

Human and Behavioral Factors Contributing to Spine-Based Neurological Cockpit Injuries in Pilots of High-Performance Aircraft: Recommendations for Management and Prevention

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In high-performance aircraft, the need for total environmental awareness coupled with high-g loading (often with abrupt onset) creates a predilection for cervical spine injury while the pilot is performing routine movements within the cockpit. In this study, the prevalence and severity of cervical spine injury are assessed via a modified cross-sectional survey of pilots of multiple aircraft types (T-38 and F-14, F-16, and F/A-18 fighters). Ninety-five surveys were administered, with 58 full responses. Fifty percent of all pilots reported in-flight or immediate post-flight spine-based pain, and 90% of fighter pilots reported at least one event, most commonly (>90%) occurring during high-g (>5 g) turns of the aircraft with the head deviated from the anatomical neutral position. Pre-flight stretching was not associated with a statistically significant reduction in neck pain episodes in this evaluation, whereas a regular weight training program in the F/A-18 group approached a significant reduction (mean = 2.492; $p < 0.064$). Different cockpit ergonomics may vary the predisposition to cervical injury from airframe to airframe. Several strategies for prevention are possible from both an aircraft design and a preventive medicine standpoint. Countermeasure strategies against spine injury in pilots of high-performance aircraft require additional research, so that future aircraft will not be limited by the human in control.

Introduction

The health and welfare of aviators in the U.S. Department of Defense present a challenge for military occupational health care workers because of the unique and physically taxing environment in which the aviators work and live. Aviation and aerospace represent a large component of the U.S. military budget, and pilots controlling and protecting extremely costly federal assets must be in top physical condition to perform their mission safely. The responsibility of maintaining the pilot's health and performance conditions lies with the squadron flight surgeon. The health of the pilots extends beyond their military careers, because these individuals become the core of aviation operations for the entire U.S. aerotransportation industry.

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Technological advances have produced improvements in U.S. fighter airframe composite materials, flight controls, propulsion systems, and avionics, allowing the warplane to fly farther, faster, higher, and longer. These aircraft characteristics are pushing beyond the limits of current human capability and endurance. As a result, the fighter pilot, more than ever, is at risk for injury and adverse health outcomes as a result of the occupational hazards of the profession.

The current operational fighter/attack aircraft in the U.S. inventory include the F-14, F-15, F-16, F/A-18, and AV8B (Harrier). These aircraft possess 7.5–10 × gravity (g) limitations for structural integrity. Future high performance aircraft, like the F-22, a new air-superiority fighter, or possibly the Joint Strike Fighter, may possess airframes capable of withstanding greater than 10 × g. The USAF Combat Edge Program with g-suit vest, helmet, and mask modifications ± ATAGS (advanced technology anti-g suit) are designed to push the pilot's cardiovascular g-tolerance to 12.^{1,2} Soon to follow, if funding allows, will be the Joint Strike Fighter. By the year 2020, the United States may also have a small fleet of military space planes, with even greater load-bearing limits for reentry and cross-range maneuvering. If piloted, these vehicles are bound to possess increased electronic reconnaissance and control capability, which usually translates into more intense task saturation, on top of the added physical stresses of operating at extremely high speed and g-loads. Additionally, reduced military budgets have meant a higher operations tempo with diminished manpower (getting more out of fewer personnel). This adds fatigue to increased tasking and higher physical stresses, creating conditions ripe for pilot error and injury.

During the past 15 years, there have been increasing numbers of reports of neck injury as a result of the g-forces experienced in modern fighter aircraft. These reports began appearing in the literature in the late 1970s,^{3,4} with a specific case report of a backseat injury in the F-16B appearing in 1988.⁵ The injury issue has since been evaluated with more scrutiny by both U.S. Air Force and Navy flight surgeons, first epidemiologically in 1988,^{6,7} and then mechanistically by a North Atlantic Treaty Organization ally, the Finnish Air Force, in the mid 1990s.⁸⁻¹³ The results of these evaluations pointed to a number of potential contributory factors, including (1) the load onto the cervical spine from the weight of the head and helmet with or without night vision goggles (head, 3.5–5.0 kg; helmet, visor, and communication combo [without night vision goggles], 1.1–2 kg, depending on the type of helmet [AF:HGU-55P {1.1 kg} vs. HGU-26P {1.6 kg}]),⁹ e.g., the relative load of head plus helmet on the cervical spine at 9 g = 48 to 65 kg (105–143 pounds); (2) other

forces on the spinal column, including type of force—compressive (Gz), torsional, and translational—and direction of force—Gx, Gy, etc.; and (3) type and orientation of ejection seat (upright vs. reclined).

The flight equipment that has been developed to support the cardiovascular system, to prevent g-induced loss of consciousness includes g-suit and combat edge. Also, there is equipment in the cockpit to support the pulmonary/oxygen transport system: either onboard oxygen-generating system or liquid oxygen to increase fraction of inspired oxygen near 100%, if required, and positive pressure supply to a tight-fitting aviator's mask. However, to date, there has been no equipment developed to support the musculoskeletal system.

One flight surgeon, in a recent report, has begun an inquiry into possible prevention strategies.¹⁴ Prevention strategies are felt to be critical to slow the alarming number of pilot spine injuries observed during the past few years. During joint service medical responsibility situations, such as dissimilar aircraft combat training, flight surgeons have observed an increased number of cervical neck injuries in F-16 and F/A-18 pilots. Conditions that we felt were important to evaluate, in terms of both understanding etiologic factors and developing a concrete prevention strategy, were as follows: ergonomics of airframe, flight characteristics of airframe, rapid-onset turning capability, location of the flight control stick, and rails/handles in the cockpit to brace/support the pilot's upper body during high-g turning. We also felt it was important to evaluate a number of behavioral issues that may contribute to these injuries, including (1) pre-flight behavior issues: exercise (resistive and aerobic), conditioning, stretching, warm-up, general health factors, sleep patterns, smoking, ethanol ingestion; (2) in-flight behavior issues: head and body position during bracing for turns, onset rate of pull for high-g turns; and (3) post-flight behavior issues: stretching, exercise, use of analgesics, use of ancillary therapeutic aids (heating pads, etc.). Therefore, a more in-depth evaluation of pilots was conducted to examine the issues felt to be important in the production of spinal injury.

Two illustrative case histories were selected for presentation as examples of characteristic symptom complexes and clinical evaluation and treatment methods.

Case Descriptions

Case 1

During a routine currency flight, a 32-year-old F-16C pilot, with >1,500 hours logged in high-performance jet aircraft (HPJA), experienced severe pain in his right base of neck associated with paresthesias in the right upper extremity. His last sortie had been basic fighter maneuvers (BFM), 11 days previously. The pilot was number one of a two-ship flying BFM. The symptoms began during the third engagement while he was in a right-hand defensive 6,000-foot perch. He went into initial break turn registering 8.3 g on the g-meter, followed by a second turn of 7 g with an unload for energy. The pilot repositioned himself for a better check six o'clock visual, and when he reapplied the turn, neck pain commenced with approximately 4 g on the jet. The pilot unloaded g-force from the turn and aborted the fight. He informed number two that the mission was terminated and

that they were to return to base. He called via radio to the supervisor of flying and said that he needed to perform a straight-in approach and landing but did not declare an in-flight emergency. He requested that the emergency medical services meet him at the jet because the pain had not subsided. After a challenging landing, as a result of the pain and degraded motor function of the right upper extremity, emergency medical services placed the pilot in a neck brace and transported him to the hospital emergency center. After securing the pilot to a backboard and placing him in the ambulance, there was an uneventful transport to the hospital. The patient's vital signs were stable during transport. Aside from the pain in his neck, the remaining physical examination was unremarkable. No acute neurological deficits were noted upon examination by the emergency room physician. Immediately, cervical and lumbar spine radiographs were obtained while the patient was on the backboard. These included cross-table lateral studies as well as anterior and posterior views and oblique and swimmer's views. The radiographs revealed bilateral spondylosis at the level of L4-5 in the lumbar spine, and the cervical spine was felt to be unremarkable.

Follow-Up Aeromedical Evaluation

History of Present Illness

The severe pain that occurred immediately after the injury lasted approximately 2 hours and gradually subsided. Within 8 hours of the incident, the pilot complained of less intense pain in the right base of the neck that was episodic in nature. However, he still had a shooting pain emanating from the base of the neck radiating to the right upper extremity with certain positions of the neck. The pain at the time of examination was associated with continued upper extremity paresthesias, mainly affecting the right index and little fingers. The symptoms were different from the pain that he had experienced at the time of the injury in the aircraft, in which the thumb and index finger were also affected.

His past history was significant for a previous episode (7 years earlier) of back and neck pain that occurred acutely after pulling g's in the F-16. His pain was characterized as dull in the right shoulder and neck. He was treated with cervical traction without any improvement, and subsequently he was treated conservatively with gentle manipulation, physical therapy, and anti-inflammatory agents. He reports occasional right lumbar back pain.

Physical Examination

Rotatory movement of the head was limited to 75 degrees to the right and 85 degrees to the left due to discomfort in the base of the neck and the upper right shoulder region. Flexion of the neck was limited to 60 degrees, at which point there were some paresthesias induced in the right thumb and index finger. The right shoulder at 90 degrees of elevation was able to be internally rotated 165 degrees forward and beyond 0 degrees backward without significant discomfort. However, abduction to 70 degrees produced pain in the base of the neck and shoulder.

Straight leg raising was negative bilaterally to 90 degrees of hip flexion bilaterally. There was no evidence of diminished pinprick sensation in the upper and lower extremities bilaterally. However, there was slight diminution of two-point discrimination in the ring and little fingers of the right hand. There were

no other abnormalities noted in the rest of the dermatomal distribution of the right upper extremity. The deep tendon reflex examination revealed normal left patellar and Achilles' tendon and normal right patellar tendon reflexes, with a decreased right Achilles' tendon reflex. The left upper extremity had normal biceps, triceps, and brachioradialis. The right upper extremity had diminished biceps and brachioradialis deep tendon reflexes but normal triceps reflexes.

The initial impression was injury to right cervical spine nerve roots secondary to g-loading with highly rotated head position; cervical disc herniation or nerve root entrapment was ruled out. The level of injury was not clear from the patient's symptomatology and neurological examination, because the C6 and C8 sensory dermatomes were affected but there was sparing of the C7 dermatome. The motor component of C6 appeared to be mainly affected, again sparing C5 and T1.

Therefore, magnetic resonance imaging with a 1.5-tesla magnet imaging unit revealed degenerative disk disease at C6–7, with mild reduction in disc height and spondylosis both anteriorly and posteriorly. There was a small left paracentric protrusion of the C6–7 disc that slightly indented the thecal sac and abutted the C7 nerve root; this protrusion appeared chronic in nature. There was mild osseous foraminal narrowing bilaterally at this level. There was also degenerative changes at C2–3 and C3–4.

A neurosurgeon consulted about the case felt that a nerve root injury had occurred when the g-forces compressed the C6–7 disc, further narrowing an already narrowed neural foramen. A robust conservative management strategy was recommended that included duties not to include flying for 3 months; a rigid cervical collar for 2 weeks, followed by a soft collar for 2 weeks; nonsteroidal anti-inflammatory medication; ibuprofen 800 mg tid for 4 weeks; and cyclobenzaprine 10 mg qid for 10 days. A cervical pillow was prescribed for nighttime use. The pain resolved completely in 2 weeks; however, physical therapy was not instituted until 1 month after the injury. At 1 month, there was normal sensory testing, Adson's testing was negative, muscle strength testing in the upper extremities was symmetrical, as were upper extremity deep tendon reflexes. There was spasm in the paraspinal musculature innervated by C5–7, as well as in the right levator scapulae and rhomboid. Trigger-point massage therapy was instituted, and after the spasms were relieved, the MacKenzie protocol and stretching exercises of the thoracic and cervical spine were used in the second month after injury. In the third month, cervical and upper body strengthening exercises, with special emphasis on the right rotator cuff, were taught to the pilot by a physical therapist and supervised for the first week. After completion of the strengthening program, the pilot was placed back in flying status, but for non-air combat maneuvering or BFM flights. After 2 weeks with no symptom recurrence, the pilot was placed back on full flight status and has flown all missions without symptom recurrence for more than 3 months.

Case 2

History of Present Illness

A 35-year-old reserve pilot with >1,200 hours in the F/A-18A had a history of episodic "stiff necks" for 15 years beginning early in his career in the F/A-18. The onset of symptoms com-

menced within 12 hours after flying combat training sorties; the symptoms were mainly soreness and stiffness in the posterior-lateral neck musculature, worsened with extreme rotary movements, especially to the right, but associated with soreness and stiffness in both sides of the neck and in both shoulders. These pain episodes were managed with the application of cold, then heat, plus anti-inflammatory agents and even chiropractic manipulation. Slowly, the symptoms would abate until the next episode.

A single event in May 1997, immediately after a rapid-onset, high-g turn while checking six to the right, with his right hand on the stick and no hands on the rail or cockpit handle, produced a pop sensation in his neck during the flight. He experienced only minimal pain during the flight, so the engagement was continued. After returning to the ground, he noted progressive sharp, severe pain in the right lateral neck associated with muscle spasms in the right shoulder blade and weakness and twitching in the right forearm.

Physical Examination

Evaluation conducted by the squadron flight surgeon and neurologist, who suspected cervical nerve root radiculopathy, found weakness in the flexor carpi radialis and diminished brachioradialis reflex. Magnetic resonance imaging revealed a C6–7 disc bulge but no frank herniation.

Orthopedic consultation recommended an anterior discectomy and removal of the pilot from the high-g environment. After much discussion, the pilot was given a medical downchit (removed from flying duties), and a trial of conservative therapy was instituted. After 2 months, the symptoms resolved. The pilot was given an upchit and has flown all scheduled sorties without symptoms for the past 8 months.

Methods

A modified cross-sectional survey design was used retrospectively to evaluate a cross-section of pilots of multiple aircraft types for the presence or absence of spinal injury or disease symptoms. The study made use of an anonymous, self-administered written questionnaire that was taken to individual squadrons across the United States and explained to the pilots or the squadron commander by the authors. Stamped self-addressed envelopes were given to the pilots to return the completed questionnaires. The questionnaire consisted of 20 questions that sought to evaluate the presence, nature, severity, and timing of symptoms, the head position at the time of onset, the factors in the cockpit contributing to the symptoms, and the behavioral characteristics of the pilot predisposing to symptom occurrence, and finally to acquire information for management and prevention strategy recommendations. A visual analog pain scale was used and explained to the pilots or commander before completion.

A broad cross-section of pilots were surveyed by squadron and individually, including pilots of the following aircraft: C-26, G-2, KC-135 (parabolic, zero-g route) T-38, and F-14, F-15, F-16, and F/A-18 fighters. A total of 95 surveys were administered, with 70 partial and 58 full responses. The working hypothesis postulated a larger prevalence of spine-related symptoms in fighter pilots than previously reported and the presence

of characteristics unique to the F-16 and F/A-18 aircraft and their pilots that make spinal injury more likely.

The survey results were analyzed by cross-tabulation matrix, using the χ^2 test to examine statistical relationships. Significance was set for $p < 0.01$.

Results

A summary of survey data from responses is presented in Table I. The data presented represent a frequency distribution of listed responses broken down by type of aircraft flown, with the exception of the pain scores, which represent mean values for each group.

Forty-nine percent of all pilots and 78% of HPJA pilots surveyed have experienced in-flight or immediate post-flight pain episodes, but 90% of fighter pilots have experienced at least one event. Pain episodes did not occur in low-g aircraft pilots (C-26, KC-135, shuttle training aircraft) and were uncommon (27%) in intermediate-g aircraft pilots (T-38). By branch of service, 92.6% of Air Force fighter pilots surveyed (F-15, F-16) versus 86% of Navy/Marine pilots (F/A-18) reported in-flight pain. F/A-18 pilots had a lower incidence of in-flight pain episodes compared with F-16 or F-15 pilots; this difference was not statistically significant ($p < 0.25$). The pain episodes in F/A-18 pilots were of greater severity than those in the other fighter pilots (7.0 vs. 6.3/5.8) and in T-38 pilots (4.7) who had pain, although the

pain severity difference was not statistically different. The number of pain episodes in fighter aircraft pilots (both F-16 and F/A-18) were significantly higher than in T38 pilots ($p < 0.001$).

Only 18 of the F/A-18 pilots provided information on the location of their pain; this information is shown in Table I. The number of in-flight pain episodes varied from 0 to 20 in the last year, the median being 2, with no trend by aircraft type. There was a trend of pain experienced by F/A-18 pilots being of shorter duration than that experienced by F-16 pilots, with the pain generally passing in hours to days rather than days to weeks. Also, several F/A-18 pilots reported that they often did not have in-flight pain but developed pain within hours after completing their sorties. The majority of pilots with pain had more than one affected site, with multiple bilateral sites being most common. In those pilots who lateralized their symptoms, the right side was affected more commonly than the left by a greater than 2:1 ratio. Interestingly, paresthesias more commonly lateralized to the right side by a 14:5 ratio across the board. However, if broken down by aircraft type, F-16 pilots lateralized to the right side, in that paresthesias occurred in a 9:2 right-to-left ratio, whereas F/A-18 pilots were evenly split, 3 right, 4 left. The thumb, index, and long fingers were affected more commonly than the ring and little fingers (6:7:6:4:2 ratio, respectively). Four pilots in multiple aircraft also reported lower back symptoms in addition to symptoms in the neck and shoulder.

Approximately 90% of pilots reported that the pain event

TABLE I
BREAKDOWN OF PAIN QUESTIONNAIRE RESPONSES BY AIRCRAFT TYPE

Question	Aircraft Type					Total
	F-16	F-15	F/A-18	T-38	Low-g ^a	
Pain in-flight or post-flight	23/24 (96%)	2/3 (67%)	19/22 (86%)	3/11	0/10	34/70 (49%)
Location						
RN	6	0	7/18	0	0	13/66
LN	1	1	5/18	0	0	7/66
R and LN	2	0	1/18	0	0	3/66
RN and RS	2	0	0	1	0	3/66
RN, LN, RA, and LA	1	0	0	0	0	1/66
Multiple bilateral sites	8	1	3/18	2	0	15/66
Multiple sites plus back	2	0	2/18	0	0	4/66
Pain severity (average)	5.8	6.3	7.1	4.7	0	6.1
Paresthesias	12/24 (50%)	2/3 (67%)	8/18 (44%)	0	0	22/66 (33%)
R	9	1	3	0	0	14
L	2	0	4	0	0	5
Unknown or bilateral	1	1	1	0	0	3
Pre-flight stretch	20/24 (83%)	2/3 (67%)	10/18 (56%)	1/11	2/10	34/66 (52%)
+stretch, +pain	17/20	1/2	7/10	0/1	0/2	26/35 (74%)
+stretch, no pain	3/20	1/2	3/10	1/1	2/2	9/35 (26%)
no stretch, no pain	1/4	0/1	2/8	8/10	8/8	19/31 (61%)
no stretch, +pain	3/4	1/1	6/8	2/10	0/8	12/31 (39%)
Regular exercises	12/24 (50%)	0/3 (0 %)	5/18 (28%)	3/11	1/10	21/66 (32%)
+exercise, no pain	5/12	0/0	4/5	2/3	3/3	14/23 (61%)
+exercise, +pain	7/12	0/0	1/5	1/3	0/3	9/23 (40%)
no exercise, no pain	4/12	1/3	5/13	6/8	7/7	22/43 (51%)
no exercise, +pain	8/12	2/3	8/13	2/8	0/7	20/43 (47%)

Abbreviations: R, right; L, left; N, neck; S, shoulder; A, arm. +stretch, pilot stretches pre-flight; no pain, pilot did not experience pain; no stretch, pilot does not stretch pre-flight; +pain, pilot experienced pain; +exercise, pilot exercises regularly pre-flight; no exercise, pilot does not exercise regularly pre-flight.

^aLow-g aircraft: C-25, KC-135, G-2 (shuttle training aircraft).

resulted during high-g (>5 g) turns of the aircraft. Eighty-five percent of those pilots described either head/body movement during the turn or having the head rotated while turning as the precipitating behavior, usually checking the six o'clock position (looking toward the rear of the aircraft) or overhead (Fig. 1). Having the head and upper body braced before the onset of the turn was commonly reported as a means to prevent the pain episodes (Fig. 2). One pilot unloads the jet before attempting head movements. Another pilot reported keeping his head forward during turns since experiencing severe pain with his head back, with no subsequent recurrences. Several pilots commented that the pain and injury is part of their job and that there is no way to avoid it.

Pain reporting for pilots who stretch or exercise before flight was subsequent to initiation of these activities, because many pilots had experienced in-flight pain before beginning a stretch or exercise regimen. Eighty-three percent of F-16 and 44% of F/A-18 pilots reported stretching their necks before flying. Unfortunately, 76% of pilots who stretch still have experienced subsequent pain episodes during or after flight. There was no statistical difference between pilots who stretch and those who do not stretch in the number of pain episodes in either aircraft (mean = 0.24; $p = 0.624$).

Fifty percent of F-16 and 28% of F/A-18 pilots now consistently participate in weight training exercises for the neck muscles. The number of pain episodes in pilots who exercise regularly in both the F-16 and F/A-18 have been reduced compared with those in pilots who do not exercise; however, the difference was not significant in F-16 pilots, but it approached significance in the F/A-18 group (mean = 2.492; $p < 0.064$). Of those pilots who now perform the strengthening exercises regularly, only 43% have experienced subsequent pain episodes.

Discussion

There are several problems in performing an epidemiologic survey of this type in this population. Extracting information, i.e., survey participation, can be quite challenging, because pilots in general are reluctant to provide accurate personal, medical-type information. They also rarely demonstrate the patience



Fig. 1. F-16C canopy open. Checking six and overhead to right. The pilot's neck is twisted and extended, placing it in a vulnerable position for g-loading-associated injury.

to voluntarily complete a detailed survey en toto. Only one F-14 pilot responded; therefore, those data were not included in the analysis. Also, there will be bias in completing a self-report survey, both observational and recall bias, which often leads to misclassification. There are obvious confounding variables that cannot be clearly sorted in a limited brief survey. With an unproven survey data form, both the reliability and the validity of the data can be questioned. Finally, a larger sample size for all aircraft types would allow a true cross-sectional survey and would reduce variability of the data within groups. Obviously, a prospective cohort study will be beneficial to accurately compare injury events by type of aircraft and to establish a valid mechanism of injury.

We feel that the cases reported here document a unique medical scenario that results from the highly unusual environmental stressors experienced by these pilots. In both cases presented, there was injury to the cervical nerve roots without clear-cut associated herniated nucleus pulposus (HNP) on magnetic resonance imaging. Twisting the neck to full rotation and loading up to 150 pounds of weight onto the cervical spine is unique to the fighter pilot community. Acute neck pain, often with referral into the shoulder or arm and often associated with right upper extremity paresthesias (radiculopathy), is the result of this occupational exposure. We believe that the nerve root is injured by the bony lamina under the compressive force but that the force is not great enough to produce frank disk herniation. This is why these injuries are acute or subacute and can resolve with more conservative therapies. The injury mechanism is different from that reported previously in no-ejection-related spinal injuries.^{7,13}

The incidence and prevalence of cervical pain with or without radiculopathy has been increasing with each report in the literature, and the occurrence of pain in this report is the highest yet. We feel that this is attributable to several factors:

(1) More pilots are experiencing pain as they accumulate more hours in the aircraft. There seems to be a bimodal peak of incidence of injury. One small peak is found early in the fighter pilot's career, before learning techniques for avoidance but while the support structures are still vigorous, because of youth. The other peak occurs later in the pilot's career (>1,000 flight hours logged), when the accumulated effect of many load-bearing



Fig. 2. F-16C canopy closed. Checking six to left with support of the left arm on the handrail.

events takes its toll on the cervical disks^{11,15}; as the pilot ages, the supporting ligaments, muscles, and disc structure itself are less resistant to injury.

(2) The index of suspicion is higher among flight surgeons because these principles are taught in flight surgeon training programs.

(3) Anonymous survey reporting mechanisms allow pilots to reveal injury occurrences without significant concern for adverse effects on their career.

Because of the limited number of responses from F-15 pilots, the results of this survey do not allow a comparison of injuries based on the turning capabilities of the various fighter aircraft. We postulated that the injuries would be greater in the F-16 compared with the F-15 or F-14 because of the fly-by-wire computer flight control system that automatically g-limits the turn rate and allows the pilot to maximally input stick controls. The cockpit of the aircraft differ in several important ways. First, the F-16 seat is reclined 30 degrees relative to the more upright seats of the other aircraft (a feature designed to improve the pilot's Gz tolerance and to decrease g-induced loss of consciousness episodes). Second, the location of handrails on the side of the cockpit is different among the aircraft. Finally, the F-16 control stick is fixed in position on the right side of the cockpit, versus the center, floor-mounted sticks of the other fighters. Although most pilots constantly maintain center stick aircraft control with the right hand, the option exists, during a turn, to release the throttle and use the left hand to brace the upper body when looking left (Fig. 2). When turning right, however, the pilot of the center-seat aircraft (Fig. 3) could switch stick control hands and brace himself on the handrail with the right hand (Fig. 4). This option does not exist for the F-16 pilot and could be one mechanism to account for the differential rate of injury between the F-16 and F/A-18 pilots and the disproportionate distribution of injuries in the right neck and associated right-sided paresthesias. Injuries seem to occur more often when pilots turn while looking right, but there is inconsistency in pilot use of the "switch-flight-control-hand" technique.

The inclination of the seat, as pointed out in earlier reports,⁷ may also make the F-16 pilot more vulnerable to injury because of the natural neck flexion prompted by the backrest position before attempted head rotation. However, this mechanism does not account for the right-sided symptom predilection.



Fig. 3. Cockpit of F/A-18A, showing a center flight control stick.



Fig. 4. F-16C canopy open. Checking six to right without support of the right arm because of the need to keep the right hand on the stick.

Treatment of significant aviation-related cervical injuries should be individualized based on the symptoms and pathology found on diagnostic evaluation. However, because of the unique mechanism of injury, we recommend, in the absence of cord impingement by the disc or fragments, that a conservative therapeutic option be used initially. This consists of rest, motion limitation with a cervical collar, anti-inflammatory with or without antispasmodic/muscle-relaxing medications, and physical therapy, including transcutaneous electrical nerve stimulation and ultrasound treatment to facilitate early pain relief. This therapy should be conducted for several weeks to 2 months. After completion of this program and with resolution of symptoms, we recommend a rehabilitation program designed to reduce the risk of further injury. Should surgical intervention be required, we recommend a more conservative discectomy, using microscopic techniques, before advancing to spinal fusion.

The survey also revealed that lumbar back pain is also quite common in this cohort of high-performance jet pilots. This finding is not surprising considering the increased rate of HNP found among astronauts with previous HPJA flight time, compared with matched populations. A longitudinal astronaut health study found 97 cases of spinal injury in 3,598 person-years reviewed, compared with 148 cases in 11,690 person-years among controls. The increased rate of HNP is found in both the cervical (13×) and lumbar (2–3×) regions. However, the rate of radiculopathy is much lower among astronauts compared with military pilots: 27 per 1,000 person-years in astronauts versus 13 per 1,000 in controls versus 348 per 1,000, 268 per 1,000, and 132 per 1,000 reported in Air Force, Navy, and Marine aviator studies.^{16,17}

In the questionnaire, we attempted to determine if a program of stretching plus exercise could help prevent injuries in fighter aircraft pilots. Unfortunately, there was no consistency in the stretching and exercise regimens used. We feel that this is the chief reason that these measures did not result in a significantly less frequent injury rate by regular users in this analysis. Pre-flight stretching, in this survey, did not appear to prevent flight-related pain. However, there was some suggestion, in the small number of pilots who performed regular neck exercises, that neck strengthening may lessen the pain risk. We feel that there are several key points to a potentially effective prevention strategy:

(1) More human-factors work on cockpit design, including optimal inclination, helmet support that does not interfere with vision, and well-positioned hand support rails.

(2) A more defined pre-flight stretching routine to relax both anterior and posterior cervical soft tissue elements.

(3) Focused weight/strength training emphasizing specific neck, shoulder, and upper chest and back muscle groups, each trained specifically.¹⁸

(4) The pilots should be instructed to pre-place their head before initiating the turn to keep their adversary in view, but then to maintain that position during the turn, ideally with the head and upper body supported, until the jet is unloaded. Emphasize that attempting to move the head/neck during the turn may increase the risk of injury. Certainly, maintaining visual contact on the adversary is key to winning the fight, so we cannot recommend a head-neutral position during an engagement; however, we can recommend that the pilot limit his head movement during turns to just allow line of sight to the "bogey."

(5) To lessen neck injury, the "backseater," be they weapons specialist officer, radar intercept officer, or flight surgeon, may be advised to limit head movements during the engagement/weapons delivery and to monitor the cockpit instruments/displays (forward-looking infrared, etc.), unless the crew has been pre-briefed on the need to have both crew members monitor aircraft movement or visual target identification.

Factors that affect fighter pilot health in the cockpit include the life support equipment, the cockpit configuration, and the pilot's personal pre-flight and in-flight habits. The future will bring more capability to the Department of Defense flying arsenal and, as long as these vehicles are piloted, the risk of pilot injury will likely increase. Estimates are that in 2025 and beyond, less than 15% of U.S. fighters will be piloted, having given way to unmanned combat aero vehicles.¹ Until then, we should study the mechanism of spinal injury more thoroughly to give accurate information to ergonomic designers/engineers so that they can build a safer and more effective human-machine interface for the next generation of aerospace vehicles.

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