Performance Optimization and Injury Mitigation for Air Force Student Fighter Pilots

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ABSTRACT

Introduction:

Military fighter aircrew report high rates of cervical pain and injury. There is currently no consensus regarding the best training methods for this population. Eglin Air Force Base (AFB) and Luke AFB have multidisciplinary teams specializing in aircrew training, performance, and injury mitigation. All student pilots (SPs) completing Basic Course training at these locations engage in an 8-week Spine Training Program (STP). The STP originated at Luke AFB in 2020 and was expanded to Eglin AFB in 2022. The primary aim of this study was to assess whether the STP led to significant changes in the performance measure studied, Cervical Endurance Hold (CEH). Further, this study aimed to determine if the CEH training effect was independent of location of STP administration. We hypothesized that SPs would exhibit statistically significant CEH training adaptations irrespective of base location.

Materials and Methods:

Air Force F-16 and F-35 SPs from Luke AFB and Eglin AFB were actively enrolled in the Basic Course and participated in the standardized STP from 2020 to 2023. The CEH test was administered prior to (intake) and following (exit) the 8-week STP. SPSS for Windows version 29 software (IBM, Armonk, NY) was used to retrospectively analyze the data from this study. Participants were excluded if they were unable to perform the CEH test at intake or exit. The study was approved by the Air Force Research Laboratory Institutional Review Board and was performed in accordance with the ethical standards of the Declaration of Helsinki.

Results:

One hundred and ninety-eight SPs (Luke AFB, males $n = 170$, females $n = 12$; Eglin AFB, males $n = 16$) completed the STP program. There was no significant difference between intake and exit concerning age, height, weight, % body fat, and fat-free mass at Luke AFB or Eglin AFB ($P < 0.05$). Statistically significant improvements in CEH were observed within all groups from intake to exit ($P < 0.001$). When considering all participants collectively, there was a notable 33.6% increase in CEH from intake to exit ($P < 0.001$) with an overall effect size of $d = 1.14$. When analyzing specific subgroups, females from Luke AFB experienced a significant 20.4% increase in CEH ($P < 0.001$, $d = 1.14$), males from Luke AFB exhibited a significant 34.5% increase ($P < 0.001$, $d = 1.09$), and males from Eglin AFB demonstrated a significant increase of 55.7% in CEH ($P < 0.001$, $d = 1.97$).

Conclusions:

This retrospective analysis showed significant improvements in the CEH across all groups following the completion of the STP. Furthermore, CEH results from both bases exhibited a large effect size indicating a meaningful change was

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Presented as a poster at the 2023 Military Health System Research Symposium, Kissimmee, FL; MHSRS-23-10057.

The authors of this manuscript are responsible for the study design, analysis of results, discussions, views, and recommendations provided. The opinions and assertions expressed herein are those of the authors and do not reflect the official policy or position of the 33d Fighter Wing, 56th Fighter Wing, 1st Fighter Wing, 4th Fighter Wing, 49th Wing, 19th Air Force, Air Combat Command, U.S. Air Force, or the Department of Defense.

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doi:https://doi.org/10.1093/milmed/usae153

found between intake and exit regardless of training location. These preliminary study results should be interpreted with caution as a control group was unable to be established. In the future, a randomized control trial should be performed to test the STP used in this study against other STP programs. This may better inform experts on the best spine training methods for fighter aircrew.

INTRODUCTION

High Performance Aircraft (HPA) training missions pose a significant risk of cervical injury to fighter pilots with 85% of United States Air Force fighter aircrew reporting acute neck pain at some point in their career.[1] A survey conducted by Headquarters Air Combat Command Human Weapon System Branch in 2022 sampled all fighter aircrew in the United States Air Force. A 33% response rate garnered a total of 2,029 responses. Of respondents, 98% of fighter aircrew reported flying-related neck pain during their career and 75% reported that their pain directly affected performance during High-G (High Positive Gravitational) operations. Traumatic minor cervical strains and repetitive forces have been shown to alter proprioceptive feedback and muscle activation, therefore altering the ability to execute coordinated, purposeful movements.[2,3] These factors may pose a threat to fighter aircrew health, occupational effectiveness, and flight safety.

To mitigate the potential impacts of High-G operations, Eglin Air Force Base (AFB) and Luke AFB have multidisciplinary teams specializing in fighter aircrew performance. Both teams coordinate efforts to support standardization of fighter aircrew student production. All student pilots (SP) completing the F-16 and F-35 Basic Course at these locations engage in an 8-week interdisciplinary Aircrew Conditioning Program (ACP) to enhance physical performance, mental performance, and aircrew resilience.

One component of the ACP is the standardized Spine Training Program (STP). Prior research has shown that the deep neck flexor muscles serve an important role in segmental stability during gross cervical spine movements. During flight, pilots must perform extensive cervical motion while stabilizing the weight of the head and helmet against High-G forces.[3,4] Training that improves the pilot's ability to engage the deep neck flexors may prove beneficial in the mitigation of cervical injury. Additionally, targeted exercises initiated at the start of pilots' flying career may better prepare fighter aircrew for High-G stressors.[5] STPs integrated into course syllabi at pilot training bases may provide an ideal construct for delivering this specialized training.

There is currently no consensus regarding the best training methods, nor the degree of physical preparedness required for fighter aircrew. A recent study performed by researchers from the University of Canberra and Royal Australian Airforce highlighted challenges of assessing highly variable cervical spine loading in fighter aircrew, concluding ultimately that "individual monitoring of the intensity, frequency, duration and type of head motions that aircrew perform is needed to understand injury, conditioning parameters, and to inform risk management."[6] To date, most cervical strengthening programs involve bulky research grade equipment, resistance bands, and/or resistance tubing to be utilized in one isolated plane of motion at a time. To address this gap in the aeromedical literature and fighter aircrew training, Aerospace Physical Therapists and Strength and Conditioning Specialists at Luke AFB developed the STP. This program incorporates the weight of the head and an external load throughout the entire cervical range of motion while utilizing portable/low-cost equipment. To the best of our knowledge, this represents the initial analysis of a program of this nature within fighter aircrew. Moreover, there was no standardized training or testing being conducted specific to the cervical spine in the United States Air Force prior to the creation of the STP and administration of the Cervical Endurance Hold (CEH) test.

The CEH test was selected as the neck health metric for the Aircrew Conditioning Program Assessment (ACPA) because of the role the deep neck flexors play to stabilize the cervical spine during flight, in addition to the test being low cost, time effective, and requiring minimal equipment.[3,4,7–9] Additionally, the CEH has been shown to be valid and reliable in both asymptomatic and symptomatic populations, with asymptomatic individuals displaying longer endurance hold times.[8] The CEH test was deployed at the same time the STP went live for all student training being conducted at Luke AFB in 2020. This Aircrew Performance construct is still in the expansion phase, with only Luke and Eglin currently completing CEH testing and the STP. The end state of aircrew production, maintenance, and optimization will include ACPA testing to be conducted at various timepoints throughout a fighter pilot's career. When this future state is achieved, the CEH has the potential to identify when a pilot experiences neck pain and/or injury.[8] This may improve the readiness of aircrew by enabling training and treatment interventions to occur before an extended period of Duties Not Including Flying (DNIF) becomes necessary.

The STP is a component of the ongoing ACP that has been executed at Luke AFB since 2020. The primary purpose of this study was to retrospectively examine whether the integration of the STP resulted in statistically significant improvements in the CEH. In 2022, the STP and CEH test administration expanded to Eglin AFB and by mid-2024 they are both expected to extend to Tyndall AFB, Langley AFB, Holloman AFB, and Seymour Johnson AFB. Given the novelty of this training, a secondary aim of this study was to examine if the results of the STP were reproducible at other AFBs by exploring whether the location of STP implementation had an impact on the CEH training effect. We hypothesized that SPs

would exhibit statistically significant CEH training adaptations, irrespective of their base location (Luke AFB and Eglin AFB).

METHODS

Subjects

A retrospective analysis study was conducted to determine if the STP is effective in enhancing cervical endurance in SPs from 2020 to 2023. Air Force pilots from Luke AFB and Eglin AFB were actively enrolled in the F-16 or F-35 Basic Course and participated in the STP. Participants' data were excluded from the analysis if they were unable to perform the CEH test at intake or exit. This study was approved by the Air Force Research Laboratory Institutional Review Board and was performed in accordance with the ethical standards of the Declaration of Helsinki.

Procedures

The participating SPs across both locations completed the CEH test before (intake) and after (exit) an 8-week STP. The CEH test and the STP were led by an active duty Aerospace Physical Therapist, an active duty Aerospace Physical Therapy Technician, and/or a civilian Nation Strength and Conditioning Association certified strength and conditioning specialist (CSCS).

CEH

The CEH test was administered during intake and exit testing of the F-16 and F-35 Basic Course ACPA. The standardized methodology and criteria for test termination outlined in reliability of measurement and normative value studies was utilized.[7–9] Since the test was being conducted in the tactical environment with significant time constraints, the CEH was only performed once and had a strict 3-minute time limit. Equipment needed for this test was a flat bench, felt tip marker, and a stopwatch. Following a demonstration of the CEH protocol, proper body positioning, and test termination criteria, the SPs were positioned lying down in the supine position with knees bent, feet flat on the bench, and hands resting on the abdomen. To mark focal points on the skin, the test administrator requested that SPs first perform the chin tuck, and then lift their head 2.5 cm off the bench while maintaining the chin tuck position. While in this position, a line was drawn on the SPs neck, perpendicular to two skin folds. The SPs were then instructed to relax so that their head was resting on the test administrator's fingers. To begin the test, the SPs re-engaged a chin tuck and raised their head approximately 2.5 cm so that the back of their head maintained light contact with the test administrator's fingertips. The SPs ability to maintain this position was measured in time (seconds), beginning when the SP attained the "starting position." Each participant received a maximum of one corrective warning to maintain proper positioning. The test was terminated if the second occurrence of the following criteria was met: (1) the edges of the drawn lines across the SPs skin folds no longer touched each other because of loss of the chin tuck position; (2) the SPs' head was raised too high, and thus the SP was no longer maintaining contact with the administrators' fingers; and (3) The SPs' head rested on the test administrator's fingers for more than 1 second. The test was immediately terminated if the following criteria was met: (1) the SP was no longer capable of continuing and (2) the SP was able to hold the testing position for more than 3 minutes.

STP

The STP occurred 3 times per week for 8 weeks while the SPs were participating in the ACP. This 8-week training program was performed during the academic phase of training, when the SPs were not flying. During the first 2 weeks of the ACP, the STP was performed in a blocked training format with 15 minutes dedicated to the instruction and execution of the STP exercises. From weeks 3 through 8, the STP was integrated into the resistance training program during the rest periods of main compound lifts. Total time dedicated to the STP during these weeks was 10 minutes per session. The STP exercise selection and volume were standardized across both training locations. Exercise intensity was not standardized at either location with progressive overload being encouraged when appropriate for the SP (∼week 6 of training). This pragmatic approach allowed the subject matter experts overseeing the training session to adjust workload intensity based on individual pilot needs. The STP training objectives were to: (1) increase spinal stability and dynamic control, (2) increase kinesthetic awareness, and (3) increase neural control and pilot tolerance in provocative end of range positions (for both contractile & non-contractile tissue). The STP utilized a progressive approach that moved from prioritization of mobility and motor control to volume and load attenuation. Following the initial mobility-based phase of the STP, external load was added if the student demonstrated the ability to perform the exercises through the full range of motion while maintaining adequate neuromuscular control. External loading was achieved by utilizing the CerviFit at Eglin AFB and ringside neck weight at Luke AFB.

Statistical Analysis

SPSS for Windows version 29 software (IBM, Armonk, NY) was used to analyze the data from this study. Descriptive data of age, height, weight, % body fat (%BF), fat-free mass (FFM), and CEH scores are presented as mean ± SD. All participants with missing data were removed from the analysis. Data were inspected for outliers and data entry errors. A Shapiro-Wilk test was conducted to test for normality. A two-tailed paired samples *t*-test was conducted to examine the mean difference between CEH, anthropometric measurements, and body composition values at the beginning of STP training (intake) and the end of the training program (exit). Additionally, an independent *t*-test was used to determine

if statistical differences existed between the two bases. The targeted sample size used a priori power *G power analysis (effect size = 0.3, α =0.05, $P \geq 0.05$) of 147 participants to achieve a power of 0.95.

RESULTS

One hundred and ninety-eight SPs (Luke AFB, males $n = 170$, females $n = 12$; Eglin AFB, $n = 16$) completed the STP program. There was no significant difference between intake and exit concerning weight, %BF, and FFM (all $P < 0.05$) at Luke AFB or Eglin AFB. When separating participants into groups based on the two military bases and between biological sex, no significant difference was seen in body weight, %BF, and FFM (all $P > 0.05$) (Table I).

Table II shows that while looking at all SPs together, there was a statistically significant 33.6% increase in CEH between intake and exit ($P < 0.001$) with an overall effect size of $d = 1.14$. When looking at SPs in subgroups (female Luke AFB, male Luke AFB, and male Eglin AFB), all subgroups had a statistically significant increase in CEH ($P < 0.001$). Females from Luke AFB saw a significant 20.4% increase in CEH from intake and exit ($P < 0.001$) with an overall effect size of $d = 1.14$. The males from Luke AFB saw a significant 34.5% increase in CEH from intake and exit ($P < 0.001$) with an overall effect size of $d = 1.09$. The males from Eglin AFB also saw a significant increase of 55.7% ($P < 0.001$) with an overall effect size of $d = 1.97$. Statistical significance for the mean increase in CEH was present as both locations. Furthermore, Supplementary Fig. S1 displays the CEH results from both Luke AFB and Eglin AFB showing a large effect size, indicating that these preliminary findings may show meaningful change was found between intake and exit performance regardless of training location.

DISCUSSION

The primary aim of this study was to examine if a novel standardized STP led to statistically significant changes in cervical endurance. The study findings indicate significant improvements in CEH across all participant groups following the completion of the STP. The secondary aim was to assess scalability of the STP as a component of aircrew training curriculum at other training locations. Our analysis indicates that CEH results from both bases showed a large effect size indicating a consistent and meaningful change was found between intake and exit performance regardless of training location (Luke AFB and Eglin AFB). These study results should be interpreted with caution, as a control group was unable to be established and no cervical testing data were available for comparison prior to this study.

To the best of our knowledge, this is the first study that investigates a STP of this nature for fighter aircrew. These data suggest that the current standardized exercise selection and volume, coupled with individualized progressive overload, may be suitable for achieving significant improvements

TABLE I. Student Pilot Descriptive Data

	Females Luke AFB ($n = 12$)			Males Luke AFB ($n = 170$)			Males Eglin AFB ($n = 16$)		
	Intake	Exit	*P*	Intake	Exit	*P*	Intake	Exit	*P*
Age (years)	26.3 ± 2.3	26.4 ± 2.4	0.166	26.2 ± 2.6	26.2 ± 2.6	1.0	26.8 ± 1.9	26.8 ± 1.9	1.0
Height (cm)	167.4 ± 6.7	167.4 ± 6.7	1.0	181.5 ± 6	181.5 ± 6	1.0	180.7 ± 5.4	180.7 ± 5.4	1.0
Weight (kg)	67.7 ± 8.6	68 ± 8.7	0.296	84.0 ± 10.8	84.2 ± 10.6	0.181	83.9 ± 8.1	84.5 ± 8.1	0.117
%BF	24.2 ± 5.2	23.7 ± 4.6	0.349	16.5 ± 5.6	16.4 ± 5.2	0.570	17.6 ± 6.1	17.9 ± 6.4	0.389
FFM (kg)	51.1 ± 5.9	51.7 ± 6.1	0.145	69.8 ± 7	70.1 ± 6.8	0.077	69 ± 8.1	69.3 ± 8	0.268

Abbreviations: AFB, Air Force Base; FFM, fat-free mass; %BF, % body fat.
Data are mean ± SD, rounded to the nearest 0.1.

TABLE II. Student Pilot Cervical Endurance Hold

	Females Luke AFB ($n = 12$)			Males Luke AFB ($n = 170$)			Males Eglin AFB ($n = 16$)		
	Intake	Exit	*P*	Intake	Exit	*P*	Intake	Exit	*P*
CEH	93 ± 25.7	112.9 ± 30.2	<0.001**	88.3 ± 37.3	118.8 ± 44	<0.001**	81.8 ± 36	127.4 ± 27.9	<0.001**

** $P < 0.001$.
Abbreviations: AFB, Air Force Base; CEH, cervical endurance hold.
Data are mean ± SD, rounded to the nearest 0.1

in cervical endurance within the target population. Furthermore, the data indicate that there is potential for the STP to be expanded to additional training locations for fighter aircrew.

As mentioned previously, poor cervical endurance has been correlated with increased rates of neck pain and disability. Utilization of the CEH test prior to High Performance Aircraft training may serve as a personal baseline for fighter aircrew spine health management. Moreover, if regular testing of the CEH is employed throughout a pilot's career, this measure may serve as a valuable indicator for when Aerospace Physical Therapy and/or spine training interventions are warranted, potentially resulting in earlier medical intervention and/or implementation of injury mitigation measures. Unfortunately, operational impact surrounding cervical injury and pain rates prior to and following the implementation of the STP are not able to be assessed at this time, as information from military health records is not available for review by the authors.

In this retrospective analysis, it is important to recognize and address certain inherent limitations. This analysis relied on existing, de-identified data that were collected in an operational training environment, and as such, increased risk for missing or incomplete information exists. We attempted to control for this limitation, by removing participants with missing data from our analysis and inspecting the data for outliers and data entry errors. Additionally, recall bias can be a potential issue as participants may not accurately remember past events or circumstances. Furthermore, confounding variables such as training to the test that were not originally considered, measured, or controlled for may affect the generalizability of the results of this study. Despite these limitations, we believe this retrospective analysis was valuable for analyzing our hypotheses and exploring associations within the existing data sets at Luke AFB and Eglin AFB.

In the future, a randomized control trial should be performed to test the STP against other existing or newly generated programs. This may better inform human performance experts on the best spine training methods for fighter aircrew. Additionally, intake and exit testing was only completed prior to and following the academic phase of the F-16 and F-35 Basic Course. Thus, the STP and CEH testing have not historically continued into the flying phase of training. Since continued training is necessary to retain training adaptations, investigation of STP inclusion during the flying phase of training is warranted. Lastly, incorporation of additional specific performance assessment measures that quantify force, acceleration through cervical range of motion, kinesthetic awareness, and medical data may be helpful to inform and refine future iterations of STPs for this population.

CONCLUSIONS

This retrospective analysis shows preliminary findings consistent with significant increases in cervical endurance hold

times in Air Force fighter aircrew when the standardized STP is performed. These improvements were seen across multiple time points (2020–2022), two different training locations (Luke AFB and Eglin AFB), and regardless of biological sex (female and male). There were no differences between age, height, weight, %BF, or FFM when comparing SPs at either AFB. Further research is needed to validate the results of this study.

ACKNOWLEDGMENTS

The authors would like to acknowledge the contributions of all Aerospace Medicine and Fighter Aircrew colleagues that influenced the Spine Training Program and expansion of United States Air Force aircrew human performance curriculum.

INSTITUTIONAL REVIEW BOARD (HUMAN SUBJECTS)

This study was approved by the Air Force Research Laboratory Institutional Review Board.

INSTITUTIONAL ANIMAL CARE AND USE COMMITTEE

Not applicable.

INDIVIDUAL AUTHOR CONTRIBUTION STATEMENT

Authors at 33d Fighter Wing and 56th Fighter Wing designed this research, collected the data, analyzed the data, and drafted the original manuscript. Authors at 19th Air Force Aircrew Performance Branch and Headquarters Air Combat Command Human Weapon System Branch were ultimately responsible for this research and therefore supervised, advised, and approved this study. All authors read and approved the final manuscript.

INSTITUTIONAL CLEARANCE

Institutional clearance was obtained by 19th Air Force Aircrew Performance Branch and Headquarters Air Combat Command Human Weapon System Branch.

SUPPLEMENTARY MATERIAL

Supplementary material is available at *Military Medicine* online.

SUPPLEMENT SPONSORSHIP

This article appears as part of the supplement "Proceedings of the 2023 Military Health System Research Symposium," sponsored by Assistant Secretary of Defense for Health Affairs.

CONFLICT OF INTEREST STATEMENT

The authors of this manuscript have no competing interests to disclose.

DATA AVAILABILITY

The data that supports the findings of this study are available on request from the corresponding author.

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