Factors Contributing to Pain in Military Helicopter Pilots

by

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ABSTRACT

It is commonly accepted that for military helicopter pilots, neck and back pain is part of the job. This pain can decrease pilot situational awareness, increase medically related downtime, and increase healthcare costs incurred due to pilots. This literature review analyzes factors that contribute to neck and back pain and injury in military helicopter pilots, evaluates effectiveness of exercise regimes in mitigating pain, and assesses the potential for engineering design changes to reduce pain. Most of the reviewed literature confirms that exercise could be an effective means at decreasing pain in pilots; however, there was no universal finding regarding the impact of factors such as height, age and flight hours, gender, and airframe on pilot pain and injury. These topics remain worthy of further study as it is important to fully understand what factors contribute to pilot pain so they can be addressed in future military helicopter cockpit designs.

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Chapter 1: Introduction

Being a pilot is one of the most sought-after positions in all branches of the U.S. Military. In fact, in 2016, nearly 50% of cadets who were branched Army Aviation had to sign up for additional years of service to be considered for the branch [1]. Depending on what type of helicopter a pilot flies, they may preform various critical roles including tactical offensive action, surveillance, logistics and battlefield support, troop and cargo transport, search and rescue, medical evacuation, and disaster relief. Across all military branches (Army, Navy, Air Force, Marine Corps), flight school lasts approximately 1 to 1.5 years and is conducted in phases. These phases generally include officership training, general flight instruction on a training aircraft, airframe-specific aeronautical training, and SERE (survival, evasion, resistance, and escape) training. SERE training includes instruction on appropriate responses to emergencies such as wilderness crashes, enemy avoidance, and prisoner of war survival techniques [2]. While all four branches have helicopter assets, the Army is the only branch that predominately flies helicopters, as opposed to jets and propeller airplanes.

Neck and back pain are well-documented results of flying military helicopters. In fact, one study found that military helicopter pilots experience lumbar disk herniation at 1.22 times the rate of non-pilot controls [3]. Helicopter pilots were also shown to have significantly more lumbar disorders than fixed wing (airplane) pilots [3]. Back and neck pain in helicopter pilots is such a large problem that many have resorted to seeking treatment at civilian medical facilities rather than insurance-covered treatment at military facilities for fear of jeopardizing their military careers [4]. Pilot pain can have serious consequences. It can decrease pilot situational awareness through distractions, increase medical down time, and increase long-term healthcare costs, especially after military separation when pilots are more likely to seek medical treatment [5].

Many factors may be contributing to military helicopter pilot back and neck pain and injury (NBPI) such as the cockpit design in different airframes, total flight time, gender, height, weight, and other human factors. The primary object of military helicopter design is crash and gunfire survival. Avoidance of non-life-threatening discomfort and consideration of the long-term health of aviators have received minimal attention. Limiting the number of flight hours is not an option since that leads to poorly trained pilots [6]. In order to inform appropriate changes in military helicopter design, it is important to understand what factors contribute to neck and back pain among these pilots [6]. This thesis inspects the current landscape of research on how different human factors impact NBPI in military pilots through a literature review of 14 papers.

Chapter 2: Methods

2.1 Research Questions

The goal of this literature review was to survey the current landscape of research connecting different factors to NBPI among military helicopter pilots to inform future decisions in military helicopter design. The author had particular interest in answering the following questions:

1) How does height affect NBPI in military helicopter pilots?
2) How does age/flight hours affect NBPI in military helicopter pilots?
3) How does gender affect NBPI in military helicopter pilots?
4) How does airframe design affect NBPI in military helicopter pilots?
5) Are exercise programs effective at reducing NBPI?
6) What are the current gaps and disagreements in this field of research?

These questions were of interest because although the military prescribes strict physical standards for pilots, there still exists a range of physical profiles that meet these standards. This results in a variety of pilot profiles that end up interacting with the cockpit. Additionally, it is important for engineers to understand how cockpit design impacts pilot safety and comfort so that future designs may be adjusted accordingly.

2.2 General Methods

To answer these questions, the author reviewed 14 academic papers on topics related to human factors in military helicopter design. The author leveraged Google Scholar and MIT's access to Web of Science to find papers. Key search terms used during the research process were "military helicopter pilot" combined with "flight hours", "age", "gender", "exercise", "pain", "injury", and "height", "female helicopter pilot", and "neck pain in military helicopter pilots". The author found it helpful to narrow results to those published by the Department of Defense and other military organizations. During research the author noticed trends in the types of papers found. The papers generally fell into two categories: exercise regimes and pain, and other factors and pain. Four papers were related to exercise regimes, eight were related to other factors, and the remaining two were focused on the importance of this issue and its impacts on the military. Most of the reviewed papers were published in aviation medicine journals, although some were published in human performance, medicine, aviation, and human rehabilitation journals.

The author further reviewed papers that addressed the same factors to compare conclusions regarding how individual factors relate to NBPI. The objective was to identify specific factors proven to be associated with NBPI so that more informed design changes could be made to future helicopter platforms.

2.3 Answers Sought

To answer the questions outlined in Section 2.1, the author focused on trends in conclusions reached by the reviewed papers to determine which factors were generally agreed to influence pain in military helicopter pilots and which factors resulted in disagreements as to their relation to NBPI. The factors explored in this literature review were limited to those identified by the key words. Namely, this means that factors related to flight gear such as goggles, helmets, and combat gear were not explored.

Chapter 3: Results

This literature review found that the current landscape of research relating NBPI to various human factors in military helicopter pilots is lacking. The key finding is that every factor explored in this review (height, age/flight hours, gender, and airframe) had studies with conflicting conclusions as to whether those factors significantly contributed to pilot NBPI. Table 1 highlights these differences and shows that for all factors except age, there are discrepancies as to whether the factors contribute to pilot pain or not. Human factors need to be thoroughly understood before altering the design of any particular aircraft frame.

Table 1: Studies that found a relation between a factor and NBPI versus those that found no correlation between said factor and NBPI, sorted by factor. Comments on differences in research methodologies are included to inform conclusions made by this data.

Factor	Studies showing relation	Studies showing no relation	Comments
Height	[7]	[8]	Both studies used a retrospective questionnaire to collect pain data. However, [7] asked about the lower back and only analyzed data for pain lasting at least 30% of the flight while [8] asked about the region from the shoulder blades to the lower buttocks and did not limit its analysis to pain above a specific threshold.
Age	[8], [9]		
Flight Hours	[8]	[8], [9]	Source [8] found positive correlation between flight hours on some airframes and pain, but also found no correlation with other airframes. While [8] looked at self-reported pain, [9] used medical databases to look at cervical and lumbar injuries in pilots.
Gender	[10]	[3]	Source [10] did not limit its study to pilots. The authors found that female service members were more likely to experience pain. Source [10] examined instances of lower back pain in a military medical database from 1998-2006 while [3] examined instances of lumbar disc displacement in the same database from 2006-2015.
Airframe	[11], [8]	[7]	Although multiple sources found a relationship between airframe and pain, these studies presented conflicting results. Source [11] found that utility airframe pilots were more likely to experience pain than attack platform pilots. Source [8] found that in combat, attack and cargo pilots experienced the most pain whereas in training observation pilots cited the most pain. All three of these sources utilized retroactive questionnaires, however [7] used Active Duty, Reserve, and National Guard U.S. Army aviators, [8] used active Naval aviators, and [11] used active Israeli aviators.
Exercise	[12]	[13]	Source [12] utilized a 6-week neck and shoulder exercise program in active duty Swedish Air Force pilots and measured neck pain directly after and 12 months after the study while [13] used a similar 20-week program in the Royal Danish Air Force and measured neck and shoulder pain intensity immediately after the intervention.

The most conclusive results of this review were that age contributes to pilot pain and preventative exercise programs focused on strengthening neck, shoulder, and back muscles may be able to decrease pilot pain although it is unsure how compliant pilots would be to this type of program.

Chapter 4: Discussion

4.1 Factors Related to Neck and Back Pain

4.1.1 Height

A 2013 study [7] found that although prior studies had not shown a correlation between height and in-flight lower back pain, it was commonly accepted in helicopter communities that increased height was associated with more need to hunch over and therefore more lower back pain. The same study found that male military helicopter pilots had the odds of experiencing back pain increase by 9.3% for every inch over the median height of pilots studied (71 inches). Those equal or taller than the median were shown to have over twice the odds of experiencing back pain than those shorter than the median height. This study is limited in scope as it was unable to evaluate enough female pilots to have statistically significant results, so the conclusions reached are only valid for male pilots. These results may not be able to predict the relation between height and pain in female pilots, even if the pilots reflected a similar height to the male pilots in the study, due to musculoskeletal difference.

Not having enough female pilot study participants to have statistically significant results was a common trend among the studies evaluated, as only 4-10% of U.S. Army helicopter pilots are women [14, 15]. Additionally, the sample of pilots used in the 2013 study were skewed slightly taller than other reported data. The 2013 study reflected 5th and 95th percentile heights of 67 and 75 inches respectively [7] whereas a 2012 anthropometric survey of U.S. Army pilots reflected 5th and 95th percentile heights of 65.55 and 74.17 inches respectively for males and 5th and 95th percentile heights of 61.77 and 69.06 inches respectively for females [16]. A 2017 study [8] found that height and weight were not significantly correlated to back pain ratings. These differences may be due in part to self-reported height data in the 2017 study, however it is more likely that different participants in the studies resulted in these different conclusions.

4.1.2 Age and Flight Hours

While the relationship between age and back pain in active duty pilots is well accepted (increased age means increased back pain) it is hard to separate the effects of age and the effects of total lifetime flight hours in military pilots. The older the pilot is, the more total hours they have likely flown. One study found that age had a statistically significant, but weak correlation with both back-pain severity, onset during flight, and grounding. This means that not only did older pilots spend more time medically uncleared to fly, but when cleared to fly, they experienced more intense back pain and experienced it earlier in their flights [8].

While that study was able to find that back pain levels increased as flight hours increased in the UH-60 (utility helicopter) [8]. The study was unable to find the same link in the other airframes evaluated (AH-64, CH-47, OH-58). Another study found, after adjusting for the age of the pilots, that there was no statistically significant correlation between flight hours and cervical and lumbar disorders, suggesting that age was a better indicator of risk for back disorders [9].

4.1.3 Gender

A 2016 study [15] cited the small proportion of female pilots and as the reason for limited studies on neck pain and lower back pain in female versus male pilots. Based on the high proportion of civilian females with neck and lower back pain as well as musculoskeletal differences in males and females, the study predicted that females would have less cervical and trunk strength but greater range of motion than their male counterparts, potentially making females more predisposed to pain. The study found that females pilots were significantly shorter, lighter, and had lower cervical flexion strength, trunk flexion strength and trunk right rotation strength while they had greater cervical right and left rotation and no significant differences in range of motions. While this study did characterize musculoskeletal differences between genders that may make females more predisposed to neck or lower back pain, it did not characterize this pain among pilots.

In another study focused specifically on lumbar disc herniation, gender was not found to be an independent risk factor for the injury [3]. This study was limited to lumbar disc herniation and not general lower back pain although the two may be linked. Due to small sample size, Kelley et.al. were unable to link gender to back pain but noted that it remained an area worth future exploration [8].

Based on significant differences in the functional leg length and arms spans of the 95th percentile male and female army helicopter pilot (4 inches and 6 inches respectively), the musculoskeletal differences characterized in the 2016 study described above, and that among all active duty U.S. service members (not limited to aviators) women were found to experience lower back pain at 1.45 times the rate of men [10], it is likely that gender does play a role in back and neck pain among helicopter pilots although further work will need to be done to confirm this hypothesis.

4.1.4 Airframe

The airframe, or model of airplane or helicopter, has been broadly linked to increased risk of lumbar disk herniation. One study found that rotary wing (helicopter) pilots demonstrated significantly more lumbar disorders than fixed wing (airplane) and noted that Army aviators had the highest risk of experiencing lumbar disc herniation out of all of the services [3]. This is likely due to differences in full body vibrations produced by helicopters and planes [3]. However, in a study that leveraged flight simulation, pilots reported no difference in pain when vibration was turned off suggesting further research on full body vibrations is necessary before coming to a concrete conclusion [17]. Army aviators likely exhibited the highest risk of the injury because most army aviators fly rotary wing aircraft whereas Navy and Air Force pilots are more likely to fly fixed wing aircraft. Other studies noted that the helicopter's ergonomic design causes pilots to take a forward, flexed position of the spine that may cause increased neck and back pain [6, 18].

Beyond the broader differences between helicopters and planes, studies have not been able to conclusively identify the type of helicopter that causes the most pain. One study that did account for specific rotary wing airframes found no difference in the frequency or type of pain experienced by pilots of the UH-60 (utility helicopter), TH-57 (training helicopter), CH-53 (cargo helicopter), and CH-46 (cargo helicopter) [7]. However, another study [8] found that when analyzed by hours flown in combat, the AH-64 (attack helicopter) and CH-47 (cargo helicopter) pilots experienced more pain than those who flew the UH-60 (utility helicopter). When the same study analyzed that data by cockpit hours (hours flown not in combat) they found that OH-58 (observation helicopter) pilots experienced slightly more pain than those flying other rotary wing airframes. The study suggests that the discrepancy is due to different gear and equipment required in each environment such as body armor. Changes to this equipment may prove an effective means of minimizing neck and back pain though more studies will need to be done to confirm the role they play. Although UH-60 (utility helicopter) pilots did not experience the most pain when analyzed by combat or cockpit hours, the airframe received the most complaints in the study. The author suggests this is due in part to the fact that UH-60 pilots reported nearly double the flight hours as their counterparts. In future studies, comparing flight pain experienced per hour may be a good, normalized data set to compare pain across various airframes.

While the previous study only noted more complaints from those flying the UH-60 platform, another study [11] found that between attack helicopter platforms and utility helicopter platforms, utility helicopter pilots had more prevalent and more severe back pain. While the study was able to link general frequency and intensity of pain to different airframes, it was unable to link pain in certain areas of the back to specific aircraft types.

These differing results could be due to which militaries were being observed for each study. While one study looked at US military aviators, the other looked at Israeli military aviators. Different gear, training programs, and flight hour requirements could account for some of the discrepancies between the studies. A data set including flight gear weight and minimum flight hours may allow a better comparison across multiple militaries since it would allow analysis of whether airframe is truly an independent risk factor for pain or if there are other confounding variable at play. Regardless, this remains a worthy area for future study.

Additionally, while the U.S. military has no published medical standards for specific airframes (e.g. "Attack helicopter pilots should be within XY height") it is possible that different builds of pilots are prioritized for specific airframes or that the distribution of heights for a specific airframe does not match that of pilots in general. For this reason, future studies should consider analyzing height distributions across helicopter type in order to separate what results may be cause by height instead of by airframe.

Future studies should strive to find a correlation between airframe and pilot pain independent of height. That information would allow comparisons between controls placement, seat design, cockpit height, and other specific cockpit design elements across airframes to inform appropriate cockpit design changes.

4.2 Exercise as a Preventative Method to Reduce Pain

Several studies have noted that exercise therapy may be a safe and effective way to reduce neck and lower back pain in pilots. A study of 68 active duty Air Force helicopter pilots found that a supervised neck and shoulder exercise regime focused on strengthening neck-flexor muscles was effective in reducing pain and that participants who did general strength training of more than an hour a week before the study reported lower levels of pain [12]. Another study found that pilots who reported lower back pain had significantly lower trunk extension strength, lateral flexion range of motions, and greater side-to-side asymmetries than those who didn't report back pain, suggesting that exercises that target trunk strength, range of motion, and correcting side-to-side asymmetries may be an effective way at lowering back pain in helicopter pilots [19]. Others have noted that exercise programs are a good solution because they address pilots' back pain and their hesitancy to seek medical treatment for it [18].

However, it is difficult to tell how likely pilots would be to adhere to an exercise program, especially if self-administered. A study of 69 pilots and crew members found that after a 20-week exercise program focused on strengthening and increasing the endurance and coordination of neck and shoulder muscles, there was no significant reduction in neck pain intensity among the control group and the trial group likely due to low adherence to the self-administered program [13].

In the studies that implemented an exercise program, the exercises were focused on strengthening rather than increasing range of motion. Future studies should consider exploring exercises that also help increase range of motion in military helicopter pilots.

Chapter 5: Conclusions

There remains a paucity of data that clearly points to certain factors being significant contributors to neck and back pain among military helicopter pilots. Methods for addressing this problem generally fall into three categories: limiting flight hours, exercise programs designed to strengthen important muscles, and cockpit or equipment redesign. As limiting flight hours is not an option, the other two categories should be considered more. While research shows that exercise programs may be an effective way to decrease the bodily pain associated with flying, it is hard to tell how well pilots would adhere to any sort of self-administered exercise program. Before informed decisions on cockpit and equipment redesign can be made, more research should be done to fully understand what human factors are related to the pain military helicopter pilots experience. Focus on pain per flight hour across different airframes could provide insight into which airframes cause the most pain. From there, cockpit design features can be compared across airframes to determine what features are likely contributing to pain. It is likely that minor redesigns informed by this data set supplemented with an exercise program could positively impact military pilot health.

References

[1] 2016, *FY17 Branch Close-Out*, U.S. Army Cadet Command.

[2] 2018, "Student Information," U.S. Army Aviation Center of Excellence and Fort Rucker [Online]. Available: https://www.rucker.army.mil/newcomers/students/. [Accessed: 24-Jan-2019].

[3] Knox, J. B., Deal, J. B., and Knox, J. A., 2018, "Lumbar Disc Herniation in Military Helicopter Pilots vs. Matched Controls," Aerosp. Med.Hum. Perform., **89**(5), pp. 442–445.

[4] "The Military Addresses Chronic Neck and Back Injury in Aviators" [Online]. Available: https://www.militaryhub.com/article?id=337. [Accessed: 19-Dec-2018].

[5] Phillips, A. S., 2011, "The Scope of Back Pain in Navy Helicopter Pilots," Thesis, Monterey, California. Naval Postgraduate School.

[6] van den Oord, M. H. A. H., De Loose, V., Meeuwsen, T., Sluiter, J. K., and Frings-Dresen, M. H. W., 2010, "Neck Pain in Military Helicopter Pilots: Prevalence and Associated Factors," Mil Med, **175**(1), pp. 55–60.

[7] Orsello, C. A., Phillips, A. S., and Rice, G. M., 2013, "Height and In-Flight Low Back Pain Association Among Military Helicopter Pilots," Aviat. Space Environ. Med., **84**(1), pp. 32–37.

[8] Kelley, A. M., MacDonnell, J., Grigley, D., Campbell, J., and Gaydos, S. J., 2017, "Reported Back Pain in Army Aircrew in Relation to Airframe, Gender, Age, and Experience," Aerosp. Med.Hum. Perform., **88**(2), pp. 96–103.

[9] Hermes, E. D. A., Webb, T. S., and Wells, T. S., 2010, "Aircraft Type and Other Risk Factors for Spinal Disorders: Data from 19,673 Military Cockpit Aircrew," Aviat. Space Environ. Med., **81**(9), pp. 850–856.

[10] Knox, J., Orchowski, J., Scher, D. L., Owens, B. D., Burks, R., and Belmont, P. J., 2011, "The Incidence of Low Back Pain in Active Duty United States Military Service Members," Spine, **36**(18), pp. 1492–1500.

[11] Grossman, A., Nakdimon, I., Chapnik, L., and Levy, Y., 2012, "Back Symptoms in Aviators Flying Different Aircraft," Aviat. Space Environ. Med., **83**(7), pp. 702–705.

[12] Ang, B. O., Monnier, A., and Harms-Ringdahl, K., 2009, "Neck/Shoulder Exercise for Neck Pain in Air Force Helicopter Pilots A Randomized Controlled Trial," SPINE, **34**(16), pp. E544–E551.

[13] Murray, M., Lange, B., Nornberg, B. R., Sogaard, K., and Sjogaard, G., 2017, "Self-Administered Physical Exercise Training as Treatment of Neck and Shoulder Pain among Military Helicopter Pilots and Crew: A Randomized Controlled Trial," BMC Musculoskelet. Disord., **18**, p. 147.

[14] "Female Army Helicopter Pilots Crash Less Often | Time" [Online]. Available: http://time.com/8404/army-women-helicopter-pilots/. [Accessed: 19-Dec-2018].

[15] Nagai, T., Keenan, K. A., Abt, J. P., Sell, T. C., Smalley, B. W., Wirt, M. D., and Lephart, S. M., 2016, "A Comparison of Cervical and Trunk Musculoskeletal Characteristics between Female and Male Army Helicopter Pilots," Int. J. Aviat. Aeronaut. Aerosp., **3**(3), p. UNSP 8.

[16] Morris, J. E., "2012 Anthropometric Survey of U.S. Army Pilot Personnel: Methods and Summary Statistics," p. 449.

[17] Shanahan, D. F., and Reading, T. E., 1984, "Helicopter Pilot Back Pain: A Preliminary Study," Aviat Space Environ Med, **55**(2), pp. 117–121.

[18] Salmon, D. M., Harrison, M. F., and Neary, J. P., 2011, "Neck Pain in Military Helicopter Aircrew and the Role of Exercise Therapy," Aviat. Space Environ. Med., **82**(10), pp. 978–987.

[19] Nagai, T., Abt, J. P., Sell, T. C., Keenan, K. A., Clark, N. C., Smalley, B. W., Wirt, M. D., and Lephart, S. M., 2015, "Lumbar Spine and Hip Flexibility and Trunk Strength in Helicopter Pilots with and without Low Back Pain History," Work, **52**(3), pp. 715–722.