A Systematic Review and Meta-Analysis About the Prevalence of Neck Pain in Fast Jet Pilots

Amelia Riches; Wayne Spratford; Jeremy Witchalls; Phil Newman

BACKGROUND: During flight, fast jet pilots frequently move their heads into extreme positions while withstanding large amounts of stress on their cervical spines. These factors are thought to contribute to episodes of neck pain.

METHODS: We conducted a systematic review and meta-analysis of previous neck pain prevalence data in fast jet pilots to determine an overall pooled prevalence. Subgroup analyses were performed according to when pilots complained about their neck pain, whether these same pilots sought treatment, and if they lost time from flying. Four research databases were searched. Studies were eligible for inclusion if they were written in English, involved a group of fast jet pilots who were actively flying high performance aircraft, and reported quantitative prevalence data about neck pain in these pilots. These eligibility criteria were independently applied by two reviewers and risk of bias was evaluated. MetaXL software was used to conduct the meta-analysis.

RESULTS: In total, 8003 fast jet pilots across 18 eligible studies were included in the review. The overall pooled prevalence of neck pain in fast jet pilots was 51%. It was found that 39% of subjects lost time from flying, while only 32% sought medical treatment.

DISCUSSION: Neck pain in fast jet pilots adversely affects operational capabilities of defense forces. The prevalence of neck pain varies according to the definitions or thresholds of complaints used across the literature. Further research is required to standardize the definition of neck pain.

KEYWORDS: frequency, cervical spine, fighter aircrew.

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The term 'fast jet pilot' describes military personnel who operate high performance aircraft.[51] Their primary goal is to provide combat air power for their national government. This involves executing various airborne mission roles, some of which place high degrees of physical stress on the pilots.[51] These pilots are also involved in planning missions, briefings, debriefings, and other administrative tasks which are completed in office settings.[11,51]

A skill required for aerial combat is the ability to move the aircraft while executing offensive and defensive flight maneuvers. This is called air combat maneuvering, and is essential for the pilot to perform optimally within a combat environment.[39,42] Throughout these tactical movements, fast jet pilots constantly turn their heads to scan for targets in the air and on the ground.[29] Hence, air combat maneuvering involves rapid and repetitive excursions of the cervical spine away from the anatomically neutral position.[29,54,55] Fast jet pilots complete these maneuvers while they are also exposed to high gravitational accelerations (G force or G),[28,30] which increase compression and stress along the axis of the spine.[30,39,52] Axial loads equivalent to 65 kg are exerted on the neck due to the weight of the head, helmet and helmet-mounted equipment when pilots fly at 9 G.[2,26] Although some cross sectional studies suggest that exposure to these forces can initially strengthen the neck,[1,18] it is widely acknowledged that they likely contribute to acute and/or chronic episodes of neck pain.[1,37,51] Due to these physically demanding occupational factors, it is expected that fast jet pilots will have a higher prevalence of neck pain

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compared to that of the general population.[24] The prevalence of neck pain within the global community is 4.9%, where 90% of cases are attributed to injuries of the intervertebral discs, 80% to anterior spinal ligaments, and 40% to facet joints following vehicle collisions.[9] Neck pain can result in lost workdays and reduced flying capacities for fast jet pilots.[37,51] Given that $15.2 million is required to train one pilot for an F/A-18 Hornet aircraft,[36] days lost from flying are expensive to defense forces[48] and informed risk strategies are required. This issue has gained international focus and is supported by a specialized North Atlantic Treaty Organization (NATO) Research Task Group: HFM 252.[43]

The prevalence of neck pain in fast jet pilots must be determined to understand the magnitude of the issue and the characteristics of those fast jet pilots who are affected. This is important due to the growing advances in aircraft technology and helmet-mounted devices, which will influence the forces applied to the neck.[2] To date, there is only one published systematic review and meta-analysis which examines neck pain in the fast jet pilot population.[45] However, this study did not define neck pain[45] which reduced the clarity of research findings.

There is large variation in how pain and injuries are reported in epidemiology research.[50] They typically fall into one of three definitions; 'all complaints reported,' 'time lost,' and 'medical attention sought.'[8,50] 'All complaints reported' refers to the expression of any health-related incident irrespective of its ramifications or the interventions required.[8] Injuries defined by 'time lost' are those which impair an individual's ability to fully engage in training or activity, while 'medical attention sought' refers to injuries requiring medical assessment.[8,50] With several definitions of neck pain and injury available to researchers, there is little comparable prevalence data which makes drawing clear conclusions from the literature challenging. The present review aims to address this gap and clearly convey the prevalence of neck pain in fast jet pilots. The focused questions for this review are:

1. What is the prevalence of neck pain in fast jet pilots?
2. How does prevalence vary across four thresholds of complaints (i.e., 'any complaint experienced at any time,' 'any complaint experienced during a specified time,' 'medical attention sought,' and 'time lost from flying')?

METHODS

The Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines were followed when completing this review.[31] The protocol for the review was registered on the 19th of February 2018 in the PROSPERO international prospective register for systematic reviews website (https://www.crd.york.ac.uk/prospero/), registration number CRD42018088909. The review did not meet the criteria outlined by the University of Canberra's Human Research Ethics Committee and therefore did not require ethical approval.

Procedure

Four electronic databases including Medline, CINAHL, Scopus, and Google Scholar were searched for literature published between the years 2000 and 2018. Search terms related to fast jet pilots, prevalence, and neck pain. Searches were repeated to identify papers published between review completion and submission in February 2019.

Titles and abstracts were screened separately by two reviewers to identify relevant studies. Both reviewers retrieved full text copies of these papers and independently examined them for relevance. Reference lists of each study were scanned (forward and backward citation tracking) to ensure all eligible papers were identified. Blinding throughout was achieved by using the Covidence software package.[10] Disagreement between the reviewers was resolved thereafter by consensus.

Predetermined eligibility criteria were used to screen titles, abstracts, and full texts. Studies were eligible for inclusion if they met these criteria: 1) were written in English; 2) involved a discernible group of fast jet pilots who were actively flying; and 3) reported quantitative data about the prevalence of neck pain in these pilots.

Studies were excluded for the following reasons: 1) they were not written in English; 2) included fast jet pilots who could not be easily distinguished from a larger sample of pilots; or 3) were case studies, expert opinions or reviews.

The literature considers aircraft capable of flying at 5 G or more high performance 'airframes.'[1,2,54] Since the majority of subjects operated high performance aircraft, their exposure to increased G force was high. The reviewers agreed that operating high performance aircraft and therefore flying at high G force was the exposure of interest.

The number of fast jet pilots, age, sex, military flying hours, and type of aircraft flown were recorded to determine the parity and differences between studies (**Table I**).

The outcome of interest was the prevalence of neck pain in fast jet pilots. Prevalence was recorded as the number of fast jet pilots who reported neck pain out of the total number of fast jet pilots sampled (Table I). When a prevalence value was not specified, a proportion was calculated when and where data presented in the papers allowed. Prevalence was documented according to four thresholds for complaints including 'any complaint experienced at any time,' 'any complaint experienced at a specified time,' 'time lost from flying,' and 'medical treatment sought.' Only the proportions of affected pilots who flew high performance aircraft were recorded for analysis.

Selection, nonresponse and measurement biases of the included studies were assessed independently by two researchers using the Quality assessment Checklist for Prevalence Studies.[23] The tool was designed for the evaluation of observational prevalence studies. It contains nine dichotomous items which assess external and internal validity while providing a summary score.[23] Literature shows that the overall interrater agreement of the tool is 91% with a 'strong' Kappa agreement of 0.82.[23,34] Therefore, the instrument was considered appropriate given its high reliability and applicability to prevalence research.

Statistical Analysis

Data were extracted from the studies and cross-checked by a second reviewer. The methods of each paper including the

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Table I. Summary of the Included Studies.

PAPER	SUBJECTS	AIRCRAFT	DESIGN	DEFINITION OF NECK PAIN	PREVALENCE
Alricsson, 2004[1]	$N = 40$ Age: - RG: 29.4 (± 4.5) - NRG: 29.4 (± 3.1)	Not specified	Cross-sectional	Not specified	AST: 17/40 (42.5%)
Ang, 2005[2]	$N = 60$ Age: 37 (± 7.5)	JAS 39 Gripen and JA 37 Viggen	Cross-sectional	"…defined as any neck-pain experience, neck stiffness or tenderness."	AST: 16/30 (53.3%)
De Loose, 2008[11]	$N = 90$ Age: not specified	F-16	Cross-sectional	"…more than two episodes of neck pain [lasting] at least 1 [day during] the past 12 [months]…defined as pain in the head and neck…"	AST: 17/90 (18.9%) ST: 4/17 (23.5%) FTL: 6/17 (35.3%)
Drew, 2000[13]	$N = 79$ Age: 31.4 (± 4.5)	F-16 and F-15	Cross-sectional	"…specific spinal symptoms which occurred… [and their] effects… on aviator flying performance…"	AAT: 19/35 (54.3%) AST: 12.6/35 (36.0%) ST: 15/19 (78.9%) FTL: 6/19 (31.6%)
Greeves, 2006[16]	$N = 144$ Age: not specified	Not specified	Cross-sectional	Not specified	AAT: 100/144 (69.9%) AST: 23/144 (16.0%) ST: 31/100 (31.0%)
Grossman, 2012[18]	$N = 566$ Age: 31.21 (± 8.15)	F-15, F-16, Skyhawk	Cross-sectional	"…[any back pain]…recalled. Location…was categorized as cervical,… thoracic… and… lumbar… pain."	AAT: 101/214 (47.2%)
Hermes, 2010[20]	$N = 19{,}673$ Age: - DOB < 1966: 6279 (± 31.9) - DOB > 1967: 13,394 (± 68.1)	Not specified.	Cross-sectional	"…presence of an initial waiver in the [aeromedical] database where the primary diagnosis was related to a cervical or lumbar intervertebral disc bulge, disc herniation or protrusion, disc degeneration, and/or spondylosis."	ST: 34/5681 (0.6%)
Jones, 2000[26]	$N = 70$ Age: not specified.	C-26, KC-135, G-2, T-38, F-15, F-16 and F/A-18	Cross-sectional	"The questionnaire… sought to evaluate the presence, nature, severity, and timing of symptoms…"	AAT: 25/27 (92.6%)
Kang, 2011[27]	$N = 1003$ Age: 29.3 (± 5.1)	Fighters: F-4, F-5, F-15, F-16 Trainers: KT-1, T-50, T-59	Cross-sectional	"…neck pain was defined as the presence of any neck pain or pain radiating to an upper extremity…"	AAT: 483/998 (48.4%)
Landau, 2006[28]	$N = 30$ Age: 35.2 (± 4)	F-4, F-15 and F-16	Cross-sectional	"…the duration and frequency of off-flight symptoms on average retrospectively per year."	AST: 0/10 (0%)
Lange, 2011[29]	$N = 58$ Age: not specified.	F-16	Cross-sectional	"[the questionnaire] asked for the frequency of any pain… in the spine… [subjects] were asked to identify area(s) of discomfort on a figure of the human back."	AAT: 56/58 (96.6%) AST: 48/58 (82.8%) ST: 29/56 (51.8%) FTL: 24/56 (42.9%)
Moon 2015[35]	$N = 63$ Age: - No neck pain group: 30.6 (± 3.88) - Neck pain group: 29.4 (± 3.85)	F-4, F-5, F-16, F-15, and T-50	Cross-sectional	"…neck pain during the past 1 yr. …frequency, duration, and referred pain were investigated…"	AST: 27/32 (84.4%)
Netto 2011[37]	$N = 82$ Age: 31 (± 7.4)	Hawk 127 and F/A-18	Cross-sectional	"…the survey assessed neck strain, pain or injury…"	AAT: 78/82 (95.1%)
Rintala 2015[42]	$N = 195$ Age: 30 (± 5)	Not specified.	Cross-sectional	"The location of flight-induced musculoskeletal symptoms over the past 6 months was marked in each subject's pain observation chart."	AST: 69/113 (61.1%)

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Table I, *Continued*

PAPER	SUBJECTS	AIRCRAFT	DESIGN	DEFINITION OF NECK PAIN	PREVALENCE
Thoolen, 2015[49]	*N* = 59 Age: - < 30 yr: 29% - 30-40 yr: 46% - > 40 yr: 25%	F-16	Cross-sectional	"Pain was defined as any pain or discomfort… A figure was used to define… the neck and lower back."	AST: 35/59 (59.3%)
VanValkenburg, 2016[54]	*N* = 250 Age: - SP's 20-29: 90% - IP's 25-34: 70% - IP's 35-44: 24%	T-6, T-38 and T-1 SUPT	Cross-sectional	Not specified	AAT: 92/250 (36.8%)
Verde, 2015[55]	*N* = 70 Age: - F-16: 32.54 (± 4.71) - Typhoon: 33.37 (± 3.84)	F-16 and Eurofighter Typhoon	Cross-sectional	"…at least two episodes of neck pain after flight in the last 2 months."	AST: 19/35 (54.3%)
Wagstaff, 2012[56]	*N* = 105 Age: - 20-29: 47 - 30-39: 45 - 40-45: 7 - > 50: 6	F-16, F-14, F-5, T-38, T-37, and CF-104	Cross-sectional	"Neck pain events in general and specifically in the last 12 months."	AAT: 76/105 (72.4%) AST: 53/105 (50.5%)

design, definition of neck pain used and outcome data (i.e., prevalence of neck pain) were recorded (Table I). Prevalence values from all studies were then subject to meta-analysis to determine a pooled prevalence of neck pain. This was conducted using MetaXL software version 5.3.[6] In accordance with published recommendations,[5] a double arcsine transformation was applied across the data to limit the overweighting associated with inverse variance analysis of pooled effects.[5] Since the I^2 statistic exceeded 50%, a random effects model was used. Subgroup analyses were then performed according to the four thresholds of complaint, where the proportions of pilots who sought medical treatment and lost time from flying were determined from the group of pilots with neck pain. Subgroup analyses were completed if there were two or more comparable studies.

RESULTS

A total of 176 potentially relevant studies were returned from the database searches (**Fig. 1**). After duplicates were removed, 125 papers remained. Titles and abstracts were independently screened against the eligibility criteria, with 83% agreement between the two reviewers. Once disagreements were resolved by discussion, 30 papers were left for full text appraisal. The level of agreement between the reviewers during full text evaluation was 93% with disputes being resolved by consensus. Eighteen studies met the eligibility criteria and were included for review.

A total of 8003 fast jet pilots were anonymously surveyed about neck pain across the 18 studies. The mean age of the subjects ranged from 29.3 to 37 yr (Table I). After the studies were categorized under the thresholds for complaints, 11 were found to define neck pain as 'any complaint experienced at any time' while nine described it as 'any complaint experienced during a specified time' (in the previous 3, 6, or 12 mo) and three reported it as both. Five studies defined neck pain by 'medical treatment sought,' while three of these also established their threshold as 'time lost from flying.'

The fast jet pilots included in 11 of the reviewed studies operated the F-16 Fighting Falcon (Table I).

Twelve studies directly reported the prevalence of neck pain as proportions. We therefore calculated prevalence values from data presented in the remaining six papers (Table I). This standardized the results to enable data combination for the meta-analysis and facilitated easier comparisons between studies.

According to the guidelines for classifying summary scores in the quality assessment tool, the studies received a mean score of 2.47 out of 9 (± 1.37) indicating a low risk of bias.[23] The reliability and validity of the questionnaires used for data collection were not reported or were unknown in all papers except three, and were consequently rated at high risk of bias (**Fig. 2**). Eight studies scored poorly in criteria associated with nonresponse bias. In contrast, each paper scored well for criteria eight, demonstrating that the mode for data collection was consistent within each study.

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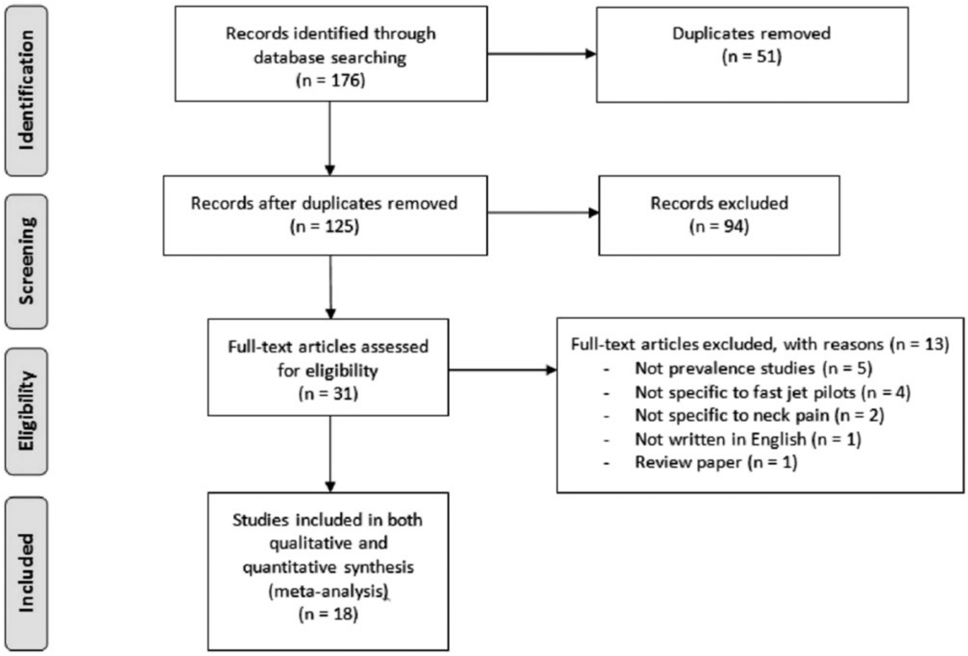

Fig. 1. PRISMA flow chart for study selection.

Interrater reliability for the quality assessment was calculated using the first-order agreement coefficient (AC1).[19] Unlike Cohen's Kappa, the AC1 is not skewed by trait prevalence or marginal probabilities and offers a more stable reflection of interrater reliability.[19,58] The AC1 for the quality assessment was calculated as 0.34, indicating that the level of agreement between both reviewers was 'fair' when assessing for risk of bias.

After pooling the prevalence data, a meta-analysis was performed **(Fig. 3)**. The I^2 statistic was calculated at 99% indicating considerable heterogeneity between the studies.[21] Since an adequate number of comparable studies were found, subgroup analyses were conducted according to each threshold for complaint.

The pooled prevalence of neck pain in fast jet pilots was 51% (95% CI, 33–68%) (Fig. 3). The prevalence of neck pain defined as 'any complaint experienced at any time,' was 71% (95% CI, 56–83%). It was found that 46% (95% CI, 0.31–0.61%) of fast jet pilots reported neck pain described as 'any complaint experienced during a specified time,' (3 to 12 mo). Of the fast jet pilots who reported neck pain, 31% (95% CI, 0–75%) sought treatment while 39% (95% CI, 30–50%) reported time lost from flying.

DISCUSSION

This review demonstrates that there is a high (51%) prevalence of neck pain among fast jet pilots. The sub-grouped analyses show that prevalence can be influenced by the definitions of neck pain or thresholds for complaints used in the research. This study therefore explains the reasons for the high variability of neck pain prevalence in fast jet pilots across the literature.

The meta-analysis demonstrates that only 32% of fast jet pilots with neck pain sought medical attention, while 39% lost time from flying. Further studies are required to explore why medical attention is not commonly sought by fast jet pilots who experience neck pain and to encourage those affected personnel to seek treatment. Additional research is also warranted to investigate solutions which prevent the initial onset of neck pain in this population.

The studies included in this review demonstrated a considerable level of heterogeneity (I^2 = 99%). This may relate to the methodological diversity of the studies, where neck pain was inconsistently defined.[25] For example, some researchers defined neck pain as symptoms which occurred during the last 3, 6, or 12 mo. However, other studies described neck pain as any neck symptom which occurred at any time over previous years. Therefore, inconsistent definitions of neck pain have likely affected the results across the papers.

The studies also provided variable descriptions of the neck. Some papers defined this area by providing shaded sections on body charts, while others encouraged subjects to mark where they had experienced neck pain on body diagrams. Pooling data from research founded on non-standardized definitions leads to high variation in the collection and assessment of results.[41] However, robust statistical adjustments[5] were applied to control for this heterogeneity and improve the generalizability of findings. Therefore, the use of non-standardized definitions has been identified as a weakness in the literature.[27,35] This gap may be addressed through Delphi studies, which will likely produce uniform definitions of both neck pain and neck regions to improve the accuracy of future results.

The risk of bias for the papers was possibly influenced by the lack of demonstrated validity and reliability of questionnaires used across the research. Although it is recommended that studies disclose the validity and reliability of their methods for data collection,[44] 15 of the included studies did not report these measures. However three papers modeled their surveys from previously validated questionnaires like the Dutch musculoskeletal questionnaire and the neck disability index. Since these tools are standardized and valid instruments,[22,33] only these studies were assessed as having a low risk of bias for the seventh domain of the quality assessment.[23] If the questionnaires used in the 15 remaining studies were of poor validity and reliability, then a higher degree of random error may have affected the results[57] and masked the prevalence of neck pain.

It is expected that low participant response rates in eight of the included studies also affected the risk of bias and pooled prevalence. Nonresponse bias is a common limitation in studies which collect data through surveys or questionnaires.[7,12] As

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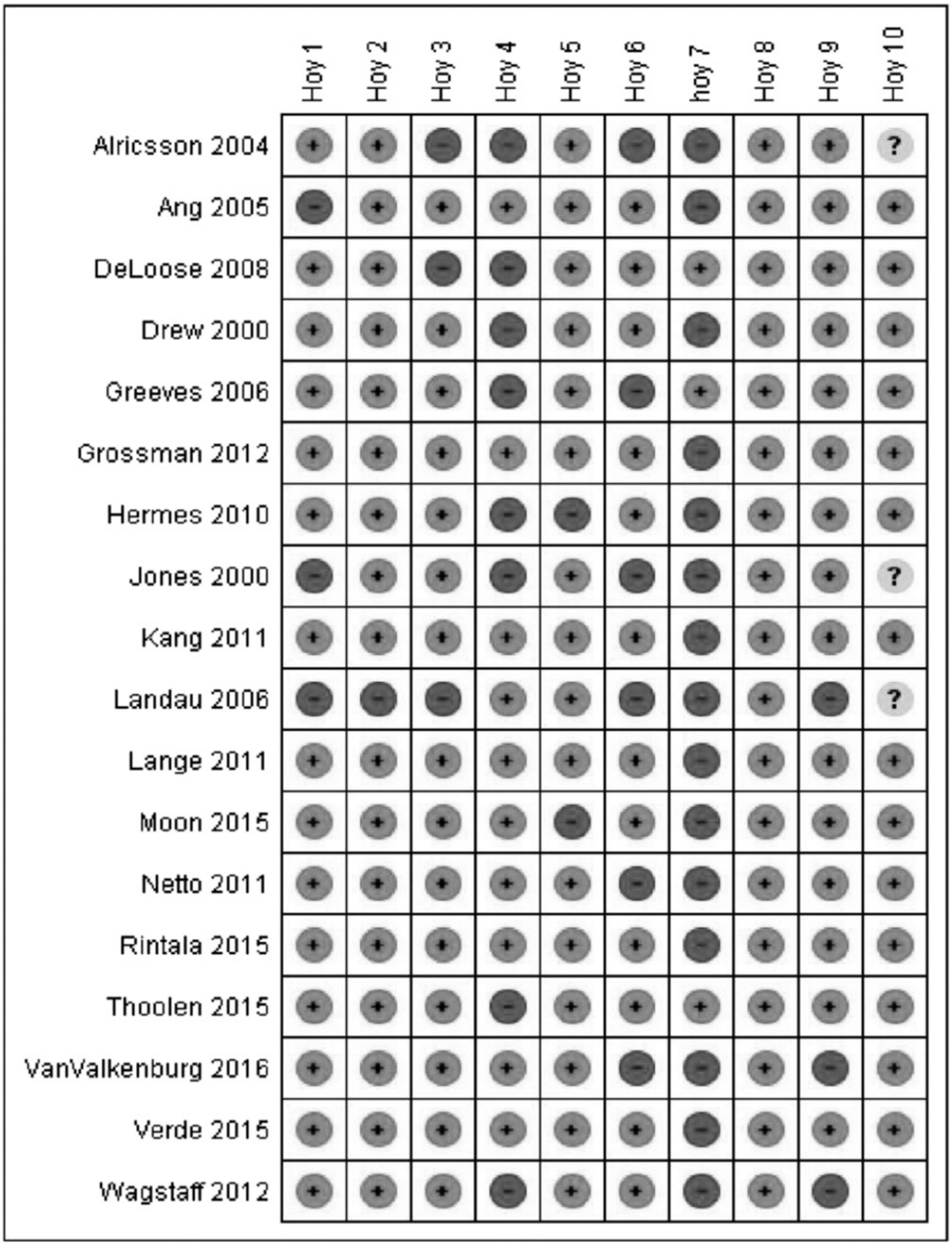

Fig. 2. Risk of bias scores for the included studies (*N* = 18). Legend: Hoy 1 = representative population; Hoy 2 = appropriate sampling frame; Hoy 3 = random selection or census; Hoy 4 = non-response bias; Hoy 5 = data collection; Hoy 6 = case defined; Hoy 7 = reliability and validity; Hoy 8 = direct data collection; Hoy 9 = numerators and denominators; Hoy 10 = summary risk of bias. Light grey (+) = 'low' risk of bias; light grey (?) = 'moderate' risk of bias; dark grey (-) = 'high' risk of bias.

acknowledged by several studies evaluated throughout this paper, any lack of total anonymity negatively influences voluntary response rates in military research.[26,47,56] Although the included studies de-identified subjects, some pilots may not have answered the questionnaires due to risk of recognition by variables like age or flying hours.[47] Literature has shown that responders to health surveys are more likely to be well, and therefore report better health statuses compared to nonresponders.[7,40,53] Hence, the prevalence of neck pain has likely been underestimated throughout the papers which may have influenced the results of the meta-analysis.

All studies except one collected data through surveys or questionnaires, indicating that the mode of data collection was consistent across the majority of papers. Only one study obtained records from an electronic aeromedical database.[20] Results from an ongoing prospective cohort study of active military personnel[15] have shown a moderate level of agreement between information gained from medical records and questionnaires.[46] Collecting data from medical records produces more statistically powerful, homogenous and generalizable results and is therefore the gold standard for data collection in epidemiological studies.[3,17] Nevertheless, this method is not immune from bias due to the typically limited disclosure of medical symptoms within military populations.[7,20,56] Although the larger statistical power of this study may have affected the heterogeneity between the papers, it is clear that a consistent approach was used to collect data across the reviewed literature.

The studies sampled fast jet pilots who shared similarities in relation to gender, age and flying hours. Hence, the pilots exhibited relatively homogenous participant characteristics. Comprehensive testing procedures are used to select candidates who are best suited for operating high performance aircraft,[38] and involve evaluating cognitive, spatial, perceptual and psychomotor abilities as well as anthropometry.[14] These standardized assessments are likely to explain the homogeneity between subjects in this review. It should be noted that several papers investigated their respective national populations of fast jet pilots, which may also explain similarities found across the subjects.[2,27,38] Therefore it is likely that the pilots sampled in each study were representative of their national fast jet pilot populations, which may have enhanced the generalizability of the results.

The F-16 Fighting Falcon was the most common aircraft operated by fast jet pilots across the studies. However, several papers sampled fast jet pilots who flew more diverse ranges of high performance airframes (e.g., student versus instructor

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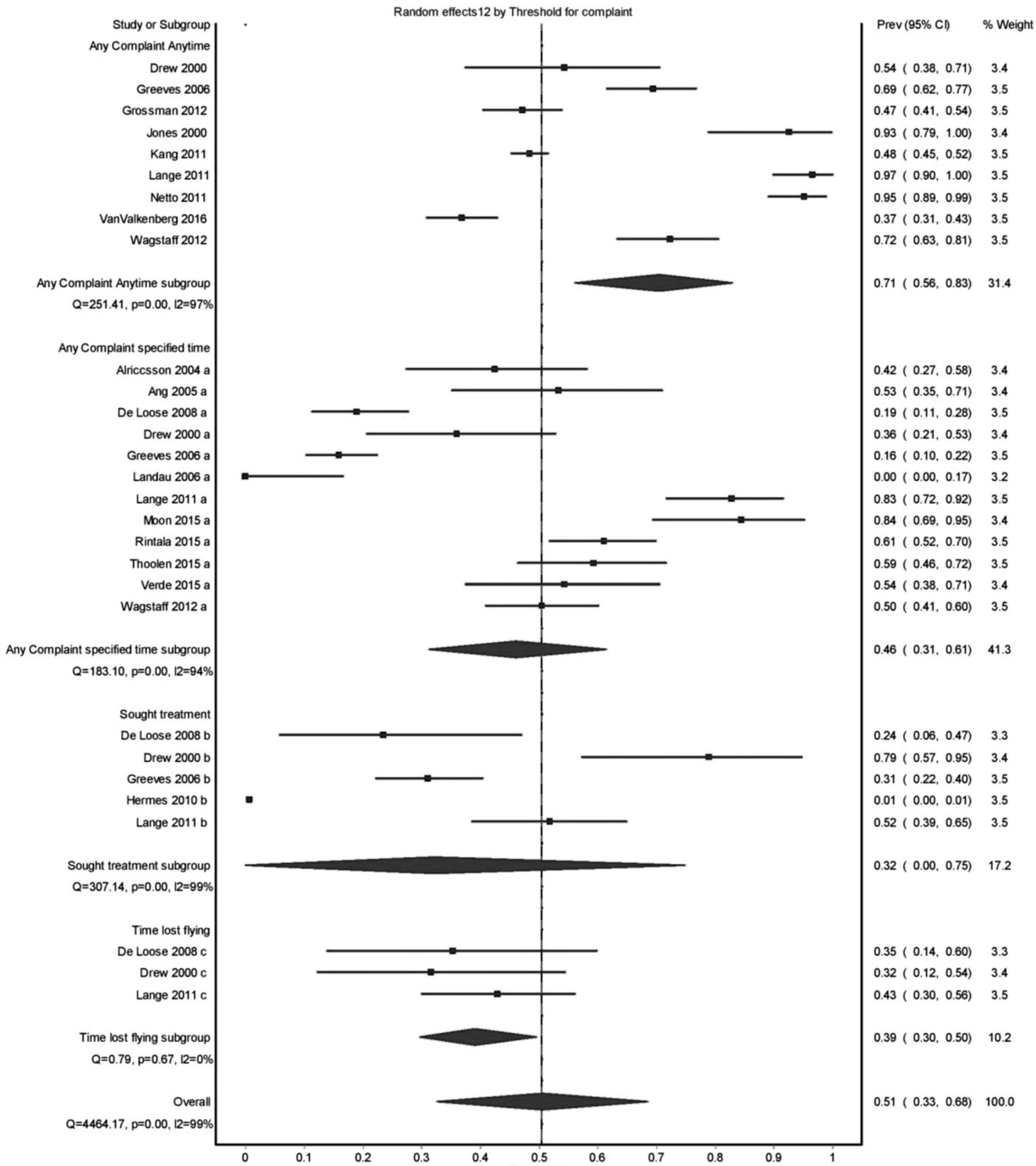

Fig. 3. Forest plot of pooled prevalence and subgroup analyses for neck pain in fast jet pilots.

aircraft). The forces imposed on fast jet pilots depend on the type of aircraft flown.[4] None of the studies included in this review specified the proportions of fast jet pilots operating each type of airframe. Although a subgrouped meta-analysis according to types of aircraft could not be performed, the combination of data from pilots of different aircraft may have enhanced the generalizability of the results to a wider population.

Agreement between the reviewers was 83% during title and abstract screening and 93% during full text evaluation. Although there are no established standards which define 'satisfactory' agreement, literature indicates that consensus levels exceeding 80% are generally acceptable.[32] However, when the studies were evaluated for risk of bias with the quality assessment tool, the AC1 statistic of 0.34 indicated a 'fair' agreement between the

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two reviewers.[19,23] It is our impression that the dichotomous nature of the instrument contributed to this level of consensus. Had the tool allowed for three choices during assessment (high, low and unclear), the reliability between the reviewers may have improved. Additionally, consensus may have been enhanced if the reviewers became more familiar with the tool through a training period. Agreement may have also improved if the reviewers standardized the interpretations of the domains with each other prior to assessing the papers.

A number of limitations must be considered when interpreting the results from this review. All studies failed to report the degree of neck pain (mild, moderate, or severe) and the proportions of fast jet pilots operating each type of aircraft. This limited our ability to investigate prevalence according to pain severity and types of airframes. Therefore our results only provide information about the prevalence of neck pain according to four thresholds for complaints. Despite these limitations, this review effectively synthesized literature applicable to the research questions, identified gaps in knowledge and suggested directions for future study.

This review calculated the pooled prevalence of neck pain in fast jet pilots as 51%, which is considerably higher than that of the global population. Several gaps in knowledge and literature were identified, including inconsistencies in defining neck pain and neck regions. This review demonstrated a limited use of validated and reliable questionnaires as well as high degrees of nonresponse bias across the research. It is recommended that subsequent researchers consider these limitations and regulate the approach for defining and assessing neck pain in fast jet pilots. Once achieved, the overall precision of results may increase, thereby allowing for more accurate conclusions. Future research should aim to establish the global prevalence of neck pain in fast jet pilots using internationally standardized methods of assessment. The mechanisms which cause neck pain and injury should also be investigated to form the basis of risk management and treatment programs.

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