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**Review Article**

# Effects of vehicle-ride exposure on cervical pathology: a meta-analysis

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**Abstract: Research to date on the effect vehicle-ride exposure has on the development of cervical pathologies in mounted Warfighters is conflicting. The purpose of this study was to determine if the literature suggests a definite effect of vehicle-ride exposure on cervical pathology. Databases were searched using multiple combinations of select terms. Twelve studies meeting the inclusion criteria were included in the meta-analysis. The results of the meta-analysis revealed that overall vehicle-ride exposure was likely to increase cervical pathology ($p$=0.01, odds ratio=1.59, 95% CI=1.16−2.17). Using vehicle type as a moderator it was found that vehicle-ride exposure in ground-based vehicles ($p$=0.01, odds ratio=2.33, 95% CI=1.41−3.85) and fixed-wing aircraft ($p$=0.01, odds ratio =1.59, 95% CI=1.13−2.23) were likely to increase cervical pathology. Using operator/other personnel moderator it was found that in the populations tested, fighter pilots or fighter jet weapons systems operators were more likely to develop a cervical pathology ($p$<0.001, odds ratio=1.78, 95% CI=1.26−2.50). The available studies indicate an increase in cervical pathology for personnel exposed to ground-based vehicles and fixed-wing aircraft.**

**Key words:** Vibration, Mechanical shock, Spine, Injury, Military

## Introduction

Reports indicate that cervical pathology is common in mounted Warfighters (i.e. Warfighters that are crewmembers or operators of ground- or air-based vehicles)[1–6]. Investigators have proposed that frequent bouts of ride induced forces (such as vibration, shock, or $+G_Z$ forces) may increase the risk of pathology in the spine[6–9]. The pain mounted Warfighters experience from an underlying cervical pathology can be debilitating, compromise mission efficacy and completion, result in profiles that limit Warfighter duty, or be career ending[5, 7, 10–13]. Studies[14, 15] examining fighter pilots specifically have reported a prevalence of cervical pathology ranging from 18.9% to 63.6% over a 12-month reporting period (termed 1 yr prevalence period).

Studies using diagnostic examinations to determine the presence of cervical pathologies reported no significant difference between fighter pilots and controls, although fighter pilots appear to have a higher prevalence of neck pain[16–18]. A comparison of cervical spine radiological changes in F-16 fighter pilots and matched controls found no significant difference between the groups (8% vs. 10%

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prevalence)[16]. Similar findings were also reported in a 13 yr longitudinal study of fighter aircraft personnel indicating occupational exposure to acceleration did not cause significant radiological changes in the spinal column when compared to matched controls[17]. In contrast, a study revealed 3% of fighter pilots and 80% of transport pilots assessed by magnetic resonance imaging presented with cervical intervertebral disc degeneration[18]. The investigators noted that age differences between the fighter and transport pilot group may play a role in the higher prevalence of pathology reported in the transport pilots. Cervical pathology also appears to be prevalent in helicopter personnel, particularly pilots, with 43 to 57% of military helicopter pilots reporting cervical pain[12, 19, 20]. The cervical pain experienced by pilots includes acute bouts of pain, as well as regular and continuous pain that hampers performance in both work-related duties and leisure time activities[20]. The literature is not definitive as it pertains to this population. The prevalence values were based on large sample sizes, however, many of these studies did not compare their findings to non-flying military control groups making it difficult to determine if the issue is related to flight or an outcome of military duty (or life). In a study that did compare helicopter pilots to nonflying controls (air traffic personnel), 5.7% of helicopter pilots (N=1599) reported frequent and continuous cervical pain as compared to 20% of air traffic personnel (N=123)[2]. However, since the data were collected via clinical examination it is possible that fewer pilots, as compared to nonflying controls, reported feeling cervical pain out of fear of being grounded.

Investigation of the prevalence of cervical pathology in ground-based military vehicle personnel is lacking in the literature. The one report available[21] indicates that Danish main battle tank personnel were not at greater risk than other types of units (infantry, signal, combat service support, engineers, and artillery) for cervical spine pathology. However, there are many types of ground-based vehicles such as main battle tanks, Humvees (i.e. HMMWV) and Bradley Fighting Vehicle, each presenting different ride characteristics. For instance, the Bradley Fighting Vehicles resembles a tank, but rides like an off-road vehicle. In civilian studies, investigators have reported both vibration and mechanical shock exposure as strongly associated with the prevalence of neck pain in populations that regularly use off-road all-terrain vehicles to help perform daily occupational tasks[9, 22]. More generally, a recent study[23] exploring the incidence of neck and shoulder pain in civilian drivers of earth moving machines, forklifts, public buses and garbage machines reported a cumulative of incidences for neck and shoulder pain of 31.9% and 21.4%, respectfully. Differences in results between the Danish main battle tank and the study observing civilian drivers may in part due to age and level of fitness. In potentially less fit or older civilian population undergoing similar types of vehicle-ride exposure, the effects of exposure may be more deleterious to the cervical spine. However, the differences between the investigations to date make interpretation difficult. Thus, the purpose of our study was to determine if evidence exists in the literature indicating a definite effect of vehicle-ride exposure on cervical pathology. This investigation utilized meta-analyses to synthesize quantitatively the available literature and to determine where future research is required.

## Methods

### *Identification, study selection and data extraction*

An online search using Medline NIOSHTIC, Military & Government Collection (EBSCO), PubMed, and Web of Science identified articles published between January 1980 and November 2014 investigating the effects of vehicle-ride exposure on the occurrence of cervical pathology. There were no restrictions placed on the origin or language of the publications. The database search used multiple combinations of the following terms: vibration, spinal pathology, neck pain, intervertebral disc degeneration, degeneration, fracture, herniated disc, shock, loading, impact, repeated loading, industrial vibration, vehicle vibration, radicular, radiculopathy, neck strain, spine, mechanical shock, and G forces. In addition, we examined the reference list of the articles acquired through the search to find additional pertinent articles.

The inclusion criteria were determined prior to the start of the database search in order to reduce any possible selection bias. To be included, studies needed to have a clear sampling method, control group, clearly defined exposure time, focus on cervical injuries resulting from vehicle-ride exposure, and explicit pathology. After screening the titles and abstracts, two reviewers (R.K. and K.G.) evaluated the relevant full text articles for final inclusion. The reviewers resolved disagreements concerning article eligibility by consensus or by arbitration of a third reviewer (J.S.) if disagreement persisted. The reviewers extracted all pertinent information from each eligible article. ImageJ (Rasband, W., National Institutes of Health, USA) enabled extraction of pertinent data contained in figures.

**Table 1. Study description and level of evidence**

| Study | Sample population | Method of assessment | Level of evidence |
|---|---|---|---|
| Aydog *et al.*16) | 732 Turkish Military pilots | Radiographs | 2 (–) |
| Byeon *et al.*26) | 186 Military Helicopter Korea Air Force | Radiograph | 2 (+) |
| Drew *et al.*10) | 35 U.S. high performance aircraft pilots | Questionnaire | 2 (–) |
| Hamalainen *et al.*3) | 12 Finnish Air Force fighter pilot | Magnetic resonance imaging | 2 (–) |
| Hendriksen *et al.*1) | 188 Royal Netherlands Air Force pilots | Radiograph | 2 (+) |
| McBride *et al.*25) | 516 Locomotive engineers employed by the national rail carrier in New Zealand | Questionnaire | 2 (++) |
| Nissen *et al.*21) | 317 Main battle tank personnel | Questionnaire | 2 (+) |
| Petren-Mallmin and Linder27) | 29 Swedish Air Force pilots | Magnetic resonance imaging | 2 (++) |
| Pippig *et al.*2) | 286 pilots examined at the German Air Force Institute of Medicine | Clinical examination, peripheral neurological examination, computerized tomography, magnetic resonance imaging | 2 (–) |
| Rehn *et al.*24) | 431 drivers of all-terrain vehicles | Questionnaire | 2 (–) |
| Solvelius *et al.*17) | 12 Finnish Air Force pilot cadets | Magnetic resonance imaging | 2 (–) |
| Tachibana and Hanada28) | 40 Japanese Air Defense Force pilots | Magnetic resonance imaging | 2 (0) |

*Data analysis*

All data were entered into a custom Microsoft Excel spreadsheet (Microsoft Corporation, Redmond, Washington, USA) and later transferred to the statistical software Comprehensive Meta-Analysis version 2 (Biostat, Englewood, NJ, USA) for statistical analyses. The meta-analysis utilized an unweighted random effects model using an odds ratio centered on 1.00 as the effect metric. Ninety-five percent confidence intervals greater than 1.00 indicate that vehicle-ride exposure had a significant effect on cervical pathology. The sample sizes and number of injuries recorded for the treatment and control groups for each study were used in the analyses. Subsequent sub-analyses were conducted using data collection method [imaging (i.e. magnetic resonance imaging, radiograph, computed tomography) or questionnaire], vehicle type (i.e., ground-based vehicles, fixed-wing aircraft and rotary-wing aircraft) and operator/other personnel as moderators. For the operator/other personnel moderator, the investigators defined "operator" as anyone flying (i.e. fighter jet, jet, transport, or helicopter pilots) or driving (i.e. wheeled- or tracked-vehicle drivers) a vehicle. "Other personnel" represented anyone other than the operator on the vehicle (such as a weapons systems operators, flight surgeon, flight engineer, tank commander, loader, or gunner). Risk of publication bias was assessed using a funnel plot and a fail-safe number identified any presence of selective reporting within the studies. The Scottish Intercollegiate Guidelines Network (SIGN) grading system was used to evaluate the quality of evidence for each article included in the meta-analysis (Table 1).

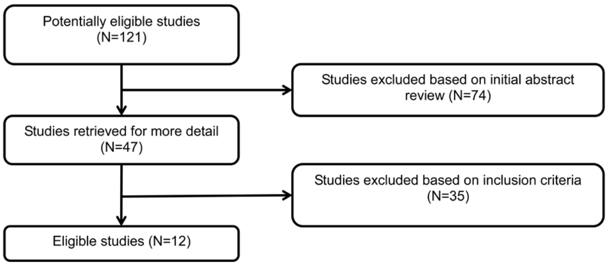

**Fig. 1. Outline of literature search and selection.**

## Results

The literature review yielded 121 potential articles. Twelve studies1–3, 10, 16, 17, 21, 24–28) met all inclusion criteria and were used for later analyses (Fig. 1). The data extracted for the analysis included: number participants in the treatment and control groups; total number of injuries in the treatment and control groups; vehicle type (fixed-wing, rotary-wing, or ground); and exposure time in hours. Table 2 displays the effect estimates and confidence intervals for each datum point selected. In some cases, more than one effect size was calculated per study. The funnel plot was symmetrical, indicating no publication bias (Fig. 2). In addition, a fail-safe N determined that 573 negative data points would be required to increase the *p*-value for the overall meta-analysis to above 0.05.

The results of the meta-analysis indicated that vehicle-ride exposure is more likely to increase cervical pathology ($p$=0.01, odds ratio=1.59, 95% CI=1.16−2.17) as compared to controls. Follow-up analysis using data collection

**Table 2. Effect of vehicle-ride exposure on cervical pathology**

| Study name | Vehicle description | Data collection method | Odds ratio | Lower limit | Upper limit | *p*-value |
|---|---|---|---|---|---|---|
| Aydog *et al.*[16] | FW: Fighter | radiographs | 1.31 | 0.61 | 2.79 | 0.49 |
| Aydog *et al.* [16] | RW: Helicopter | radiographs | 2.09 | 1.15 | 3.80 | 0.02 |
| Aydog *et al.* [16] | FW: Jet | radiographs | 1.10 | 0.63 | 1.91 | 0.74 |
| Aydog *et al.* [16] | FW: Transport | radiographs | 0.71 | 0.31 | 1.59 | 0.40 |
| Byeon *et al.*[26] | RW: Helicopter | MRI | 3.19 | 1.71 | 5.95 | ≤0.001 |
| Drew *et al.*[10] | FW: Fighter | questionnaire | 1.92 | 0.72 | 5.10 | 0.19 |
| Hamalainen *et al.*[3] | FW: Fighter | MRI | 1.67 | 0.22 | 12.35 | 0.62 |
| Hamalainen *et al.*[3] | FW: Fighter | MRI | 5.50 | 0.51 | 59.01 | 0.16 |
| Hamalainen *et al.*[3] | FW: Fighter | MRI | 2.00 | 0.38 | 10.41 | 0.41 |
| Hamalainen *et al.*[3] | FW: Fighter | MRI | 0.60 | 0.08 | 4.45 | 0.62 |
| Hamalainen *et al.*[3] | FW: Fighter | MRI | 1.50 | 0.25 | 8.84 | 0.65 |
| Hamalainen *et al.*[3] | FW: Fighter | MRI | 1.67 | 0.22 | 12.35 | 0.62 |
| Hendriksen *et al.*[1] | FW: Fighter | radiographs | 4.32 | 1.46 | 12.81 | 0.01 |
| Hendriksen *et al.*[1] | FW: Fighter | radiographs | 2.17 | 1.32 | 3.57 | ≤0.01 |
| Hendriksen *et al.*[1] | FW: Fighter | radiographs | 2.10 | 1.15 | 3.80 | 0.02 |
| Hendriksen *et al.*[1] | FW: Fighter | radiographs | 1.31 | 0.57 | 3.05 | 0.52 |
| Hendriksen *et al.*[1] | FW: Fighter | radiographs | 2.29 | 1.30 | 4.05 | ≤0.01 |
| Hendriksen *et al.*[1] | FW: Fighter | radiographs | 1.66 | 0.86 | 3.20 | 0.13 |
| Hendriksen *et al.*[1] | FW: Fighter | radiographs | 1.28 | 0.61 | 2.69 | 0.51 |
| Hendriksen *et al.*[1] | FW: Fighter | radiographs | 3.08 | 1.01 | 9.38 | 0.05 |
| Hendriksen *et al.*[1] | FW: Fighter | radiographs | 1.41 | 0.84 | 2.37 | 0.19 |
| Hendriksen *et al.*[1] | FW: Fighter | radiographs | 1.85 | 0.48 | 7.12 | 0.37 |
| Hendriksen *et al.*[1] | FW: Fighter | radiographs | 1.80 | 1.06 | 3.03 | 0.03 |
| Hendriksen *et al.*[1] | FW: Fighter | radiographs | 4.32 | 1.46 | 12.81 | 0.01 |
| Hendriksen *et al.*[1] | FW: Fighter | radiographs | 1.23 | 0.60 | 2.53 | 0.57 |
| Hendriksen *et al.*[1] | FW: Fighter | radiographs | 2.80 | 0.58 | 13.41 | 0.20 |
| Hendriksen *et al.*[1] | FW: Fighter | radiographs | 6.99 | 2.07 | 23.56 | ≤0.01 |
| Hendriksen *et al.*[1] | FW: Fighter | radiographs | 3.69 | 1.23 | 11.07 | 0.02 |
| Hendriksen *et al.*[1] | FW: Fighter | radiographs | 2.69 | 1.32 | 5.50 | 0.01 |
| Hendriksen *et al.*[1] | FW: Fighter | radiographs | 2.79 | 1.33 | 5.86 | 0.01 |
| Hendriksen *et al.*[1] | FW: Fighter | radiographs | 6.36 | 2.19 | 18.46 | ≤0.001 |
| Hendriksen *et al.*[1] | FW: Fighter | radiographs | 3.28 | 1.08 | 9.94 | 0.04 |
| McBride *et al.*[25] | Locomotive | questionnaire | 1.89 | 1.43 | 2.50 | ≤0.001 |
| Nissen *et al.*[21] | GB: Main Battle Tank | questionnaire | 0.99 | 0.68 | 1.45 | 0.96 |
| Petren-Mallmin and Linder[27] | FW: Fighter | MRI | 14.83 | 0.73 | 295.97 | 0.08 |
| Pippig *et al.*[2] | FW: Fighter | CT/MRI | 0.08 | 0.05 | 0.14 | ≤0.001 |
| Pippig *et al.*[2] | RW: Helicopter | CT/MRI | 0.06 | 0.03 | 0.12 | ≤0.001 |
| Pippig *et al.*[2] | FW: Transport | CT/MRI | 0.21 | 0.12 | 0.39 | ≤0.001 |
| Rehn *et al.*[24] | GB: Forest Machine | questionnaire | 4.23 | 2.73 | 6.55 | ≤0.001 |
| Rehn *et al.*[24] | GB: Snow Groomer | questionnaire | 3.78 | 2.15 | 6.63 | ≤0.001 |
| Rehn *et al.*[24] | GB: Snow Mobile | questionnaire | 2.52 | 1.56 | 4.07 | ≤0.001 |
| Solvelius *et al.*[17] | FW: Fighter | MRI | 1.14 | 0.21 | 6.37 | 0.88 |
| Tachibana and Hanada[28] | FW: Fighter | MRI | 0.59 | 0.17 | 2.05 | 0.40 |
| Tachibana and Hanada[28] | FW: Fighter | MRI | 1.26 | 0.32 | 4.93 | 0.74 |
| Tachibana and Hanada[28] | FW: Fighter | MRI | 0.33 | 0.10 | 1.10 | 0.07 |
| Tachibana and Hanada[28] | FW: Fighter | MRI | 1.70 | 0.49 | 5.93 | 0.40 |
| **Summary Effect** | | | **1.59** | **1.16** | **2.17** | **0.01** |

FW: fixed-wing, RW: rotary-wing, GB: ground-based, CT: computerized tomography, MRI: magnetic resonance imaging

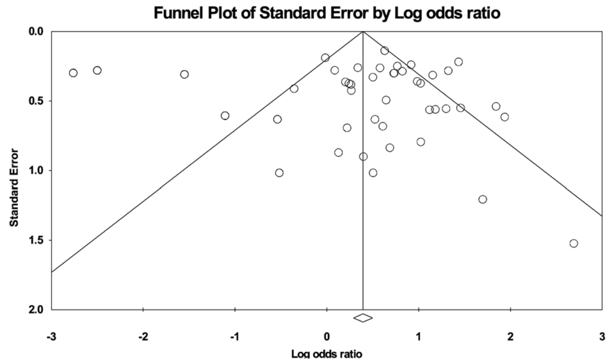

**Fig. 2. Funnel plot of included studies.**

method (i.e. imaging or questionnaire) as a moderator revealed studies using some type of imaging for the method (i.e. magnetic resonance imaging, radiograph, computed tomography) of collecting their injury data indicated that vehicle-ride exposure (*p*=0.04, odds ratio=1.50, 95% CI=1.02−2.20) was significantly likely to increase cervical pathology. In studies that used a questionnaire to collect their injury vehicle-ride exposure data, we also observed that vehicle-ride exposure (*p*=0.001, odds ratio=2.28, 95% CI=1.44−3.60) was significantly likely to increase cervical pathology. Using vehicle type (i.e. ground-based vehicles, fixed-wing and rotary-wing) as a moderator revealed that vehicle-ride exposure in ground-based vehicles (*p*=0.01, odds ratio=2.33, 95% CI=1.41−3.85) and fixed-wing aircraft (*p*=0.01, odds ratio=1.59, 95% CI=1.13−2.23) were significantly likely to increase cervical pathology (Fig. 3). Vehicle-ride exposure in rotary-wing aircraft (*p*=0.82, odds ratio=0.75, 95% CI=0.06−8.65) was not likely to increase cervical pathology (Fig. 3). Analyzing the data using vehicle operator/other personnel type (e.g. pilot and crewmembers) as a moderator, the results revealed that being a fighter jet pilot or weapons systems operator was significantly likely to increase cervical pathology (*p*<0.001, odds ratio=1.78, 95% CI=1.26−2.50) (Fig. 3). The results also revealed that being a transport pilot (*p*=0.10, odds ratio=0.38, 95% CI=0.12−1.21) was not significantly likely to increase the development of cervical pathology (Fig. 3).

Due to the lack of ground-based studies, we could not perform separate analyses using the operator/other personnel as a moderator for the different classes of ground-based (e.g. wheeled- or tracked) vehicle operators as previously performed with fixed-wing aircraft (e.g. fighter jet and transport plane) pilots. In addition, we were not able to use operator/other personnel as a moderator in the rotary-wing aircraft group because the studies used in the analysis only reported data on helicopter pilots. Furthermore, only one of the included studies identified the type of helicopter (e.g. attack or transport helicopter) flown by the pilot reporting the cervical pathology; thus, further sub-categorization of the rotary-wing group was not possible.

## Discussion

The purpose of this study was to determine if the literature provides definitive evidence that vehicle-ride exposure influences the incidence of cervical spine pathology. Our main finding is that the current literature suggests vehicle-ride exposure increases cervical pathology. Most studies utilized radiological and magnetic resonance imaging to diagnose the presence of cervical pathology. Five out of the seven studies using diagnostic testing indicated radiologists, neuroradiologists or other medical doctors examined the diagnostic imaging[1, 3, 16, 17, 26]. Only four studies (6 out of 46 data points) collected data on cervical pathology using a questionnaire[10, 21, 25, 29]. The imaging and questionnaire studies both indicated vehicle-ride exposure is likely to increase cervical pathology, suggesting that both evaluation approaches provide similar outcomes.

Examination of vehicle type (i.e. ground-based vehicles, fixed-wing aircrafts and rotary-wing aircraft) suggests that vehicle-ride exposure in ground-based vehicles and fixed-wing aircraft increases cervical pathology. However, we observed that fixed-wing aircraft accounted for 38 of 46 data points, with ground-based and rotary-wing vehicles accounting for 5 of 46 data points and 3 of 46 data points, respectively. The minimal number of data points for ground-based vehicles and rotary-wing aircraft makes it difficult to assess accurately the effect of ride exposure in these vehicles. Additional studies in rotary-wing and ground-based vehicles need to be completed in order to understand how these types of vehicles influence cervical pathology.

Fixed-wing aircraft fighter pilots and fighter jet weapons systems operators were significantly more likely than controls to report a cervical pathology when vehicle operator/other personnel was used as a moderator. Our results suggest that transport pilots are not likely to incur a cervical pathology; however, a limited number of studies including transport pilots met our inclusion criteria. The analysis using transport plane operator/other personnel as a moderator represented only two data points from two separate studies. This lack of research is also evident in both the ground-based vehicle and rotary-wing aircraft literature. More research is required within the ground-based group investigating the effects of vehicle-ride exposure on

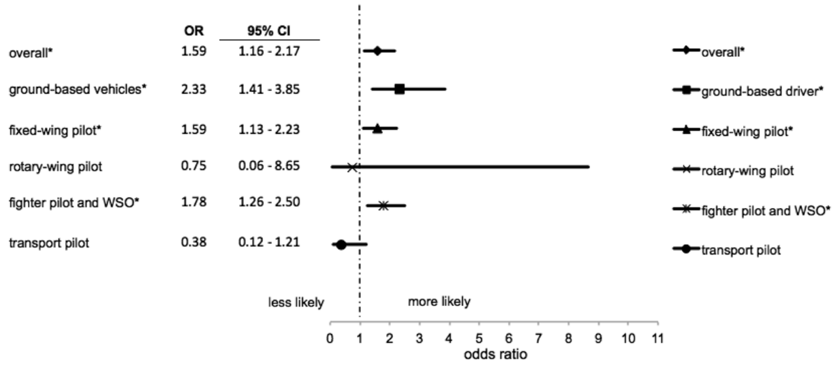

**Fig. 3. Forest plot of overall and moderated analyses.**
WSO: weapons systems operator; (*$p<0.05$).

cervical pathology in wheeled- and tracked-vehicle drivers and other personnel.

Further research is also required to understand the influence of ride exposure on cervical spine pathology in rotary-wing aircraft, specifically type of helicopters, given their importance in military operations. Only three studies2, 16, 26) with helicopter data met the inclusion criteria outlined a priori in the present analysis. Of the included studies, only one2) identified the type of helicopters and that study did not report the prevalence of cervical pathology per type of helicopter. In addition, the observed confidence intervals of this particular moderated analysis were very large (*p*=0.82, odds ratio=0.75, 95% CI=0.06−8.65)2). This finding may be due to the very low number of participants in the control group (N=123) as compared to helicopter pilots (N=1,599) of one of the included studies. The authors of the study2) reported 20% of the control group (N=25/123) was identified with a cervical pathology as compared to about 2% of the helicopter group (N=32/1,599). This is in contrast to the other two studies2, 16) included in the moderated analysis. Aydog *et al*.16) reported that reported 10% of the control group (N=21/202) and 19% of the helicopter group (N=31/159), while Byeon *et al*.26) reported 18.2% of the control group (N=16/88) and 41.5% of the helicopter group (N=68/164) were identified as having developed a cervical pathology. The results of these two studies differ greatly from Pippig and Kriebel2). We believe that the lower number of participants in the control group of the Pippig and Kriebel2) study may have artificially inflated the reported value of 20% in the control group; thus impacting the 95% CI of the moderated analysis exploring the influence of vehicle exposure on helicopter pilots.

Additional research is needed to assess the impact of vehicle exposure in helicopter populations as compared to nonflying controls. Future research should also seek to distinguish between various types of helicopters (e.g. AH-64 Apache Longbow attack helicopter as compared to CH-47 Chinook transport helicopter) to better identify the effects of flight exposure in pilots as well as other flight personnel. This information is vital to gaining a better understanding of how vehicle specific ride (or flight) exposure influences the incidence of cervical pathology in mounted Warfighters.

Ground-based vehicles experience vibration between 0.2 to 20 Hz30) with superimposed episodes of mechanical shock30); while fighter jets expose a pilot to repeated $+G_Z$ forces6). Helicopter pilots and other helicopter personnel contend with largely vibratory forces as compared to the frequent +G environment experienced by fighter pilots and fighter jet weapons systems operators8, 31). Helicopters experience lower vibratory amplitude than armored vehicles, but higher dominant frequencies30). Using the ISO 2631-1 standards for health criteria researchers of an early study8) indicated that helicopter mean vibration measures were approximately 0.54 $\mathrm{m{\cdot}s^{-2}}$ at the seat, with some flight values exceeding 0.60 $\mathrm{m{\cdot}s^{-2}}$. A more recent study32) that evaluated helicopter vibration under different flight profiles (e.g. hovering, cruising at normal speed, max speed, and descent) found that weighted vibration measures (calculated according to ISO 2631-1 standard) in the z-axis ranged from 0.32 $\mathrm{m{\cdot}s^{-2}}$ to 0.51 $\mathrm{m{\cdot}s^{-2}}$ depending on the type of helicopter.

The differences in ride exposures combined with the lack of vehicle specific information and vibratory and shock profiles for current vehicles suggests researchers should direct their attention to both ground-based vehicle and helicopter personnel in future studies where currently a lack of controlled design studies exist. For example, several studies12, 18, 20) have reported that helicopter pilots have an increased prevalence of cervical pathology; however, these studies have failed to compare the findings to non-flight personnel with comparable age and career work experience.

Both ground-based vehicle and aircraft studies should seek to compare vehicle operators and other vehicle personnel to active duty and civilian non-vehicle or flight personnel. Research also needs to investigate the injury prevalence in all crewmembers, as the ride posture and exposures vary significantly from position to position (tank driver compared to tank commander for example). To date, most of the literature has focused on pilots and drivers with minimal attention given to other crewmembers. A better understanding of how vehicle exposure influences cervical pathology in other personnel with different seating positions and locations is required.

The use of helmets with and without additional head-supported mass also deserves further investigation. None of the studies meeting the inclusion criteria included specification on the weight of the helmet and other gear supported by the head and cervical spine. The literature indicates this as a potential injury risk factor[33–36]. Future studies should provide helmet and head supported mass specifications. This will allow the helmet and associated gear to be used a moderator allowing for a clearer interpretation of the effects of vehicle-ride exposure forces on cervical pathology.

Future investigations need to determine if a dose-response relationship exists between vehicle-ride exposure time and development of cervical pathology. We were unable to explore this question through a predictive model in the present study due to lack of data. However, we did observe an interesting pattern within our career vehicle-ride (flight) time data in studies that collected injury data via questionnaire. Figure 4 shows that as exposure time increases, the report of a cervical pathology is more likely until a saturation point is reached at approximately 4.00 log (time), which is equivalent to 10,000 h. Clearly, more data are required to generate any reasonable conclusions. We did not observe this same type of pattern in a scatter plot between career vehicle-ride (flight) time and effect size derived from studies using imaging (e.g. radiography) to identify pathology. Imaging is an objective indicator of changes to soft or bony tissues; however, it cannot identify the presence of pain. Questionnaires allow for subjective measures (i.e. pain), which may increase with increased vehicle-ride exposure even in the absence of confirmed tissue changes via imaging.

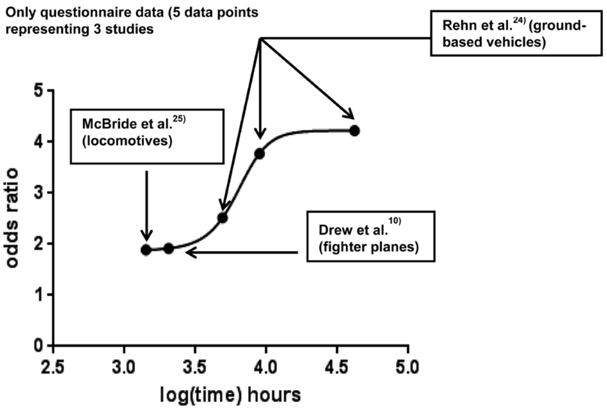

**Fig. 4. Graph of odds ratio and log of time (hours) for the studies using a questionnaire.**

This study suggests that populations exposed to frequent $+G$ forces require injury prevention interventions. Investigators have proposed several injury risk factors such as repeated exposure to accelerative $+G_z$ forces[6]; unanticipated high $+G_z$ accelerative forces[37]; decrease endurance at the neck musculature[3]; and head[3, 38] and seat positioning[10] during high $+G_z$ maneuvering. Intervention strategies and or programs proposed in the literature to help mitigate some of these risks include: having pilots brace their heads against the seat (or canopy) prior to high $+G_z$ load[38–40]; performing pre-flight warm-ups that include stretching and isometrics[5, 15, 39]; unloading (decreasing the $+G_z$) prior to moving the head while in flight[39]; and neck strengthening exercises[5, 15, 39, 40]. In order to develop effective intervention protocols for mounted Warfighters in all military occupational specialties (MOS), more work must be completed to further understand ride exposure and the development of cervical spine pathology.

Although the results of the present study suggest that vehicle-ride exposure likely increases cervical pathology, there are several limitations. First, there remains a possibility that not all available data (published or unpublished) were included. However, the calculated fail-safe N indicated that 573 negative data points are required to negate the positive general effect of vehicle-ride exposure on the development of cervical pathology. Second, one study represented 20 out of 39 data points; thus, this study may have influenced the results of the present study even though no indication of a publication bias as determined via a funnel plot. Third, many of the studies did not include or explicitly state the number females included in their study; thus, whether or not the same outcomes would be present in female populations remains to be determined.

Finally, in an attempt to include all published and unpublished data within the present meta-analysis meeting the inclusion criteria there is a potential that one or more studies used in the analyses were poorly performed studies. This may have adversely influenced the outcome of the analyses; however, we wanted to be inclusive of all relevant studies regardless of quality. In addition, because there were a limited number of studies meeting the inclusion criteria a possibility exists that the point estimates and confidence intervals may provide false assurances when using an unweighted random effects model[41]. Therefore, as per Borenstein[41] the authors have provided the separate effects for each datum point included (Table 2).

## Conclusion

The results of our meta-analysis provide evidence that overall vehicle-ride exposure is likely to increase cervical pathology in vehicle operators and other personnel compared to controls. The results of the present analysis suggest that exposure in ground-based vehicles and fixed-wing aircraft is likely to increase cervical pathology. In fixed-wing aircraft, fighter pilots and fighter jet weapons systems operators are more likely to develop a cervical pathology than control groups, while transport pilots were less likely to develop cervical pathology than control groups. Personnel- and vehicle-specific data in ground-based vehicle and rotary-wing aircraft that would allow the determination of the likelihood of cervical pathology in personnel other than pilots was not available at time of analysis.

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