39	0.011	-	0.421
	Right Lateral Flexion	0.885	1.233	2.560	3.045	39	0.004	-	0.481
	Left Lateral Flexion	0.961	0.510	3.012	1.071	39	0.291	-	0.169

Table C-8: Results Table for Ordinal Data in Hypothesis 2: JHMCS

	Paired *t*-test (All data not normally distributed. Used for descriptive numbers.)				**Related Samples Wilcoxon Signed Rank Test**	**Cohen's *d* Effect Size** (d_z for Repeated Measures)
Hypothesis 2 **JHMCS** (Helmet less than 10 min vs Helmet for one hour)	**Mean of the Difference** (Helmet-Helmet1Hr)	**SD of the Difference** (Helmet-Helmet1Hr)	***t***	**df**	**Sig**	d_z
Were any of the previous movements difficult or uncomfortable?	-0.050	0.221	-1.433	39	0.157	-0.226
Do you feel fatigued?	-0.020	0.405	-3.122	39	0.005	-0.494
Is the helmet uncomfortable?	-0.256	0.442	-3.620	38	0.002	-0.579
Head	-0.875	1.244	-4.448	39	< 0.001	-0.703
UpperNeck	-0.675	0.859	-4.970	39	< 0.001	-0.786
LowerNeck	-0.500	0.906	-3.491	39	0.002	-0.552
Shoulders	-0.300	0.853	-2.223	39	0.027	-0.352
UpperBack	-0.425	0.813	-3.306	39	0.004	-0.523
LowerBack	-0.250	0.742	-2.130	39	0.041	-0.337

Table C-9: Results Table for Continuous Data in Hypothesis 3

		Paired *t*-test (Used if data normally distributed.)					**Related Samples Wilcoxon Signed Rank Test** (Used if not normally distributed.)	**Cohen's *d* Effect Size** (d_z for Repeated Measures)
	Hypothesis 3 (ΔHelmet 55/P vs ΔHelmet JHMCS)	**Mean of the Difference** (55/P-JHMCS)	**SD of the Difference** (55/P-JHMCS)	***t***	**df**	**Sig** (2-tailed)	**Sig**	d_z
Range of Motion (deg)	Flexion	-3.225	9.169	-2.224	39	0.320	-	-0.352
	Extension	2.925	13.010	1.422	39	-	0.126	0.225
	Right Rotation	-0.189	9.317	-0.120	36	-	0.718	-0.02
	Left Rotation	-1.325	9.856	-0.85	39	-	0.408	-0.134
	Right Lateral Flexion	0.650	6.956	0.591	39	0.558	-	0.093
	Left Lateral Flexion	-1.025	7.433	-0.872	39	0.388	-	-0.138
Neck Strength (lbf)	Flexion	0.413	4.514	0.578	39	0.567	-	0.092
	Extension	-1.183	6.313	-1.185	39	0.243	-	-0.187
	Right Rotation	-1.485	3.467	-2.709	39	0.010	-	-0.428
	Left Rotation	-1.003	3.436	-1.845	39	-	0.066	-0.292
	Right Lateral Flexion	-1.215	4.187	-1.835	39	0.074	-	-0.290
	Left Lateral Flexion	-0.868	3.418	-1.605	39	0.117	-	-0.254

Table C-10: Results Table for Ordinal Data in Hypothesis 3

	Paired *t*-test (All data not normally distributed. Used for descriptive numbers.)				**Related Samples Wilcoxon Signed Rank Test**	**Cohen's *d* Effect Size** (d_z for Repeated Measures)
Hypothesis 3 (ΔHelmet 55/P vs ΔHelmet JHMCS)	**Mean of the Difference** (55/P-JHMCS)	**SD of the Difference** (55/P-JHMCS)	***t***	**df**	**Sig**	d_z
Were any of the previous movements difficult or uncomfortable?	0.000	0.320	0.000	39	1.000	0
Do you feel fatigued?	Exact – no change					
Head	-0.025	0.357	-0.443	39	0.655	-0.040
UpperNeck	-0.025	0.423	-0.374	39	0.705	-0.059
LowerNeck	-0.125	0.516	-1.533	39	0.132	-0.242
Shoulders	-0.025	0.276	-0.572	39	0.564	-0.091
UpperBack	0.025	0.158	1.000	39	0.317	0.158
LowerBack	0.025	0.158	1.000	39	0.317	0.158

Table C-11: Results Table for Continuous Data in Hypothesis 4

		Paired *t*-test (Used if data normally distributed.)					**Related Samples Wilcoxon Signed Rank Test** (Used if not normally distributed.)	**Cohen's *d* Effect Size** (d_z for Repeated Measures)
	Hypothesis 4 (ΔFatigue 55/P vs ΔFatigue JHMCS)	**Mean of the Difference** (55/P-JHMCS)	**SD of the Difference** (55/P-JHMCS)	***t***	**df**	**Sig** (2-tailed)	**Sig**	d_z
Range of Motion (deg)	Flexion	-0.350	8.078	-0.274	39	-	0.983	-0.043
	Extension	-2.875	8.370	-2.172	39	0.036	-	-0.343
	Right Rotation	-0.667	7.552	-0.530	35	-	0.573	-0.088
	Left Rotation	-0.150	7.995	-0.119	39	0.906	-	-0.019
	Right Lateral Flexion	-1.000	6.695	-0.945	39	0.351	-	-0.149
	Left Lateral Flexion	-0.925	6.685	-0.838	39	-	0.581	-0.132
Neck Strength (lbf)	Flexion	0.235	4.739	0.314	39	0.755	-	0.049
	Extension	-0.658	5.056	-0.823	39	-	0.221	-0.130
	Right Rotation	1.107	3.877	1.807	39	-	0.032	0.286
	Left Rotation	0.670	3.726	1.137	39	0.262	-	0.180
	Right Lateral Flexion	0.650	2.920	1.408	39	0.167	-	0.222
	Left Lateral Flexion	-0.058	4.183	-0.087	39	0.931	-	-0.014

Table C-12: Results Table for Ordinal Data in Hypothesis 4

	Paired *t*-test (All data not normally distributed. Used for descriptive numbers.)				**Related Samples Wilcoxon Signed Rank Test**	**Cohen's *d* Effect Size** (d_z for Repeated Measures)
Hypothesis 4 (ΔFatigue 55/P vs ΔFatigue JHMCS)	**Mean of the Difference** (55/P-JHMCS)	**SD of the Difference** (55/P-JHMCS)	***t***	**df**	**Sig**	d_z
Were any of the previous movements difficult or uncomfortable?	-0.025	0.276	-0.572	39	0.564	-0.091
Do you feel fatigued?	-0.050	0.389	-0.813	39	0.414	-0.129
Is the helmet uncomfortable?	-0.154	0.540	-1.78	38	0.083	-0.285
Head	-0.500	1.340	-2.360	39	0.020	-0.343
UpperNeck	-0.175	0.931	-1.189	39	0.202	-0.188
LowerNeck	-0.100	0.744	-0.850	39	0.394	-0.134
Shoulders	-0.050	0.714	-1.443	39	0.566	-0.070
UpperBack	-0.175	0.931	-1.189	39	0.239	-0.188
LowerBack	-0.100	0.632	-1.000	39	0.366	-0.158