Exercise Effects on Neck Function Among F-15E Aircrew

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BACKGROUND: Neck pain (NP) is common among high performance aircrew, yet evidence remains insufficient to guide examination, treatment, and prevention. The purpose of this randomized pilot study was to collect baseline data for neck function for F-15E aircrew and determine efficacy and feasibility of two separate exercise protocols in measuring short-term outcomes of subjective and objective neck function in order to inform future study design.

METHODS: Randomized to either progressive (PRO) or general (GEN) exercise groups were 41 F-15E aircrew. Data collection occurred at baseline, 3 wk, and 3 mo.

RESULTS: At baseline, 39% of the subjects reported current NP, 79.5% reported a history of NP attributed to flying, 12.8% reported being removed from flying duties due to NP, and 10% reported receiving medical care for NP. PRO and GEN group randomization showed similar baseline assessment data. Blinding was successful and exercise logs showed 31.6% compliance with prescribed exercise regimens. There were small but statistically significant increases in neck range of motion in both groups over the course of the study. Aircrew with current NP had significantly higher F-15E flight hours.

DISCUSSION: This study supports the high prevalence of NP in aircrew, yet low frequency of seeking care for NP. Future studies to assess NP prevention and treatment in aircrew require an integrated approach that includes operational exercise policy and long-term data collection in flying units with dedicated resources for assessment and analysis.

KEYWORDS: neck pain, cervical spine, pilot, high performance aircraft, exercise.

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During basic flight maneuvers in high performance aircraft, the cervical spine is placed under significant G loads compounded by head gear, night vision devices, and long sortie duration.[5,25,32] Due to these stressors, neck pain related to flying is reported to be as high as 89.1% in F-15 pilots.[19] This is substantially greater than the reported 50% prevalence of neck pain in the general population in any given year.[15] The mechanisms underlying persistent neck pain and functional recovery are largely unknown in the general population[10] and similarly remain unknown among high-performance aircraft pilots. Recent evidence shows no significant difference between fighter pilots and pilots of other airframes for prevalence of neck pain, or between fighter pilot and nonflyers for signs of cervical degenerative changes.[29] Currently, insufficient evidence exists to guide cervical examination, testing, injury prevention, and treatment for high-performance aircraft aircrew with neck pain, as many may face potential grounding, or removal from flight status, due to this condition. This creates a significant barrier from understanding the mechanisms of neck pain in these high-performance aircrew.

Muscle contractile forces comprise 80% of neck stability.[24] Muscles that have typically been assessed were within easy reach of surface electromyography (EMG), and commonly included the upper trapezius and sternocleidomastoid

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(SCM).[5,25] However, these muscles do not function to stabilize the neck; rather, they function as prime movers. Jull and Falla[17] reported increased SCM activity in individuals with neck pain, and Pousette et al.[25] noted that night vision devices were associated with increased SCM strain in EMG assessments. Therefore, muscle activity of neck prime movers may be inversely correlated to core neck stability. Assessment of other muscle groups used for neck stability may provide a more direct measure of the aviator's ability to protect against forces encountered in high-performance flight.

Muscles closely attached to the spine, such as the deep cervical flexors (longus colli and longus capitis),[9] as well as the deep cervical extensors (cervical multifidus and semispinalis cervicis),[4] function in a stabilization role. Lange et al.[20] noted reduced deep cervical flexor endurance in F-16 pilots who reported neck pain. These findings are consistent with reports in the literature of impaired deep cervical flexor endurance in patients with chronic neck pain, whiplash-associated disorders, and cervicogenic headache.[16,23] However, deep cervical extensor musculature function has not been thoroughly evaluated among high-performance jet aircrew.

Since aviation aircrews are traditionally reluctant to seek medical treatment for various reasons such as perceived risk of grounding actions, flying schedule requirements, lack of commitment to time consuming exercise regimens, and deployments, it is important to inform this high-risk population by creating a low-threat assessment and exercise routine to provide evidence-based instruction to improve neck function and prevent injury. Furthermore, exercise prescriptions must be targeted and specific to mitigate neck pain incidence and intensity in this population.

Thus, initial research must be undertaken to establish baseline function and improve neck function outcomes in the high-performance aircrew population by studying whether implementing basic exercise education programs are feasible, and whether such exercise education programs yield short-term improvements in neck function. It is anticipated that if exercise instructions are effectively delivered to aircrew and yield short-term functional improvements in neck function, these advances may open doors to improve pilot-provider relationships and inform future studies involving aircrew populations.

Therefore, the purpose of this randomized pilot study was to collect baseline data for neck function for F-15E Strike Eagle aircrew and determine efficacy and feasibility of two separate exercise protocols in measuring short-term outcomes of subjective and objective neck function to inform future study design. The aim of the study was to determine whether there are short-term differences in neck function outcomes among a group receiving targeted, progressive neck strengthening exercise instruction compared to a group receiving nonspecific exercise, stretching, and general range of motion (ROM) instruction after 12 wk of a neck strength and conditioning program. We hypothesized that a specific exercise program would result in significantly greater gains in neck functional outcome measures.

METHODS

The study design was a parallel group, single blinded, randomized controlled trial. The trial was conducted at RAF Lakenheath, United Kingdom, from February to June 2019. The study protocol was approved in advance by the Air Force Research Laboratory, Wright-Patterson AFB, OH, USA. All subjects volunteered and gave written informed consent prior to study enrollment.

Subjects

A convenience sample of 41 (38 male and 3 female) U.S. Air Force active-duty F-15E aircrew participated in this study. Subjects (age range: 20–54 yr, mean 31.1 ± 5.2 yr) were recruited from the F-15E aircrew population at RAF Lakenheath between February and March 2019. Eligible subjects were required to be active-duty aircrew with no flying limitations or duty restrictions. Individuals were excluded if they had a history of cervical or thoracic spine surgical procedures, epidural nerve injections, or significant head and neck injuries (e.g., significant motor vehicle injury, contact sport injury, or falls) that required medical care. Potential subjects with signs and symptoms of radiculopathy, cervical or vertebral artery insufficiency, or cervical ligament instability were also excluded. Due to enrolling all available aircrew and not just aircrew with neck pain, diagnostic imaging assessment of potential baseline cervical spine pathology was not indicated.

Subjects were recruited through informational squadron briefings, word-of-mouth peer recruitment, and squadron-wide email invitations. All F-15E aircrew were encouraged to participate regardless of whether they currently experienced neck pain or dysfunction. Relevant information and invitation to participate in this study was made readily available and potential subjects were informed that the involvement or noninvolvement in the study would not influence the aviator's career or professional standing.

Subjects were randomized and assigned to receive either progressive resistance exercise (PRO) or general exercise (GEN) group exercise instruction (**Fig. 1**). Randomization occurred using a computer-generated list of randomized numbers prior to the start of data collection by an individual not involved in recruitment or treatment of subjects. The computer-generated random group assignments were printed on sequentially numbered paper slips and placed in sealed, opaque envelopes. A flight surgeon collected outcome data and remained blind to baseline demographics and group assignment through the course of the study, including subject's initial assessment, enrollment, and visit to the physical therapist. A physical therapist, blinded to the examination findings, sequentially opened the next available envelope and proceeded with the postrandomized assignment procedures and exercise instructions.

The exercise regimens posed minimal risk of harm and were expected to benefit the subjects by improving neck function and reducing recurrent neck pain. All subjects were instructed not to disclose information about their assigned exercises to maximize subject effort and compliance across both groups.

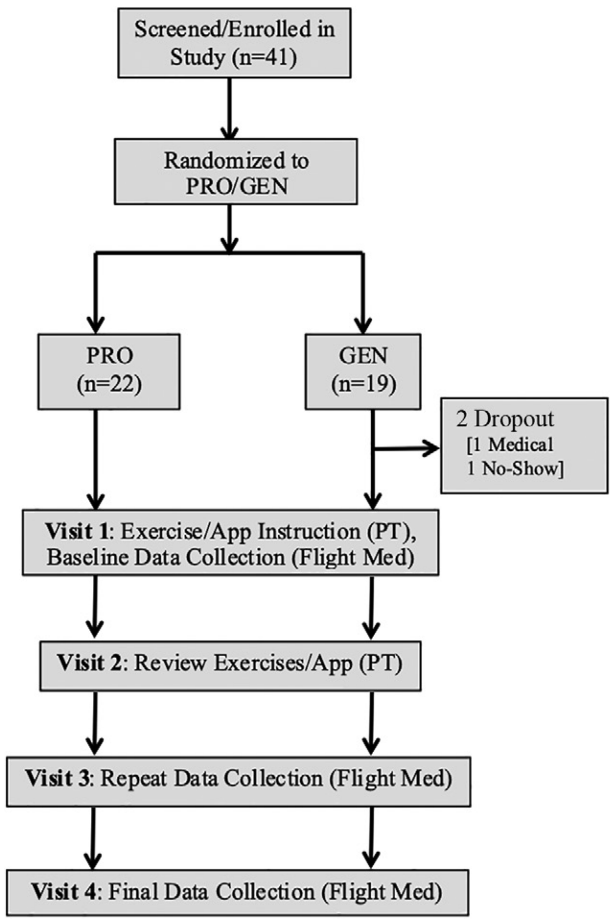

Fig. 1. Subject flow.

Subjects were instructed to maintain their typical daily activities and exercise routines while adding the specific neck exercise regimen. If a subject experienced pain with any of the prescribed exercises, they were encouraged to discontinue that exercise for the day and reattempt approximately 24–48 h later. If pain persisted, they were advised to discuss with the physical therapist who enrolled them into the study.

Procedures

Subjects assigned to the PRO group were instructed to perform 5 exercises (**Fig. 2**) on the same day, 3 d/wk with 3 sets of 12–15 repetitions performed to moderate fatigue while maintaining good form throughout the exercise session. In this manner, each subject progressed based on individual capacity, rather than a strictly scripted exercise protocol. Initial instruction included neck retractions (NR) and scapular retraction sets. Scapular retractions progressed to rows (3 sets of 12–15 repetitions to fatigue) when the subject was able to demonstrate consistent scapular retractions with proper form. Daily exercise sessions were expected to last 15–20 min.

Deep neck flexor strengthening. Deep neck flexor (DNF) strengthening was performed with a progressively challenging series of NRs. Initially, the subject was instructed to lay supine and perform the neck retraction-head lift maneuver with upper extremity assistance. As the subject demonstrated the ability to maintain this position for 20 s with good form, they were advanced to a supine DNF retraction without upper extremity assistance. Once the subject was able to maintain DNF position for 40 s, they were instructed to perform the exercise by progressively adding 1–4 lb of ankle weights positioned on the forehead. The added weights were designed to approximate the increased stabilization requirements, simulating operational gear consisting of a flight helmet, night vision device, and target cueing apparatus.

Posterior neck musculature strengthening. Posterior neck musculature strengthening was performed with a series of NR in the prone position. Once the subject was determined capable of performing NR successfully in a prone position, the subject was instructed to perform the exercise prone on his or her elbows. Then the subject was progressively advanced to the prone NR position supported by the elbows with resistance, then to the prone NR position on elbows and NR with rotational resistance applied via a resistance band centered immediately below the base of the occiput. Maintaining good form and performing exercises in slow and controlled movement patterns were emphasized. The subject was encouraged to advance to the next progression only when the instructing therapist deemed that the aviator was capable of performing the current exercise pain-free and without compensated movements.

Core strengthening. Core strengthening progressed based on the subject's ability to demonstrate core strength and muscular endurance with proper form. Initially, the subject was instructed to perform the abdominal drawing-in maneuver correctly. Once successful, the subject was instructed to perform the prone plank. Once the subject demonstrated proficiency of the prone plank, the member progressed to the prone plank with NR and shoulder protraction to engage the serratus anterior.

The target goal was 70 s duration plank hold while maintaining the chin retraction hold throughout the plank exercise.[27] Once proficiency was demonstrated for this exercise, the subject was advanced to perform the maneuver with a resistance band located immediately below the occiput to facilitate deep cervical extensor activation.[28] Subjects performed 3–5 repetitions of the prone plank position exercise at the level that challenged them to reach moderate fatigue by the end of each repetition.

Mid-thoracic strengthening. Midthoracic strengthening was performed initially from a seated position. The instructing therapist advised the subject to maintain good spinal alignment and a solid base of support in a seated position prior to performing seated rows with scapular setting and NR with the number and duration of hold advanced as the subject demonstrated proper exercise performance. With demonstrated proficiency, the subject was advanced to performing rows in the

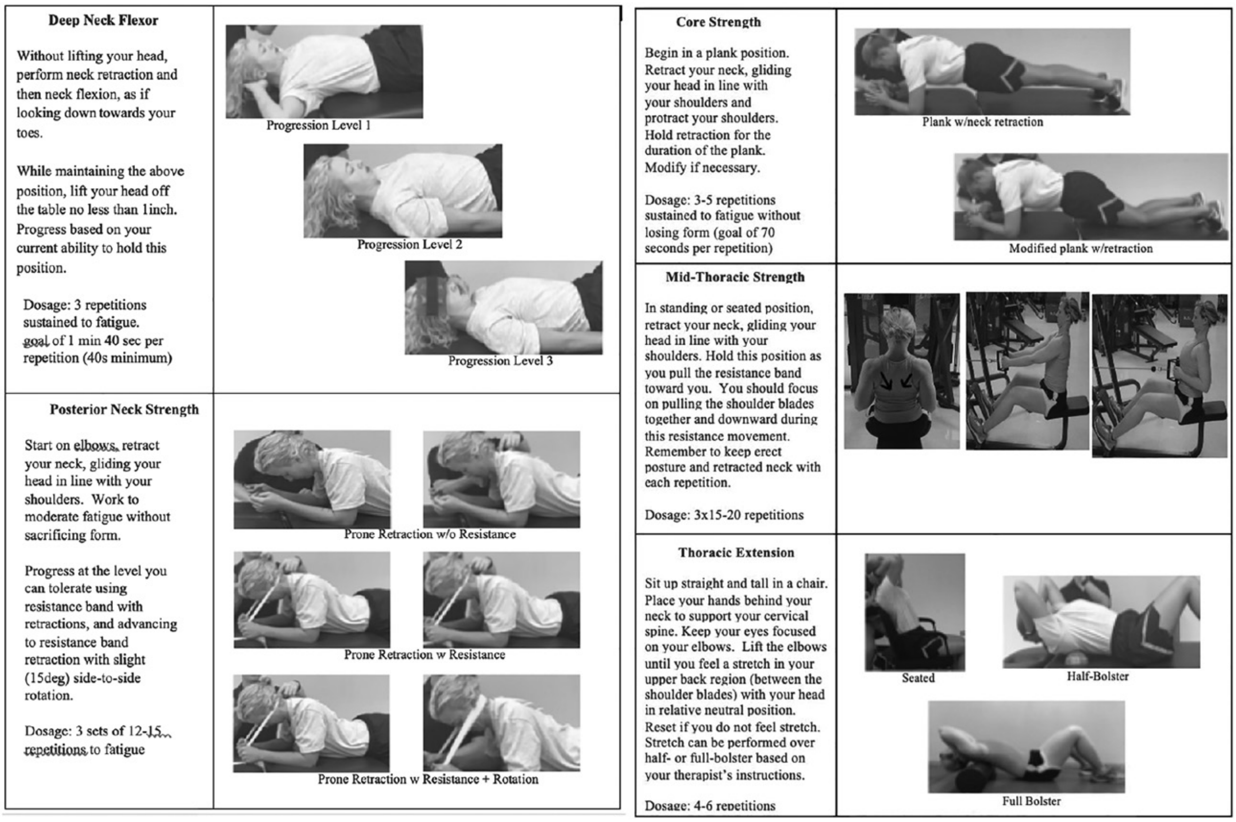

Fig. 2. PRO group exercises.

standing position; again, advancing scapular sets and NR as proficiency improved.

Thoracic extension mobility. Thoracic extension mobility repetitions were performed at subject preference either over a chair from a seated position (4–6 repetitions, held for 10–15 s), or over a foam roller from the supine position (4–6 repetitions, held for 20–30 s). The subject was advised that improving thoracic spine mobility may complement neck mobility by augmenting the overall rotational range of motion.

Subjects assigned to the GEN group were provided with exercises consisting of primarily cervical range of motion and general warm-up exercises. These exercises were expected to improve neck mobility, mitigate neck pain, and provide little benefit toward neck strengthening or endurance. Subjects were instructed to perform all prescribed exercises at the same day, 3 d/wk. Daily exercise session duration was expected to be 15–20 min, and emphasized slow, controlled movements.

All subjects in the GEN treatment group received the exercises specific to the GEN group (**Fig. 3**). The following items were instructed at initial assessment: trunk twists, large shoulder circles, neck rotations, and neck isometrics. Neck isometric performance was reviewed and initiated for individuals who did not have pain with this exercise. General warm-up exercises, emphasizing large general movements, were advised by the physical therapist. Additionally, the physical therapy team provided upper trapezius, levator scapula, and lumbar stretch instructions and subjects were encouraged to perform these stretches as desired (4–5 repetitions held for 20–30 s) throughout the day. Furthermore, subjects in the GEN group were specifically encouraged to stretch after being seated for greater than 30 min consecutive duration and immediately preceding and following aviation duties.

Prior to study initiation, written and video instructions of all exercises were created and entered into the TrainHeroic^{TM} mobile app (Peaksware Inc., Denver, CO, USA). The physical therapist provided initial exercise instruction specific to the group to which the subject was assigned, then provided each subject access and instruction for viewing exercise progressions and entering exercise compliance data into the TrainHeroic^{TM} mobile app. Subjects were progressively challenged and exercises advanced when able to demonstrate proper technique for the maximum number of repetitions and sets. Factors considered in advancement of exercise difficulty included ability to perform the exercise with proper form (i.e., no substitution in muscle recruitment or compensated movement patterns), perceived level of exertion, and minimal or no discomfort. Subjects were instructed to log in to the app each time they performed their prescribed exercises and document their exercise performance.

After the enrolling physical therapist had screened the subject, the subject was randomly allocated to a study arm, and

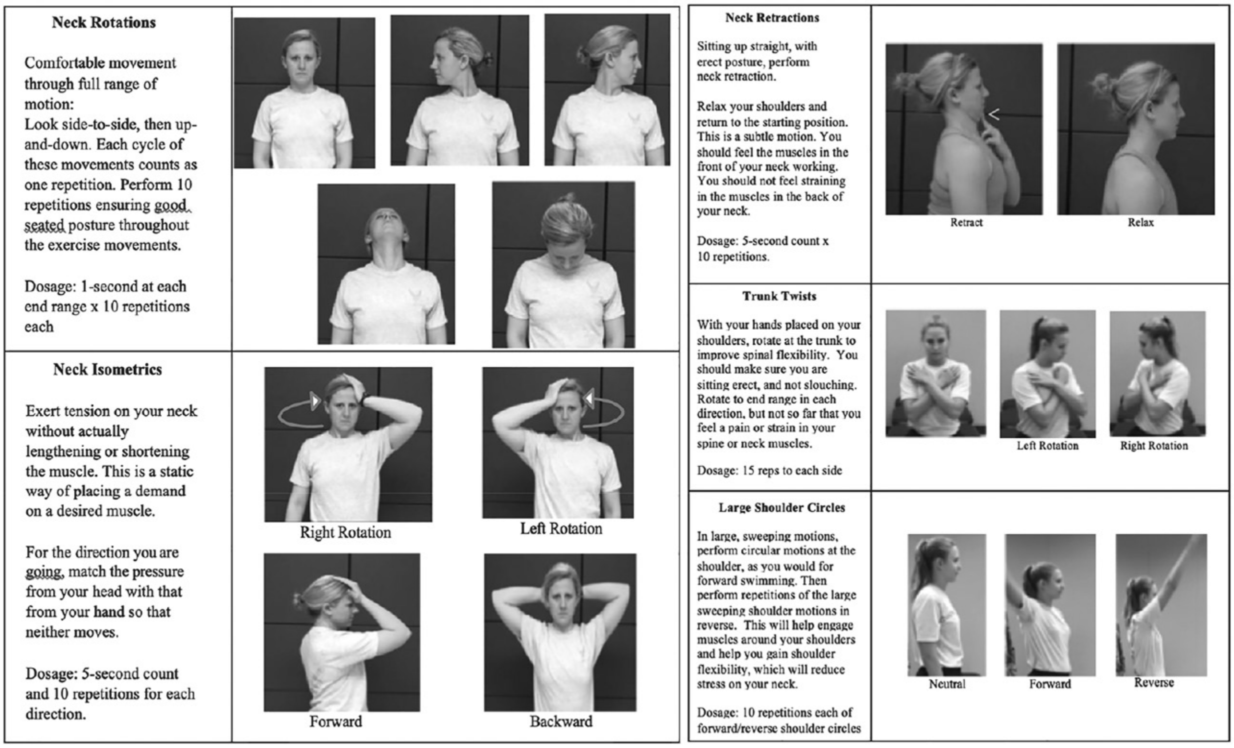

Fig. 3. GEN group exercises.

then baseline neck function was collected by the blinded flight surgeon during visit #1. Each subject was required to return to the physical therapist for follow-up for visit #2 at approximately 7 d after enrollment to review exercises and discuss any impediments to exercise completion. At this time, the TrainHeroic™ mobile app data log was reviewed. During visit #3, approximately 3 wk after enrollment, neck function data was again collected by the flight surgeon. At visit #4, approximately 12 wk postenrollment, final recorded data from the TrainHeroic™ app were collected and recorded.

Descriptive statics of demographic information, including age, sex, height, weight, BMI, self-reported activity level, exercise history, flight hours, and history of neck pain, were collected. Additional clinical information related to subjective and objective neck function were collected as described below.

Numeric Pain Rating Scale. An 11-point Numeric Pain Rating Scale was used to measure pain intensity with the scale anchored on the left with the phrase "No Pain" and on the right with the phrase "Worst Imaginable Pain." Numeric pain scales have been shown to have moderate reliability for patients with neck pain.[33] This was collected on subjects with a complaint of neck pain at time of enrollment.

Neck Disability Index. The Neck Disability Index (NDI) is a 10-item scale that measures the activities of daily living in persons with neck pain and is scored on a 0–50 scale.[31] Although the NDI has high test-retest reliability,[33] there are no validated self-assessment measures of neck pain specific to high-performance aircraft aircrew. The NDI was selected as the best available assessment to study baseline and over time characteristics of neck discomfort in high performance aircrew. This was collected on subjects with a current complaint of neck pain.

Cervical range of motion. Standard cervical goniometric range of motion measurements were taken for cervical flexion, extension, sidebending, and rotation.

Neck girth. Circumferential neck measurements were collected with a flexible metal tape measure. Measurements were taken on bare skin, just below the larynx and perpendicular to the long axis of the neck. Interrater reliability of girth measurement testing is high at 0.84.[8] While neck girth is speculated to provide some protection from physiological stresses relevant to high-performance flying, this has not been established in the literature.

Deep neck flexor activation. Assessment of DNF muscle endurance was measured with the neck retraction-head lift maneuver method.[13] The test was performed with the subject in crook lying on a plinth. The subject's head was positioned in slight upper neck flexion by the examiner, who placed their hand on the table just below the subject's occiput. The subject was asked to gently flex his or her upper neck and lift his or her head off the examiner's hand while retaining the upper neck flexion. The test was terminated when the subject was unable to maintain the position of head off the examiner's hand.

The subject completed the test twice with a 3-min rest between tests. This test yields high reliability and validity correlated to hold durations among individuals experiencing neck pain.[13]

Joint position error. Proprioceptive measurements were assessed with a forehead mounted laser pointer as described in the joint position error (JPE) test.[30] This test is a valid and reliable measure of cervicocephalic proprioception and neck reposition sense and is most commonly tested for left and right cervical rotation, but has been measured in flexion/extension and sidebending positions with good to very good intra- and interrater reliability.[2] We collected JPE data for cervical rotation and cervical flexion/extension (transverse and sagittal) planes.

Subject comments regarding exercise program and adherence. All subjects were asked to provide general comments regarding their assigned exercise program and adherence.

Data and Statistical Analysis

As a feasibility study, presence of neck pain was not required to enter the study. Our literature review found no outcome measures applicable to this study design. Therefore, a power analysis to determine sample size was not performed.

Main analyses were performed in accordance with the intention-to-treat principle for missing data for those who completed at least one follow-up visit in the study. Baseline variables were captured to characterize the sample. To assess for baseline differences in age, height, weight, BMI, total flight hours, and F-15E flight hours, *t*-tests were utilized. Chi-squared and Fisher's exact test were used to identify potential baseline differences in categorical variables to assess the success of blinding, and to assess between-group differences in JPE. Two (group) by three (time) repeated measures ANOVA tests were performed to compare differences between the PRO and GEN groups for ROM measures, DNF, and neck girth. If Mauchly's test of sphericity was significant, then Huynh-Feldt corrections were used for data analysis. Exercise compliance was measured and compared between PRO and GEN exercise groups, as well as subgroup compliance for those with or without pain. Additional baseline comparisons assessed differences in subjects with the dichotomy based on self-report of neck pain at enrollment in the study, those with and without neck pain, before group allocation. A value of $P < 0.05$ was used as an indicator of statistical significance. All statistical analyses were performed using SPSS 24.0 (IBM Corp., Armonk, NY, USA). Finally, general subject feedback regarding barriers to exercise program compliance was collected at the final visit.

RESULTS

There were 41 subjects (38 men and 3 women) who consented and enrolled in the study. Of these, 22 subjects were randomized to the PRO group and 19 were randomized to the GEN group (Fig. 1). Two subjects from the GEN group dropped out at the beginning of the study and were thus excluded from analysis. There were no statistical differences between groups at baseline (**Table I**). Of the subjects, 16 (41%) self-disclosed current presence of neck pain during enrollment, 10.3% reported prior neck injury, 12.8% reported history of being removed from flight status due to neck pain, and 79.5% of subjects reported neck pain attributable to flying at some point during their military career. Data for 24 (61.5%) subjects were carried forward due to at least 1 missed follow-up session.

Outcomes from the 2 × 3 repeated measures ANOVA tests are presented in **Table II**, with group means/standard deviations for these variables presented in **Table III**. There was a significant effect over time for both cervical flexion range of motion and total range of motion, with both groups showing statistically significant improvement in these motions over the course of the study, without any interaction effects at any point in the study. There was a statistically significant interaction effect for cervical left sidebending, with the GEN group surpassing the PRO group at the final evaluation point. There was a significant effect for time for the deep neck flexor endurance test, with both groups showing shorter duration of hold times over the course of the study. There was a significant effect over time for neck girth, but no group interaction effects. There were no statistically significant differences between groups via Chi-squared test at any point in the study for JPE, with *P*-values ranging from 0.06 to 0.90. Blinding was successful ($P < 0.01$), with 71.4% of the GEN group and 94.4% of the PRO group reporting that they were in the active intervention group. Exercise compliance was similar between groups ($P = 0.504$) with 25.0% of the GEN group and 36.4% of the PRO group documenting at least 50% compliance in the TrainHeroic™ mobile app.

Paired *t*-tests comparing baseline difference of subjects with current neck pain vs. those without neck pain revealed a significant difference in F-15E flight hours. Specifically, those with

Table I. F-15E Subjects' Baseline Characteristics.

	GEN (*N* = 17)	**PRO GROUP (*N* = 22)**
Age (yr)	30.5 ± 5.2	31.6 ± 5.3
Sex [male, *N* (%)]	15 (89)	21 (95)
Height (inches)	71.0 + 2.5	71.2 ± 3.0
Weight (lb)	174.0 ± 14.6	179.5 ± 21.1
BMI (kg · m^{-2})	24.2 ± 1.4	25.1 ± 2.1
Neck girth (cm)	38.2 ± 0.5	38.7 ± 0.5
Total flight hours	1103 ± 925	1268 ± 1021
F-15 flight hours	707 ± 747	785 ± 755
Current pain [*N* (%)]	8 (47)	8 (36)
Neck pain d/t flying [*N* (%)]	7 (42)	7 (36)
Prior neck pn d/t flying [*N* (%)]	16 (94)	15 (68)
Seeking healthcare [*N* (%)]	6 (35)	8 (38)
Prior neck injury [*N* (%)]	0 (0)	4 (18)
Prior grounding action [*N* (%)]	2 (12)	3 (14)
Self-reported activity (avg/active/very active)	6/7/4	2/7/13
Aerobic activity frequency (1×/wk, 1–3×/wk, >3×/wk)	3/13/1	1/14/7

Abbreviations: BMI, body mass index; d/t, due to; pn, pain.
Values are mean ± SD unless otherwise indicated.

Table II. Repeated Measures ANOVA Output.

MEASURE	GROUP	TIME	TIME × GROUP
Cervical Flexion	$F(1, 37) = 0.19, P = 0.67$	$F(1.48, 54.68) = 3.81, P = 0.04$	$F(1.48, 54.68) = 1.45, P = 0.24$
Cervical Extension	$F(1, 37) = 0.01, P = 0.94$	$F(1.6, 59.21) = 1.61, P = 0.21$	$F(1.6, 59.21) = 0.36, P = 0.65$
Cervical Right Rotation	$F(1, 37) = 0.02, P = 0.89$	$F(2, 74) = 2.98, P = 0.06$	$F(2, 74) = 1.74, P = 0.18$
Cervical Left Rotation	$F(1, 37) = 0.01, P = 0.92$	$F(2, 74) = 2.16, P = 0.12$	$F(2,74) = 0.54, P = 0.58$
Cervical Right Sidebend	$F(1, 37) = 0.70, P = 0.41$	$F(2, 74) = 0.37, P = 0.69$	$F(2, 74) = 1.81, P = 0.17$
Cervical Left Sidebend	$F(1, 37) = 0.16, P = 0.69$	$F(2, 74) = 1.91, P = 0.16$	$F(2, 74) = 3.89, P = 0.03$
Total Cervical Motion	$F(1, 37) = 0.13, P = 0.73$	$F(1.82, 67.23) = 9.38, P < 0.01$	$F(1.82, 67.23) = 0.62, P = 0.53$
DNF	$F(1, 37) = 2.54, P = 0.12$	$F(1.64, 60.64) = 8.31, P < 0.01$	$F(1.64, 60.64) = 0.08, P = 0.89$
Neck Girth	$F(1, 37) = 0.25, P = 0.62$	$F(1.84, 68.16) = 4.45, P = 0.02$	$F(1.84, 68.16) = 0.51, P = 0.59$

DNF = deep neck flexion.

current neck pain reported significantly higher flight hours [$t(21.75) = -2.31$, $P = 0.031$; **Table IV**]. Baseline deep neck flexor endurance was lower in the subgroup currently experiencing neck pain compared to those without neck pain, but the differences were not statistically significant [$t(37) = 1.05$, $P = 0.303$]. Although nonsignificant, it was noted that exercise compliance for the group with current neck pain was 43.8% vs. 22.7% for those without neck pain ($P = 0.17$).

Adverse events, defined as moderate to severe symptoms that were serious, distressing, persistent, and/or necessitated the subject to withdraw from study participation, were not reported in this study. Four subjects (3 PRO and 1 GEN) experienced treatment side effects which were reported as mild transient pain, stiffness, or muscular fatigue that was precipitated by cervical isometric resistance exercises. No headaches, persistent pain, change in flying status, or medical follow-up for

Table III. Comparison of Group Means.

OUTCOME/VISIT	GEN GROUP	PRO GROUP
Cervical Flexion Range of Motion*		
Baseline	54.3 ± 11.4	57.4 ± 8.1
Visit 2	57.1 ± 10.3	57.8 ± 7.2
Final Visit	59.0 ± 9.3	58.5 ± 7.0
Cervical Extension Range of Motion		
Baseline	58.7 ± 7.8	58.6 ± 7.4
Visit 2	60.7 ± 8.7	60.2 ± 8.1
Final Visit	59.5 ± 7.6	60.6 ± 7.7
Right Cervical Rotation Range of Motion		
Baseline	78.4 ± 9.8	79.3 ± 7.7
Visit 2	81.5 ± 8.9	79.9 ± 7.4
Final Visit	80.1 ± 9.9	81.8 ± 6.0
Left Cervical Rotation Range of Motion		
Baseline	83.0 ± 10.7	83.4 ± 8.4
Visit 2	83.5 ± 9.4	82.2 ± 7.4
Final Visit	81.4 ± 10.4	81.5 ± 5.3
Right Cervical Sidebend Range of Motion		
Baseline	46.2 ± 7.1	49.6 ± 8.5
Visit 2	47.3 ± 7.7	49.0 ± 9.1
Final Visit	47.7 ± 7.0	49.1 ± 9.3
Left Cervical Sidebend Range of Motion		
Baseline	44.1 ± 8.3	47.1 ± 9.5
Visit 2	45.6 ± 7.9	47.2 ± 11.1
Final Visit	47.5 ± 7.2	46.5 ± 10.6
Total Cervical Range of Motion		
Baseline	358.8 ± 38.6	367.0 ± 26.6
Visit 2	375.7 ± 43.4	376.3 ± 33.6
Final Visit	375.2 ± 42.4	377.9 ± 30.7
Deep Neck Flexors**		
Baseline	41.8 ± 30.6	52.0 ± 27.0
Visit 2	35.7 ± 22.9	48.0 ± 26.7
Final Visit	27.4 ± 12.6	40.0 ± 27.8
Neck Girth***		
Baseline	38.2 ± 2.1	38.7 ± 2.3
Visit 2	38.3 ± 2.2	38.6 ± 2.2
Final Visit	37.9 ± 2.1	38.4 ± 2.2

Values are mean ± SD.
*Range of motion values are in degrees; **deep neck flexor hold times are in seconds; ***neck girth is measured in centimeters.

Table IV. Subgroup Analysis F-15E Baseline Characteristics Pain vs. No-Pain Cohort.

	CURRENT PAIN (*N* = 16)	NO CURRENT PAIN (*N* = 23)
Age (yr)	33.0 ± 6.1	29.8 ± 4.2
Sex [male, *N* (%)]	13 (81)	23 (100)
Height (inches)	71.2 ± 3.6	71.1 ± 2.2
Weight (lb)	180.1 ± 22.3	175.0 ± 15.6
BMI ($kg \cdot m^{-2}$)	25.4 ± 1.4	24.3 ± 1.4
Neck girth (cm)	38.7 ± 2.9	38.3 ± 1.6
Total flight hours*	1495.5 ± 1133.4	989.0 ± 801.6
F-15E flight hours*	1089.4 ± 898.6	515.8 ± 510.8
Neck Disability Index	6.3 ± 3.4	0
Neck pain	1.9 ± 0.8	0
Current pain due to flying [*N* (%)]	15 (94)	0
Prior neck pain due to flying [*N* (%)]*	13 (81)	18 (78)
Seeking healthcare [*N* (%)]*	2 (13)	2 (9)
Prior neck injury [*N* (%)]	2 (13)	2 (9)
Prior grounding action [*N* (%)]	2 (13)	3 (13)
Self-reported activity (avg/active/very active)	4/6/6	4/8/11
Aerobic activity frequency (1×/wk, 1-3×/wk, > 3×/wk)	1/12/3	3/15/5
Deep neck flexion endurance (s)	41.8 ± 26.9	51.6 ± 29.8
Flexion ROM (°)	53.1 ± 11.4	58.1 ± 7.9
Extension ROM (°)	59.0 ± 7.7	58.5 ± 7.5
R rotation ROM (°)	78.2 ± 10.3	79.4 ± 7.4
L rotation ROM (°)	81.8 ± 11.7	84.2 ± 7.4
R side bend ROM (°)	45.6 ± 8.1	49.8 ± 7.7
L side bend ROM (°)	43.4 ± 8.0	47.4 ± 9.4

Abbreviations: BMI, body mass index.
*$P < 0.05$.
Values are mean ± SD unless otherwise indicated.

side effects was reported. Four themes emerged from subject comments: exercises were time-consuming, exercises were repetitive, four subjects reported increased neck pain, and temporary technological setbacks with the use of the mobile app.

DISCUSSION

Despite reported reluctance by military aircrew population to divulge information regarding pain and injury that may impact their ability to remain on flight status,[3] this study achieved its purpose to assess effects of two exercise programs and collect baseline neck pain data from F-15E aircrew. Statistically significant range of motion improvements in this study were small, with single motion measured differences within the normally accepted 5° bounds of measurement error. However, total ROM (sum of left and right axial rotation, left and right lateral flexion, and neck flexion and extension) improvements were 10.9° for the PRO group and 16.4° for the GEN group from baseline. Although clinical significance of total ROM remains unknown, gains may have a positive impact on subject performance in an increased ease of their ability to move. For example, improved neck mobility may have been recognized by subjects to visualize from the forward and down position when acquiring information from the targeting pod located on the left side of the F-15E cockpit, then quickly looking back to "check six," and transitioning to clearing the forward airspace. De Loose et al.[11] reported that ROM may be more closely related to reduction in pain than either strength gains or joint position, allowing more comfort with cervical motions when under the stresses of flight. Increased ROM in a minimally impaired population, many of whom did not complain of neck pain or impairments to movement, may represent a new frontier for functional assessment and human performance enhancement using operational parameters.

Baseline scores for DNF endurance compared favorably with published literature[13] as expected in this relatively young and healthy sample population. However, DNF worsened slightly in both groups over the course of this study. This finding contradicts reports of DNF improvements in aircrew after exercise intervention.[5] We primarily suspect the declining DNF performance was due to examiner error, as the examiner in this study did not routinely collect this measure in the performance of his duties, and disclosed that, in retrospect, the criterion for measuring the duration may have inadvertently become progressively stricter in recording the data during follow-up visits. Other explanations for declining DNF performance in our sample may have occurred due to large known variances in test scores[13] or subjects, who may have been experiencing discomfort at the time of testing, and may have provided less effort since the presence or intensity of pain was not assessed by the blinded examiner during follow-up visits.

Historically, JPE was reported to be impaired among individuals with chronic idiopathic neck pain. Early evidence from randomized controlled trials suggested that proprioception-targeted treatment improves joint position sense, resulting in reduced neck pain.[18] However, recent evidence found no difference between individuals with chronic idiopathic neck pain and asymptomatic individuals on seven cervical sensorimotor control tests, including JPE.[34] The authors concluded that JPE testing is either not sensitive enough to discriminate between individuals with chronic idiopathic neck pain or that no difference in sensorimotor control as assessed by JPE exists in their studied population. Thus, the pre-existing assumption that JPE is worse among individuals with recurring atraumatic neck pain and whether such neck pain can be effectively mitigated by interventions targeted to improve joint position sense warrants further investigation for aviators in the high-performance high G-forces environment.

In this sample, 79.5% of subjects reported a prior history of neck pain attributed to flying, with 41.1% currently experiencing neck pain symptoms. Of those with current symptoms, 94% attributed their neck pain to flying duties. Despite a large percentage of aircrew reporting neck pain, this study found that only 36.4% had previously sought medical care for neck pain, 10.3% reported a significant previous neck injury, and 12.8% reported being removed from flight duties due to neck pain. When subject's baseline data were dichotomized to those with compared to those without current neck pain, aviators with current neck pain reported a 51.2% higher average number of total flight hours ($P = 0.027$), and more than double the number of F-15E Strike Eagle flight hours ($P = 0.006$) compared to those not currently experiencing neck pain.

The low level of neck pain and disability reported at baseline in those who reported neck pain during study enrollment suggest symptom etiology may be related to repetitive, episodic stresses rather than a single injury event.[6,32] Premature signs of aging (i.e., osteophytes, disc-related changes, etc.) in the cervical spine, as seen on imaging, are prominent among aircrew compared to the age-matched nonflying population and may partially explain the presence of neck pain in individuals with symptoms.[14] The parameters for assessing and randomizing participants with radiographs and other objective neuromuscular studies were considered, but not included in the study due to the variability of correlating imaging to functional neck deficits[12] and implications of adjudicating asymptomatic but abnormal findings, as it may place the aviator in a nonflying status and drive an aeromedical waiver for findings that may not correlate with subjective or functional deficits.[1]

Aircrew participation and training compliance was difficult as the unit maintained a high operational tempo throughout the duration of the study, resulting in data for 24 (61.5%) subjects being carried forward for at least 1 missed follow-up session. The carried forward data from our intention-to-treat protocol likely limited our ability to detect differences. Factors identified as contributing to missing data included: subject compliance, mission requirements, pain encountered with specific exercises, and the research team's inability to locate/contact subjects.

Training compliance rate in this study was suboptimal in part due to competing duty requirements in this cohort. Training adherence compliance was defined as a subject completing at least 50% of their prescribed exercises. In our study, 31.6% of subjects were compliant in completing and documenting their exercise performance through the TrainHeroic™ mobile app. Adherence to exercise recommendations in our study were similar to that of Murray et al.,[22] but low in comparison to other published reports.[6,21] Based on the available studies, it is evident that exercise adherence is higher among aircrew when exercises are supervised rather than self-administered. However, supervised exercise is not always feasible among pilots and aircrew due to dynamic work schedules and operational demand. Since each of the published studies suggest that exercise adherence is lower than the recommended 80–99%,[7] ongoing efforts to improve exercise adherence in this population are imperative. As noted, those with current neck pain showed a higher, although not significantly different, rate of exercise compliance. This may suggest that those with neck symptoms are more likely to invest in their prescribed exercises due to positive expectation of benefit.[3,26] Although we purposely kept the exercise program to a select number of exercises and duration to maximize compliance, dedicated research support resources may yield improved compliance and reporting to better elucidate the effects of exercise in our study subjects. Due to low exercise compliance, the authors do not recommend generalizing the outcome measure statistical results to the high-performance aircrew community.

Despite suboptimal exercise regimen compliance, our study indicates that implementing an exercise protocol guided by a training app for aircrew is feasible. Subjects enrolled in this study were able to effectively perform instructed exercises, including incremental progressions, and track completion of their exercise sessions with the use of the app. Since the app was accessible on the subjects' smartphones, it was readily accessible during or shortly after exercise sessions. Both groups reported that the training app was useful in instructing exercise technique. This is important because Ang et al. reported larger physical performance gains and exercise adherence among aircrew who felt engaged in an exercise program with a perceived preventative benefit.[6]

Four themes emerged when subjects were asked about exercise adherence in this study. First, some individuals suggested that exercise sessions were time-consuming, requiring up to 30–45 min per session. The exercise protocols for this study were initially designed to take 15–25 min per session with minimal equipment. Future studies with in-session coaching and intermittent check-ups for performance and progression may assist the individual in achieving a reasonable timeframe for exercise completion. Second, several individuals found the exercises repetitive. While some repetition to the exercises is required, intermittent coaching might have provided more specific assessment and progression to continually challenge the subjects over the duration of the study. Third, four subjects reported increased neck pain, particularly with isometric exercise repetitions. An embedded exercise specialist would likely have been able to identify mechanisms to account for the increased neck pain and provide education to mitigate this pain and allow for continued exercise progression. Finally, while most subjects reported effectiveness and demonstrated proficiency in the use of the TrainHeroic™ mobile app, a few individuals found temporary technological setbacks with their training app, such as an exercise session being deleted, difficulty viewing a specific exercise update, or temporary loss of access. The technological challenges were quickly resolved, but the setbacks likely impacted compliance and/or accuracy in accounting for all completed training sessions.

Limitations

Our study size was smaller than some previous aircrew studies,[5,11] which may have limited our ability to find group differences. However, based on the design of our study, there were no prior outcomes on which to base a power analysis. Additionally, we limited this study to one operational installation and one airframe type. Lastly, this study did not include a control group. Therefore, it is uncertain to what extent individual neck function and subjective pain might have improved or worsened over time without intervention. Future studies should be multicenter trials with various high-performance airframes that have similar combat mission profile.

The findings of this pilot study are well-positioned to inform future research regarding neck pain in aircrew. In an exploratory manner, we attempted to dichotomize results to those reporting current neck pain (eight subjects per group). Although not an aim of the study and not reported as official results, this is a sample preview that may guide future power analysis and study design. We found no baseline differences between the PRO and GEN subgroups for those with pain, and no statistical differences for any measure other than DNF. DNF was only significant for time, with hold duration decreasing in both groups. There were no group or time × group interactions.

Larger, multicenter studies with dedicated research support teams and long-term follow-up are necessary to enroll and perform data analysis on sufficient numbers of participants to determine the effectiveness of treatments in prevention and management of neck pain in aircrew. Advertising enrollment to all available aircrew and then using methods to subgroup subjects disclosing current neck pain may allow further assessment of the impact of treatments to movement and muscle function while assessing impact of prevention impacts in those without neck pain. This enrollment method is essential to avoid the stigma pilots may perceive if the focus is solely on those with neck pain. Finally, NDI and pain scores were low at baseline for those subjects who reported current neck symptoms at time of enrollment. This indicates the need to develop alternative methods to assess the impact of neck pain on flight duties.

Mitigating chronic, recurrent neck pain in military aircrew could improve aviator mission availability, retention rates, and readiness. Although statistical differences between exercise groups may have uncertain clinical significance, this study assessed the feasibility in recruiting aircrew with neck pain, and the ability to use a training app to deliver exercise prescription. Future studies to assess neck pain prevention and treatment in high-performance aircrew would benefit from an integrated approach with unified operational training policies and dedicated research support.

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