2019

TACTICAL RESEARCH UNIT REPORT

Army Cadets at Training in a Gymnasium, Location Unknown First World War, 1914-1918

Australian War Memorial record: HO2420

Officer Cadets at ADFA, 2016
Photographer John Carroll

Source: Defence Media Online

Measuring occupational exposures to osteoarthritis in the lower limb in Australian Defence Force job categories

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ABBREVIATIONS and ACRONYMS

ADF	Australian Defence Force
ADFA	Australian Defence Force Academy
AMSTAR	A MeaSurement Tool to Assess systematic Reviews
BMI	Body mass index
CI	Confidence interval
CINAHL	Cumulative Index of Nursing and Allied Health Literature
DVA	Department of Veterans' Affairs
EBSCO	Elton B Stevens Company
GAG	Glycosaminoglycan
HR	Hazard ratio
IET	Initial Employment Training
IOC	Initial Officer Course
JEM	Job exposure matrix
JEM-OLL	Job exposure matrix - Osteoarthritis of the lower limb
K/L	Kellgren and Lawrence [grading system]
MRCA	Military Rehabilitation and Compensation Act
NEOC	Navy New Entry Officers' Course
OA	Osteoarthritis
OLL	Osteoarthritis of the lower limb
OR	Odds ratio
PMKeyS	Personnel Management Key Solution
PT	Physical training
PTI	Physical training instructor
RMC	Royal Military College
RMA	Repatriation Medical Authority
RR	Risk ratio
SoP	Statements of principles
SRCA	Safety, Rehabilitation and Compensation Act
THR	Total hip replacement
TKR	Total knee replacement
VEA	Veterans' Entitlements Act
WHO	World Health Organisation
WHS	Workplace Health and Safety

Physical training	Physical training in the military differs to general fitness training or general exercise. The nature of the training undertaken, work rates and efforts, durations, etc. are ouside the locus of control of the individual. Participants typically do not have a choice regarding participation or content and may be under scrutiny and expected to perform maximally during each session.
Statements of Principles	"Statements of Principles (SoPs) determined by the RMA are legislative instruments and have the same legal effect as any legislation passed by Parliament. SoPs exclusively state what factors must exist to establish a causal connection between particular diseases, injuries or death and service." (http://www.rma.gov.au/sops/)
Reasonable hypothesis	With regard to the two bases for SoPs, "The more generous (beneficial) standard, known as the reasonable hypothesis standard, applies to veterans and serving members who have operational (or equivalent) service." (http://www.rma.gov.au/faqs/most-frequently-asked-questions/why-are-there-two-sops-for-each-medical-condition/)
Balance of probabilities	With regard to the two bases for SoPs, "The balance of probabilities standard is for veterans and serving members with non-operational service", and tends to be less generous or require a more stringent level of proof (http://www.rma.gov.au/faqs/most-frequently-asked-questions/why-are-there-two-sops-for-each-medical-condition/)

EXECUTIVE SUMMARY

Purpose and Background

The summary and technical reports comprising this document encapsulate the scope, methods, and findings for the Australian Defence Force (ADF; comprising the Royal Australian Air Force (RAAF), Royal Australian Navy, and Australian Regular Army) from the Department of Veterans' Affairs (DVA)-sponsored research project *ARP1706 Measuring Occupational Exposures to Osteoarthritis in the Lower Limb (OLL) in Australian Defence Force (ADF) Job Categories*. The project scope was limited to examining exposures that occur during the initial training of full-time ADF personnel and comparing these findings with the exposure threshold levels set out in the Statements of Principles (SoPs) for OLL established by the Repatriation Medical Authority (RMA).

Research Questions

The guiding research questions were:

- To what degree does initial training undertaken by ADF members meet the exposure thresholds for OLL set out by the RMA, including thresholds of exposure to joint trauma that may lead to OLL?
- To what extent do individual factors (e.g., body weight, sex, fitness, and age) affect the risk of military personnel developing OLL or their exposure to occupational risk factors for OLL, including joint trauma?
- How have exposures during initial training to factors that increase the risk of ADF personnel developing OLL changed over preceding decades?

Research Design

To answer these questions, the project encompassed six key elements:

1. a desktop analysis of purposively selected ADF initial training courses;
2. construction of a job exposure matrix (JEM) for OLL;
3. direct observations of training and surveys of trainees and staff to confirm, or examine, the types and extent of any variations in observation findings from findings of the desktop analysis in order to further inform the JEM-OLL;
4. an historical review of ADF initial training;
5. an analysis of osteoarthritis (OA) claims data 1994–2018; and
6. literature reviews, including an umbrella review of previous reviews, a critical review with meta-analysis, and additional reviews to examine the influences of specific factors on the risk of military personnel developing OLL or their exposure to occupational risk factors for OLL.

Umbrella Review of Previous Reviews

The aim of the umbrella review was to identify and synthesise findings from previous literature reviews that have examined risk factors for development of OLL in physically demanding occupations. A systematic search was conducted using the databases PUBMED, CINAHL, and EBSCO to identify literature reviews that were published in the last 15 years and associations were examined between lower-limb OA and occupational tasks. These reviews were rated for their methodological quality using the AMSTAR 2 before information was extracted, tabulated, and synthesised using a narrative approach.

Sixteen reviews were found, published between 2003 and 2018. Seven of these pertained to OA affecting the knee, four to hip OA, two to OA in a variety of joints across the body, and three to both hip and knee OA. One review was deemed to be of high methodological quality and the others of moderate methodological quality.

Most of the studies included in these reviews were of a cross-sectional design, which may create a selection bias and disallow definitive identification of a causal relationship. Further, most studies used questionnaires to obtain information on exposure to occupational tasks, which can be affected by recall bias. This methodological approach (i.e., self-report questionnaires) has been found to provide, at times, an overestimation of workload, and this is an issue also common in case-control studies, which made up 36% (*n* = 10) of the studies reviewed.

Considering these limitations, the reviews provided moderate to good evidence that heavy occupational lifting was associated with an increased risk of OA at the knee and the hip. The definition of 'heavy' ranged from 10 kg to 50 kg. Other occupational tasks that may increase the risk of OLL developing if performed in excess of specific thresholds include kneeling, squatting, and climbing.

The findings regarding tasks were diverse, reflecting varying periods of time, loads, and actions, and raised the possibility that performance of some of the occupational tasks (e.g., climbing) at subthreshold levels may help prevent OLL. In addition, previous injuries to joints and being overweight were found to predict lower-limb OA. Given that these sorts of tasks and joint injuries are common in military personnel and may be performed in excess of specific thresholds for OLL risk due to military training requirements, it is not surprising that military personnel experience greater rates of OA than do members of the general population.

Efforts to reduce exposure to these tasks, reduce joint injury rates, and ensure optimal body weight and full rehabilitation of injuries may reduce risks of OLL developing, but further research is needed to confirm this.

Critical Review With Meta-Analysis

The aims of the critical review with meta-analysis were to:

1. identify and critically review the findings of recent studies regarding the relationships between specific physically demanding occupations or occupational tasks and the development of OLL, and
2. determine other risk factors that might affect these relationships in personnel engaged in such occupations.

A systematic search of three major literature databases, PUBMED, CINAHL, and EBSCO was performed to identify studies published in the last 15 years that reported on occupational risk factors for the development of OA. Critical appraisal of included studies using the Critical Appraisal Skills Programme toolkit as well as narrative synthesis and meta-analysis of key findings was conducted.

Twenty-eight studies were eligible for inclusion, with only one study being in a military population. Physically demanding occupations such as farming, floor laying, and bricklaying were associated with OLL, particularly at the knee. Occupational tasks involving lifting/carrying heavy loads (> 10 kg / week), squatting/kneeling, and standing (> 2 hours/daily) contribute significantly to the development of OLL (OR 1.60 95% CI [1.36, 1.88], OR 1.22 [1.11, 1.34], and OR 1.32 [1.12, 1.55], respectively, $p < 0.001$). The effects of occupational exposures appear to be magnified by previous injury and BMI > 25 kg/m^2, which were strong risk factors in their own right (OR 3.94 [2.81, 5.53] and OR 3.04 [2.65, 3.44], respectively). Limitations in some included studies included lack of consistency in reporting exposure quantities and not reporting specifics of exposures or the exposure duration.

Desktop Analysis, Observations, Surveys, and JEM-OLL

In the desktop analysis a methodological approach previously used by leading military research institutes was employed to examine exposures to risk factors for OLL occurring during training of recruits and officer cadets from all three services (the RAAF, Royal Australian Navy, and Australian Regular Army). We also examined exposures occurring during initial employment training of selected occupations from each ADF service that were identified as having either a relatively low or high level of physical demand or exposure to a specific risk factor for OLL (e.g., occupational exposure to heavy lifting). For the RAAF, the desktop analysis included initial officer training, recruit training, Airfield Defence Guard Initial Employment Training (IET), Loadmaster IET, and Medical Assistant training. For the Navy, the desktop analysis included New Entry Officer Course training, recruit training, Boatswain's Mate training, Marine Technician Initial Technical Training, and Maritime Logistics – Personnel Operations training. For the Army, the desktop analysis included initial officer training, recruit training, Driver Specialist IET, Infantry IET, and medical assistant training.

For each course, the desktop analysis established estimates of exposure by quantifying time spent in different body postures, levels of physical activity and exertion, loads lifted and carried, and numbers of stairs and ladder rungs climbed. The desktop analysis drew on daily course programs, physical training programs, defence training manuals and instructions, and subject matter experts to account for exposures per day and week. The weekly cumulative exposures from date of enlistment were aligned with specific types of occupational exposures recognised by the RMA in its SoPs for OLL in order to ultimately derive a JEM-OLL for the selected full-time ADF employment categories.

Observation of selected training days from each of the abovementioned courses complemented the desktop analysis and was accompanied by surveys of observed trainees and their instructional staff. Observations were conducted in a manner that avoided any interference with training and observed exposures to occupational risk factors for OLL were compared with estimated exposures from the desktop analysis, with the implications for true exposures of differences between the two sources of estimates critically considered. Surveys were anonymous and sought information about exposures to risk factors considered in the observations as well as trainees' sex, age, height, weight, BMI, fitness, OLL history, and injury history.

The JEM-OLL was designed to include occupational identifiers, descriptions of all full-time, entry-level ADF occupations, and details of exposures of personnel from the selected initial training programs to risk factors for OLL recognised by the RMA, as well as other occupational exposures of potential relevance.

Main findings: Desktop analysis, observations, and JEM-OLL

As a preface to the findings detailed below, it must be noted that the research team was requested by the DVA to identify projections of timeframes within which personnel in the selected occupations would be likely to reach RMA-specified threshold exposures to risk factors for OLL, assuming exposures continued following completion of initial training at the levels at which they were observed to occur during initial training, as our best current estimates of such timelines.

We acknowledge that this assumption regarding continued levels of occupational exposure may or may not be supported by future evidence but also note, in agreement with the DVA position, that, because initial training is specifically designed to prepare personnel for the occupational roles they will fulfil, it is also unlikely that most key exposures in qualified personnel will substantially reduce or change in type following initial training. In addition, where available, we have integrated evidence pertaining to exposures that occur subsequent to initial training, and such evidence, where available, so far supports our assumption that exposures will be maintained.

It should also be noted that the SoPs developed by the RMA sometimes provide different thresholds depending on whether a claim is considered against the SoPs based on

Balance-of-Probabilities scenarios or Reasonable-Hypothesis scenarios. In some instances, the thresholds under these two scenarios are the same, but, where they differ, those based on balance of probabilities are more stringent, or demanding, and are applied to all claimants who do not meet specific service criteria. These differences are reflected in some areas of the key findings below, and for general use in assessing claims, the findings under the Balance-of-Probabilities scenario should be primarily considered.

The main findings from the desktop analysis and observations, reflected in the JEM-OLL, are the following:

Air Force

- Air Force officers cumulatively lift substantial loads comprising individual loads weighing 20 kg or more during their initial training in the 17-week IOC. If this level of heavy lifting continues after completion of the IOC, officers will reach the RMA threshold for exposure to heavy lifting under its Reasonable-Hypothesis scenario by 7 years and 31 weeks following commencement of service.
- Airfield Defence Guard trainees repeatedly lift (as opposed to carry) loads of 20 kg or more during their initial training. If this level of lifting continues after completion of their initial training, trainees will reach the RMA cumulative threshold under its Reasonable-Hypothesis scenario for exposure to heavy lifting within 1 year and 34 weeks following commencement of service. Similarly, trainees will reach the RMA threshold under its Balance-of-Probabilities scenario for exposure to heavy lifting within 2 years and 20 weeks following commencement of service.
- Airfield Defence Guard trainees also carry (as opposed to lift) loads comprising individual loads of 20 kg or more for substantial numbers of hours during their initial training. If this level of heavy carrying continues after completion of their initial employment training, trainees will reach the RMA threshold under both its Reasonable Hypothesis and Balance-of-Probabilities scenarios for exposure to heavy load carrying within 5 years and 40 weeks following commencement of service.
- Air Force Medical Assistant trainees cumulatively lift substantial loads comprising individual loads weighing 20 kg or more during their initial training. If this level of heavy lifting continues after completion of their IET, trainees will reach the RMA threshold under its Reasonable-Hypothesis scenario for exposure to heavy lifting within 2 years and 4 weeks following commencement of service. Similarly, trainees will reach the RMA threshold under its Balance-of-Probabilities scenario for exposure to heavy lifting within 3 years and 6 weeks following commencement of service.
- Loadmaster trainees cumulatively lift substantial loads comprising individual loads weighing 20 kg or more during their initial training. Loadmaster trainees may reach the RMA threshold under its Reasonable-Hypothesis scenario for exposure to heavy lifting within 30 weeks following commencement of service (i.e., prior to completion of initial training). Similarly, trainees may reach the RMA threshold under its

Balance-of-Probabilities scenario for exposure to heavy lifting within 33 weeks following commencement of service (again within the period of initial training).

- Overall, the observations of Air Force initial training programs supported the findings and conclusions of the desktop analysis that are listed above, but the observations suggested that the desktop analysis findings were generally conservative and therefore actual exposures in those occupations would be at least as great as those identified above and in some cases may be higher.
- Loadmaster trainees were observed to ascend and descend many more stairs than initially estimated in the desktop analysis due to stairs traversed on both entering/leaving aircraft and within the aircraft during flights—the latter of which they traversed numerous times within each flight. Loadmaster instructors confirmed that this is a requirement of the role for qualified personnel on more days than not. On that basis, it is estimated that loadmaster trainees would reach the RMA threshold for exposure to this climbing stairs risk factor for OLL within 2 years and 34 weeks from date of enlistment under the Reasonable-Hypothesis scenario and within 5 years and 34 weeks under the RMA's Balance-of-Probabilities scenario.

Navy

- Navy officers cumulatively lift substantial loads comprising individual loads weighing 20 kg or more during their initial training in the 22-week New Entry Officer Course (NEOC). If this level of heavy lifting continues after completion of the NEOC, officers will reach the RMA threshold for exposure to heavy lifting under its Reasonable-Hypothesis scenario by 6 years and 1 week following enlistment, and under its Balance-of-Probabilities scenario by 9 years and 1 week following enlistment.
- Although exposure of Navy officers to climbing of stairs and ladder rungs during the NEOC was not high overall, during the few days they spent at sea they climbed well over 150 stairs or ladder rungs each day. Building on this finding, consultation with Navy subject matter experts regarding other ranks revealed that Navy personnel of *all* ranks climb well over 150 stairs or ladder rungs daily when posted to sea or to vessels situated 'alongside'.

  On this basis, all Navy personnel who spend half or more of their days at sea or alongside, or who are posted to sea or to a vessel alongside for more than one year (365 days) following completion of initial training would meet the RMA-set threshold for climbing stairs and ladder rungs under its Reasonable-Hypothesis scenario within 2 years of commencing the time posted to sea or alongside, with the exact time point depending on the proportion of days in the year that they spend at sea or alongside (e.g., 1 year if every day, and 2 years if half of all days were spent at sea or alongside) and the type of sea vessel. Under its Balance-of-Probabilities scenario, the timeframe would be 2.5–5 years after commencing the time posted to sea or alongside, assuming they remained at sea or alongside for such a time period.

- Overall the observations of Navy initial training programs supported the findings and conclusions of the desktop analysis that are listed above, but the observations suggested that the desktop analysis findings were generally conservative and therefore actual exposures in those occupations would be at least as great as those identified above and in some cases may be higher.
- Consistent with this conclusion is a finding from the observations regarding exposure to ascending and descending stairs in officer, boatswain's mate and marine technician trainees (but not in Maritime Logistics – Personnel Operations trainees), where, on more days than not, trainees were observed to ascend and descend many more stairs than estimated in the desktop analysis. The specific findings mean that the cumulative numbers of days estimated from the desktop analysis on which 150 or more stairs/rungs were climbed should be increased by an average of 2.5 days per week (one additional day for each 2-day period, assuming a 5-day working week).

  This adjustment would mean that, assuming exposure to climbing stairs and ladders remains at similar levels as those encountered during initial training, personnel from all of the selected Navy occupations except for Maritime Logistics – Personnel Operations would meet the RMA-specified threshold for number of days on which 150 stairs/rungs were climbed within 1 year and 47 weeks of enlistment under the Reasonable-Hypothesis scenario and within 4 years and 40 weeks of enlistment under the Balance-of-Probabilities scenario, whether they are posted to sea or not. However, they may still meet these thresholds sooner if posted to sea or to vessels situated alongside soon after completing initial training, as concluded from the desktop analyses above.

Army

- Army officers carry loads weighing 20 kg or more for many hours during their 18-month initial officer training. If these hours of exposure to carrying heavy loads continue after completion of initial officer training, officers will reach the RMA thresholds under both its Reasonable Hypothesis and Balance-of-Probabilities scenarios for cumulative hours of exposure to heavy carrying within 4 years and 37 weeks following commencement of service.
- Infantry trainees also carry loads weighing 20 kg or more for many hours during their initial training. If these hours of exposure to heavy carrying continue after completion of their initial employment training, Infantry trainees will reach the RMA threshold under both its Reasonable Hypothesis and Balance-of-Probabilities scenarios for cumulative hours of exposure to heavy load carrying within 4 years and 45 weeks following commencement of service.
- Army Driver Specialist trainees lift loads weighing 20 kg or more during their initial training. If these levels of heavy lifting continue after completion of their initial employment training, Army Driver Specialist trainees will reach the RMA threshold under its Reasonable-Hypothesis scenario for exposure to heavy lifting within 1 year

and 4 weeks following commencement of service. Similarly, Army Driver Specialist trainees will reach the RMA threshold under its Balance-of-Probabilities scenario for exposure to heavy lifting within 1 year and 32 weeks following commencement of service.

- Army medical assistant trainees also lift loads weighing 20kg or more during their initial training. If this level of heavy lifting continues after completion of their initial employment training, trainees will reach the RMA threshold under its Reasonable-Hypothesis scenario for exposure to heavy lifting within 1 year and 48 weeks following commencement of service. Similarly, trainees will reach the RMA threshold under its Balance-of-Probabilities scenario for exposure to heavy lifting within 2 years and 46 weeks following commencement of service.
- Overall, the observations of Army initial training programs supported the findings and conclusions of the desktop analysis that are listed above, but the observations suggested that the desktop analysis findings were generally conservative and therefore actual exposures in those occupations would be at least as great as those identified above and in some cases may be higher.
- The observations also revealed that Army officer cadets and Infantry trainees spent more time each day squatting or kneeling than the desktop analysis initially indicated. The specific findings during the observations suggest that these officer cadets and Infantry trainees spend one hour or more squatting or kneeling on more days than not in a typical month.

  On this basis, and assuming this rate of exposure continues at similar levels beyond initial training for Infantry trainees in particular (because officer training is 18 months in duration), it is likely that officer cadets and Infantry trainees would reach the RMA threshold for exposure to this kneeling/squatting risk factor for OLL within 1 year of enlistment, under the RMA's Reasonable-Hypothesis scenario. The time frame to reach this threshold under the RMA's Balance-of-Probabilities scenario would be within 2 years of enlistment.
- The observations further revealed that officer cadets and Infantry trainees lifted far more load than anticipated from the desktop analysis. On the basis of the findings from the observations, it is likely that officer cadets will reach the RMA threshold for exposure to the heavy lifting (>20kg loads) risk factor for OLL within 1 year of enlistment, under the RMA's Reasonable-Hypothesis scenario. The timeframe to reach this threshold under the RMA's Balance-of-Probabilities scenario would be within 18 months of enlistment. Both of these time frames fall within the duration of officer training. Again, on the basis of the observations, it is likely Infantry trainees will reach the RMA threshold for exposure to this heavy lifting risk factor for OLL within 1 year of enlistment, under the RMA's Reasonable-Hypothesis scenario.

  The timeframe to reach this threshold under the RMA's Balance-of-Probabilities scenario would likely be within 18 months of enlistment. Both of these estimates of timepoints are shorter than those originally estimated from the desktop analysis and consider the additional lifting observed during observations, the original estimates from the desktop analysis, and the likelihood that Infantry personnel will continue these levels of heavy lifting as qualified personnel given the arduous nature of their occupational role.

Historical Review

The historical review was designed to assess whether the physical demands of initial training in the ADF have changed significantly over preceding decades, affecting the exposure of personnel to variables that are known to increase their risk of developing OLL. In the historical review, we considered evidence from historical training program documentation, images of initial training, first-hand narrative accounts from personnel, published reports detailing training undertaken and exposures of interest, and other documentation, for example training manuals.

Data were sourced widely, including from published literature, the Australian War Memorial Research Centre, and subject-matter experts. However, reflecting the limited data available regarding military training in general and to meet with emerging impacts of physical training (PT) and sport, most of the historical review was focused on PT and sport undertaken during initial training, noting that military PT differs from that of self-selected physical exercise in that it is beyond the control of the individual to select when the training takes place, the exercises selected, and the work intensities which are closely monitored by instructors and staff during initial training.

Main findings

- Participation in both PT and sport constitutes an employment requirement for ADF personnel, and personnel are regularly assessed for fitness for service and deployment, so their continued employment depends on regular engagement in PT. Both PT and sport are therefore a constant feature of service in the ADF, and this has been the case for at least 60 years.
- The main types of PT have changed little over 60 years, but the volume of PT has decreased. The intensity of training has increased in some areas and training has become more controlled. Overall, this means that estimates of occupational exposure to physical activities that increase the risk of OLL based on current initial training programs will be conservative estimates of the exposures experienced by ADF personnel in previous decades.
- Sport participation in the ADF has changed little over at least the last 60 years. However, in more recent decades sport has been removed from recruit training contexts in order to reduce injury risks and increase training completion rates. It remains a feature of other stages of initial training (e.g., initial employment training and officer training) and operational unit contexts. The removal of sport from recruit training in recent decades means that estimates of occupational exposures to physical activities that increase the risk of OLL based on current initial training programs will

be conservative estimates of the exposure experienced by ADF personnel who undertook recruit training in previous decades.

- Historically, sport (47%) and PT (24%) have contributed around 70% of working days lost due to injuries affecting ADF personnel.
- Lower-limb injuries have always been an important type of occupational exposure for ADF personnel, and these injuries substantially increase the risk of developing OLL.
- Historically, at least half and possibly more (based on findings of the productivity commission regarding availability of injury records to support claims to the DVA) of all injuries experienced by ADF personnel are likely to have gone unreported to defence healthcare providers and an estimated 80–90% or more of those reported to health care providers have not been reported on defence work health and safety incident reporting systems. Underreporting and delayed reporting have affected the visibility of the true rates of injuries in ADF personnel.
- Our best current estimates, based on construction of an estimated ADF injury pyramid, are that the historical and sustained injury incidence rates within the ADF are in the vicinity of 393 injuries per 100 full-time equivalent years of service, with higher rates during initial training and lower rates for qualified personnel in the Air Force and Navy than in the Army.
- Overall, available historical accounts of recorded injury rates observed in recruit training of Army, Navy, and Air Force, and in officer cadets from all three services undertaking training at the Australian Defence Force Academy (ADFA), suggest that lower-limb injury rates in recruit training and officer cadet training have been similar across the three services and consistently high for 40 years—most likely between 420 and 460 lower-limb injuries for every 100 years of full-time equivalent training, once the ADF injury pyramid and associated phenomena of under-reporting and delayed reporting of injuries are considered. Furthermore, it appears that 34–44% of these injuries have been acute injuries that have affected joints of the lower limbs. Notably, exposure to lower-limb injuries is a high risk factor for development of OLL and is recognised by the RMA as such in its SoPs for OLL. Therefore, these findings are highly relevant to the current project and are further discussed in this light in the section that follows.

Injury as an Important Occupational Risk Factor for OLL in ADF Personnel

Building on the historical review of ADF training injury rates and patterns discussed above, the research team completed a review of the occupational exposures of ADF personnel to trauma affecting lower-limb joints because this constitutes another recognised risk factor for OLL. Findings of this review indicate that lower-limb joint injuries represent an important risk factor for development of OLL in all ADF personnel.

It is clear from the review findings that exposure to this risk factor begins very early in a person's military career and it is likely that within 2 years from date of enlistment nearly all ADF personnel will have experienced a significant injury to a lower-limb joint that will increase their risk of developing OLL and result in them meeting one of the injury thresholds specified by the RMA in its SoPs for OLL. This is so even when the likelihood that some personnel will account for more than one injury is taken into account. In all three services, many personnel (we would estimate at least 30%) will have met one of these thresholds within the period of recruit training, initial officer training, or first 3 months of training at ADFA, and many more (we would estimate another 25–30%) will have met one of the injury thresholds within 6 months of enlistment as they continue with subsequent initial training and increase their participation in ADF sport.

Furthermore, recent research has indicated that a history of prior foot or ankle symptoms in the same or opposite leg can increase the risk of OA developing in a knee joint, and therefore injuries do not necessarily have to have affected the joint exhibiting osteoarthritis for a contribution to that osteoarthritis to have come from the prior injuries in the lower limb. Lower levels of aerobic fitness and greater age have been demonstrated to increase injury risk in trainees undertaking initial training in the ADF.

Survey Findings

A total of 271 trainees who were observed in initial training, and 18 staff members instructing or supervising that training, responded to anonymous surveys. These surveys included questions about the observed training and related exposures and, in the trainee questionnaire, questions about sex, age, height, weight, fitness, history of OLL, and injury history.

Although it is unlikely that the survey respondents were representative of the underlying populations, several findings of interest were noted:

- Fifty-six percent of the trainee respondents had enlisted within 4 weeks of survey completion, and among these trainees the incidence of reported lower-limb fractures, foot injuries, ankle injuries, and knee injuries equated to 419 injuries of these relevant types (for OLL) per 100 full-time equivalent years of service. Notably, 62% of injuries reported by these early-stage trainees prevented them from playing sport, exercising, or working for 7 or more days, indicating these were substantial injuries. These figures support the injury incidence rates discussed in the historical review and in the discussion of the section concerned with injury as an important occupational risk factor for OLL in ADF personnel.
- None of the trainee respondents (90% of whom were aged 30 years or younger) reported a previous diagnosis of OLL. This is not surprising given known rates of OLL in military personnel in this age group and the relatively small number of respondents.

- Staff respondents across the various initial training programs indicated that 90% of the observed training followed the planned programming for the respective sessions, with a minimum of 60% and maximum of 100% being estimated by staff for specific programmed days across courses. This finding suggests that ADF initial training programs are generally well regulated and standardised in their implementation, with staff being careful to follow planned activities closely where possible.

Analysis of Osteoarthritis Claims Assessed by the DVA 1994–2018

There were 85,765 claims for OA arising from ADF service personnel submitted and assessed by DVA in the years 1994–2018, with most assessed under the Veterans' Entitlements Act (VEA) 1986. Estimates indicate an average of 75 claims were submitted each year for every 1,000 Army personnel, 54 for every 1,000 Air Force personnel, and 40 for every 1,000 Navy personnel, giving ratios of submitted claims of 1.88 Army: 1.35 Air Force: 1.00 Navy. OA claims rates steadily reduced over the study period and in later years were approximately half of what they had been in the early years of the study period. Women were underrepresented in the OA claims arising from ADF service and submitted to DVA, with estimates indicating an average of 50 claims submitted each year for every 1,000 male ADF personnel and 21 for every 1,000 female personnel, giving a male:female ratio for submitted OA claims of 2.4:1.0.

Overall, 54% of OA claims arising from ADF service were accepted by the DVA, with the proportion accepted increasing from around 25% of claims in early years of the study period to around 80% in later years, and more accepted in those latter years under the Military Rehabilitation and Compensation Act (MRCA) 2004 than under the VEA or the Safety, Rehabilitation and Compensation Act (SRCA) 1988.

Rates of OA claims acceptance by DVA were similar across the Navy, Air Force, and Army, but slightly lower for female claimants (60%) than for male claimants (67%). Estimates indicate an average of 41 claims accepted by DVA each year for every 1,000 Army personnel, 27 for every 1,000 Air Force personnel and 23 for every 1,000 Navy personnel, giving ratios of accepted OA claims of 1.78 Army: 1.17 Air Force: 1.00 Navy, presumably reflecting the relative risks of OA arising from employment in each of these services. Across the ADF as a whole, the estimated average rate of OA claims accepted by DVA was 33 for every 1,000 personnel. The average age of claimants with OA claims accepted by DVA was 62 years.

Women were also underrepresented in the OA claims arising from ADF service and accepted by DVA, with estimates indicating an average of 38 OA claims accepted by DVA each year for every 1,000 male ADF personnel and 15 for every 1,000 female personnel, giving a male:female ratio for accepted OA claims of 2.5:1.0, or 2.4:1.0 after adjustment for the lower acceptance rate for claims submitted by females when compared with claims submitted by males. Again, this ratio presumably reflects the relative risks of OA arising from ADF service for each gender. However, it should be noted that long lag times (21 years, commonly) between end of service and submission of an OA claim means that the claims in the study dataset would have mostly related to periods of service that preceded opening of ADF combat roles to women, and this may have contributed to the estimated gender difference in historical risk of ADF personnel developing OA.

Eighty percent of accepted claims for OA arising from ADF service related to OA of the knee (55.4%), hip (15.3%), or ankle (9.1%). The proportions of accepted claims relating to these joints were similar across the ADF and between genders. However, a higher proportion of accepted claims from women than from men related to OA affecting the sacro-iliac joints (3.5 times higher in women) or patella-femoral joints (3 times higher in women).

The average age of claimants with accepted claims was 62 (range 17–100) years. The average age of claimants with accepted OA claims varied widely depending on the joint affected, but the average age for those with claims accepted for knee, hip, or ankle OA was in the vicinity of 60–70 years. Claims for OA submitted by younger claimants were statistically more frequently accepted (80%) than were claims from older claimants (as low as 40%), although this trend plateaued and began to reverse from age 70.

The average length of service of OA claimants with accepted claims was 11 years, and approximately half of all accepted OA claims arose from ADF service of 6 or fewer years. In accepted claims, the average length of service varied between 4 and 16 years for the different joints affected by OA. Length of service was positively, and significantly, correlated with likelihood of acceptance of a claim, with claimants who had 1–4 years of service having only a 40% chance of having their claim accepted, compared with around 70% for those who had served for 20 years or more. These findings are consistent with the understanding that these personnel would have been exposed for long periods of service to heightened rates of exposure to factors that increase their risks of developing OA, so signs and symptoms (and thus diagnosis) of OA may have occurred earlier in their lives (and often within the span of their service life) than for those who served for shorter periods.

The average lag time from end date of service to effective date for an accepted claim for OA was 30 years (standard deviation 23 years). However, the effective date for 10% of claimants with accepted OA claims fell within their period of military service. The average lag time varied between 5 and 58 years and was related to the joint affected by OA. Lag time was negatively correlated with likelihood of acceptance of a claim, with claimants who had an effective date of their OA claim that preceded their exit from the ADF by 0–4 years having the highest acceptance rate of around 80%, and the acceptance rate dropping to around 50% for those whose effective OA claim date was 25 years or more after the date they left the ADF.

This finding may be due to difficulties that people with longer lag times had in convincing the DVA assessor or gathering the necessary evidence to convince the assessor that their OA was related to their time in the ADF. It is likely that this negative correlation between lag time and acceptance likelihood largely explains the findings reported above, indicating that claims for OA submitted at a younger age (i.e., soon after leaving the ADF or even prior to leaving) were more likely to be accepted than were claims submitted at an older age (i.e., perhaps many years after leaving the ADF).

Summary

With regard to the research questions that guided this program of research, the findings suggest that:

- The degree to which initial training undertaken by full-time personnel within each of the three services meets the threshold exposure levels for OLL specified in the RMA's SoPs varies, with different thresholds (e.g., thresholds for exposure to kneeling/squatting, stairs and ladder rungs, or heavy lifting) being met at different timepoints within different services and occupations, with the only consistent variable across all three services and all occupations being the high rate of injuries arising through participation in PT, sport, and, to a lesser extent, other types of training.
- Although individual variables such as height, weight, age, physical fitness, exercise history, and sex may influence the risk of personnel developing OLL and their estimated levels of exposure to occupational variables that are associated with development of OLL during military service, the research in this area is conflicting, and other variables, notably history of personal injuries, have greater impacts on risk of developing OLL than these characteristics of individuals.
- Based on the historical review, which was particularly focused on PT and sport as leading causes of injury and associated OA, the levels of exposure to variables that are associated with development of OLL during initial training of full-time ADF personnel are likely to have been similar, if not greater, for personnel who undertook initial training in decades stretching back over at least the last 60 years. The findings of the analysis of claims for osteoarthritis assessed by DVA over the period 1994–2018 support this conclusion, given that claims rates for OA reduced over that 25-year period and the lag time between end of service in the ADF and submission of a claim for OA was, on average, 30 years. On that basis, claims for OLL considered by DVA in 1994 would typically have arisen from service in the ADF prior to 1964 (i.e., more than 55 years ago), and claims considered by the DVA in subsequent years would similarly have arisen from service in the ADF that typically occurred three decades earlier.

Conclusion

ADF service is physically demanding, and personnel perform arduous tasks that in many ways are different from activities associated with professional sports, farming, trades, and other physically demanding occupations. This increases exposure to risk factors for OLL among ADF personnel in unrecognised ways.

Notwithstanding the instances where RMA thresholds have been met, exposure to service-related lower-limb joint trauma (as well as other lower-limb injuries) is one of the greatest risk factors for OLL in ADF personnel, and the most prevalent. All ADF personnel are most likely to have been exposed to a lower-limb injury that would increase risk of developing OLL within 9 months of service in the Army, 12 months in the Air Force, and 15 months in the Navy.

Finally, overall, the physical demands of ADF initial training have changed little across preceding decades. Exposures to risk factors for OLL measured today apply also to those preceding decades. This conclusion is supported by consistently high rates of claims for OLL submitted during the last 25 years—claims that arose from ADF service that occurred in periods stretching back to the 1960s, and earlier.

PROJECT TEAM

Tactical Research Unit, Bond University

DR ROBIN ORR

Lead, Tactical Research Unit

Rob Orr joined the Australian Army in 1989 as an infantry soldier before transferring to the Defence Force Physical Training Instructor (PTI) stream. Serving for 10 years in this stream, he designed, developed, instructed in, and audited physical training programs for military personnel and fellow PTIs from both Australian and foreign defence forces. He transferred to the military physiotherapy stream following completion of his master's degree in physiotherapy and was responsible for the clinical rehabilitation of Defence members and project management of physical conditioning optimisation reviews.

Serving as the human performance officer for Special Operations before joining the team at Bond University in 2012 as both a researcher and educator, he continues to serve in the Army Reserve as a human performance officer for the Australian Army.

Lead of the Tactical Research Unit at Bond University and with a doctoral studies in military load carriage, Dr Orr's fields of research include injury prevention and tactical strength and conditioning of tactical personnel (military, police, firefighter / first responder) spanning initial training to specialist selection. Dr Orr has won awards for research outcomes and publications. He has presented his work both nationally and internationally and has been invited to present keynote addresses at internationally renowned research facilities and congresses.

DR BENJAMIN SCHRAM

Research Coordinator, Tactical Research Unit

Ben Schram has experience in officer training with the Army Reserve to complement his exercise science and doctoral degrees, enabling unique insight into the demands of tactical personnel. He has worked as an exercise physiologist, clinical physiotherapist, and assistant professor at Bond University where he completed his PhD. He is extensively involved in most aspects of the Bond University Doctor of Physiotherapy program, including musculoskeletal and maximising human potential physiotherapy subjects, along with research supervision.

As part of the Tactical Research Unit at Bond University, Dr Schram assists in conducting research in the tactical field and the management of research assistants assigned to tactical research tasks. He has presented his research both nationally and internationally and continues to be extensively involved with investigation of the unique occupational demands of tactical personnel.

MR SHANE IRVING

Research Assistant, Tactical Research Unit

Shane Irving provides research assistant support to the project based on his understanding of and extensive experience in tactical contexts. He has been a senior sergeant in the Australian Federal Police (AFP), which he joined in 2005 following specialist policing service with Queensland Police from 1994, where he was a member of the Specialist Emergency Response Team (SERT).

Shane has been involved in many domestic operational tasks, including the Sydney 2000 Olympics and Commonwealth Heads of Government Meetings, G20 summit. Having served as the officer in charge, Counter Terrorism Response, Specialist Response Group of the AFP, Shane is currently undertaking research with the Tactical Research Unit at Bond University in the area of tactical strength and conditioning for specialist policing teams. He assisted with data collection in ADF units for the current project, as well as in other aspects of the research.

MRS NICOLE POPE

Research Project Manager & Research Assistant, Tactical Research Unit

Nicole Pope is the project manager for the current project and has considerable experience in management and support of projects in ADF and other contexts. She was assistant to the coordinator of the Defence Injury Prevention Program for several years and was responsible for coordinating much of the roll-out of the program's injury surveillance system and providing troubleshooting support to ADF units around Australia for this system.

In addition, Nicole assisted in project management for the implementation of the Defence Injury Prevention Program as a whole, and she has since played quality management, research management, and project management roles in a range of other contexts, as well as teaching project management for TAFE QLD and other vocational training organisations. Nicole also provided research assistant support to the project based on her experience in providing research assistance and management in a range of contexts in the past, including the Tactical Research Unit at Bond University, a cancer care centre, and the Army Recruit Training Centre.

School of Community Health, Charles Sturt University

PROFESSOR RODNEY POPE

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Rod Pope is a senior researcher and analyst in tactical research based at Charles Sturt University. He is currently the professor of physiotherapy at that university and leads tactical research there, linked with the Tactical Research Unit at Bond University, which he established with Rob Orr. In the 16-year period 1990–2006, Rod provided clinical physiotherapy, rehabilitation, and injury prevention services at the Australian Army Recruit Training Centre before establishing and leading the Australian Defence Injury Prevention Program.

As part of this work, and more recently in his university roles, Rod has conducted and supervised wide-ranging research and consultancy projects on preventing injuries and enhancing performance during physical activity in a variety of tactical training and operational contexts, including law enforcement. Rod plays a strong role in overseeing the research design and analysis elements of tactical research projects and has published and presented widely in this field, having generated around 120 published research reports and secured over 2.5 million dollars in research funding over the years.

1. PURPOSE

The summary and technical reports comprising this document report the background, scope, methods, and findings for the three services of the Australian Defence Force (Royal Australian Air Force, Royal Australian Navy, and the Australian Regular Army) of the Department of Veterans Affairs-sponsored research project, *ARP1706 Measuring Occupational Exposures to Osteoarthritis in the Lower Limb in ADF Job Categories*.

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2. BACKGROUND

2.1 Introduction

Osteoarthritis (OA) is the most common form of arthritis and one of the most common disorders affecting the joints [1]. It manifests with pain, aching, stiffness, functional limitation, and progressive disability [2]. The prevalence of OA is rising, thought to be due to increasingly sedentary lifestyles and suboptimal body composition [3]. Among all musculoskeletal diseases, OA affecting the hip and knee is one of the greatest contributors to global disability [1], with an estimated 20% of people over 60 years of age having already undergone, or being in need of, a joint replacement due to severe pain [4].

Osteoarthritis is complicated by the fact that it can be defined clinically, radiographically, or pathologically [3], and imaging findings do not correlate well with symptoms [5]. The WHO defines OA radiographically as a joint presenting with osteophyte formation, joint space narrowing, sclerosis, and cysts [6]. Clinical diagnosis of OA is based on both the history and physical examination, typically considering components of the American College of Rheumatology classification, including morning stiffness, crepitus, and bony enlargement [5].

Known risk factors for the development of OA include older age, female gender, being overweight or obese, previous injury, involvement in competitive sports, and occupational factors [4, 7, 8]. Occupational factors that have been associated with the development of OA include physically demanding occupational tasks, heavy lifting, kneeling, squatting, crawling, and occupational trauma [4, 9]. Given the physically demanding nature of military service, the higher rates of acute injuries that military personnel experience when compared with the general population [10], and military requirements to carry heavy loads [8], military personnel are typically at greater risk of developing OA than are members of the general population [11]. Recent reviews have shown a disproportionate incidence of OA in military personnel when compared with the general population, and this appears to be rising [8, 11], with the knee being the most commonly affected joint in military personnel [8, 12]. It is not surprising, therefore, that recent research suggests that one in five military personnel who have suffered a knee injury progresses to radiographic OA before the age of 30 [13].

One of the most common causes of discharge from military service for over a decade has been issues arising from OA [14]. A few studies are beginning to appear in the scientific literature regarding the sources of pain among military personnel. The research has shown that prolonged mounted patrolling in Afghanistan resulted in up to 33% of soldiers reporting knee pain, with significant associations between the occurrence of knee pain and the amount of time the soldiers spent patrolling in vehicles each week [15]. One of the main sources of acute pain in personnel on naval vessels is OA, with knees the second most commonly reported body site of injury [16]. A potential source of knee symptoms among naval personnel could be the need to traverse naval ladders, which has been shown to increase knee flexion angle and expose the knee joint to forces equal to as much as 6.6 times body weight [17].

Other risk factors associated with the development of OA in the military context appear to include increased age, ground-based service, and higher rank [8, 12]. Given the length of service required to reach higher ranks and the greater exposure to physically demanding tasks that these additional years of service are likely to entail, length of service is also likely to be positively associated with risk of OA. Ground-based service often involves navigating difficult terrain under load, often in harsh and threatening contexts, potentially further contributing to risk of developing OA.

Figures from the US military indicate that across all service members in active duty in that country, incidence rates for OA are approximately 7.86 reported cases per 1,000 person-years, with higher incidence rates reported in Army (9.70 per 1,000 person-years) than Air Force (8.06 per 1,000 person-years), Marines (4.71 per 1,000 person-years), and Navy (6.72 per 1000 person-years) [12].

Given the magnitude of this problem, the burden of OA has become a substantial contributor to the compensation caseload of military compensation schemes such as those administered by the Australian government's Department of Veterans' Affairs and related government entities, collectively known as the DVA. The 2017–2018 annual reports from the DVA (Australian Government [18], p. 227) indicate that OA affecting the lower limbs is the second most common reason for claims submitted by serving or formerly serving personnel under the Military Rehabilitation and Compensation Act 2004, with 94% of these claims ultimately being accepted.

The Australian government's Repatriation Medical Authority (RMA) has developed a Statements-of-Principles (SoP) based on scientific medical evidence indicating the types and levels of exposures that must be established as being present in order to link the development of osteoarthritis to previous military service.[1] These types and levels of exposures include, for example, 'having trauma to the affected joint before the clinical onset of osteoarthritis in that joint', and 'carrying loads of at least 20 kilograms while bearing weight through the affected joint to a cumulative total of at least 3,800 hours within any ten year period before the clinical onset of osteoarthritis in that joint', each occurring in the course of military service. Full lists can be found at the footnoted hyperlink.

Currently, each claim for osteoarthritis submitted to DVA is considered on its merits in a case-by-case review based on the weight of evidence provided by individual claimants relative to the SoP requirements. These reviews are time consuming and can provide

[1] This SoP may be found at http://www.rma.gov.au/sops/condition/osteoarthritis

different outcomes, in part due to variation in the evidence documented and available for each individual. Military personnel and veterans are currently faced with having to provide extensive evidence to demonstrate the relationships between development of OA and specific occupational exposures within their military service, much of which can be challenging to obtain and compile at the time of submitting a claim. These challenges can lead to adversarial interactions between military personnel or veterans and government agencies such as the DVA. Furthermore, as noted above, the DVA annual reports indicate that, under the Military Rehabilitation and Compensation Act 2004, the majority of claims for osteoarthritis (94% in 2017–2018; Australian Government [18], p. 227) are ultimately accepted.

Ideally, reasonable claims from military personnel and veterans for compensation and healthcare costs relating to osteoarthritis in the lower limb should be routinely accepted without the need for claimants to provide detailed evidence of particular exposures if their service record indicates their service within their specific military occupations for the periods of time they served would have given rise to exposures that could reasonably be expected to have contributed substantially to the development of their OA.

However, the current lack of any research that has examined, by specific military occupation, the levels of exposure of military personnel to activities, actions, movements, loads, incidents, and other variables (for example, vibration) that are known to increase their risk of developing osteoarthritis in joints of the lower limb impedes implementation of a simple claims system for cases of OA affecting the lower limb. In addition, the patterns of claims to DVA for OA arising from service have not previously been described, so we have not been able to identify, for example, typical claim rates by service, age, gender, or years of service.

This knowledge, if available to military and veterans' claims authorities such as the DVA, could relieve individual military personnel and veterans of the burden of having to provide evidence of specific, relevant exposures within their military occupations because those exposures would be known to the DVA for the specific occupations in which they are recorded as having served and for the specific timeframes that personnel served within those occupations. In addition, better knowledge of historical patterns of claims would inform the DVA's advances in simplifying claims processes by, for example, demonstrating likelihoods with which individuals with particular demographics as risk factors for osteoarthritis (for example, years of service) would normally submit a claim for osteoarthritis.

2.2 Purpose, Scope, and Key Elements of the Project

With the above in mind, the DVA-sponsored research project, *ARP1706 Measuring occupational exposures to osteoarthritis in the lower limb in ADF job categories,* was instigated by the DVA. The intent of the project was to address the need of DVA to better understand and quantify the cumulative exposures of full-time Australian Defence Force (ADF) personnel across all occupation titles to activities that are known to contribute to development of osteoarthritis of the lower limb (OLL). These cumulative exposures can then be assessed against the predetermined threshold levels of exposure that must be established as having occurred to enable DVA to link a diagnosis of OLL with the military service of a veteran from a particular occupation. Under its Veteran Centric Reform initiative, the DVA may subsequently be able to use this information to simplify the claims process for many veterans seeking a determination from the DVA regarding the development of OLL as a result of their military service.[2]

Although the predetermined threshold levels of exposure for OLL are detailed in the SoPs prepared by the RMA, the SoPs currently specify exposure thresholds without any adjustment for a range of demographic and other factors that may also affect the risk of personnel developing OLL. A further purpose of the project is therefore to identify and consider the impacts of such demographic and other factors on the threshold levels of exposure associated with development of OLL in individuals and on the levels of exposure individuals experience to specific occupational risk factors for OLL.

The project was limited in scope to examining exposures that occur during the initial training of full-time ADF personnel. Initial training programs were selected for investigation because it is within these initial training programs, which all ADF personnel must undertake, that exposure to military factors associated with the development of OA commences. Because the accumulation of exposure to OA developmental factors commences during initial training, cumulative exposure accrued during later phases of active military service cannot be estimated without first considering exposure during initial training programs.

The project is designed to address the following specific research questions:

- To what extent does initial training undertaken by full-time personnel within each of the three services meet the exposure thresholds for OLL, including thresholds of exposure to joint trauma that may lead to OLL, set out by the RMA?

- What factors (such as height, weight, age, physical fitness, exercise history, and sex of individuals) increase the risk of personnel developing OLL and impact on their estimated levels of exposure to occupational factors that are associated with development of OLL (including joint trauma), during military service?

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[2] Information about the Veteran Centric Reform initiative may be found at the following site: https://www.dva.gov.au/about-dva/publications/vetaffairs/vol-33-no3-spring-2017/plan-veteran-centric-reform

- To what extent are levels of exposure to factors that are associated with development of OLL during initial training of full-time ADF personnel likely to have changed over the preceding decades?

To answer these questions, the project has encompassed six key elements:

1. A desktop analysis of selected initial training programs from each service to estimate the exposure of personnel, during initial training, to factors that are known to increase their risk of developing OLL.

2. Direct observation and surveys of personnel undertaking the selected initial training programs required of full-time personnel within each service, designed to confirm and/or examine the types and extent of any variations in observation findings from the findings of the desktop analysis, and to further inform construction of the job exposure matrix (JEM) for OLL (see below).

3. Construction of a job exposure matrix (JEM) for OLL that would incorporate descriptive information regarding each full-time occupation title from each service, details of the initial training courses undertaken by personnel from each of those occupation titles, and details of the exposure of personnel from selected occupations to factors that are known to increase the risk of developing OLL during initial training—this gleaned from Elements 1 and 2, above.

4. An historical review to assess the extent to which the exposure of full-time personnel from each service during initial training to occupational factors that are known to increase the risk of OLL may have changed over the last 60 years.

5. An analysis of OA claims data 1994–2018, to assess the rates and patterns of OA claims received and assessed by DVA in that time period.

6. Several reviews of previous research, including an umbrella review, a critical review with meta-analysis, and additional reviews of key literature, to provide an update of the available research evidence pertaining to the influence of occupational exposure and individual factors about the risk of military personnel and others in physically demanding occupations developing OLL, and the influences of individual factors on the exposures of military and other physically active personnel to occupational risk factors for OLL. In this component of the research, individual factors included height, weight, age, physical fitness, exercise history, and sex of the individual.

As part of Element 6 above, the project team undertook a review of the occupational exposure of ADF personnel to lower-limb injuries and trauma affecting lower-limb joints, with the latter constituting a further factor recognised by the RMA in its SoPs for OLL as increasing the risk of ADF personnel developing OA in the lower limbs.

The methods and key findings for Air Force, Navy, and Army of all of the six project elements are reported in the subsequent chapters of this document.

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3. RISK FACTORS FOR DEVELOPMENT OF LOWER-LIMB OSTEOARTHRITIS IN PHYSICALLY DEMANDING OCCUPATIONS SUCH AS THE MILITARY: AN UMBRELLA REVIEW

3.1 Introduction

Osteoarthritis (OA) is one of the most common disorders that affect the joints of the body and is the most common form of arthritis [1]. It is manifested by joint pain, aching, stiffness, functional limitation, and progressive disability [2]. The diagnosis of OA is based on clinical and radiographic criteria [3]. Clinical diagnosis of OA is made through both the history and physical examination of the presenting person, typically considering components of the American College of Rheumatology classification of joint pain and ensuring that at least three of the following six features are present: age > 50 years, morning stiffness lasting greater than 30 minutes, crepitus in the joint, bony tenderness, bony enlargement, and no palpable warmth emanating from the joint [4].

Radiographically, the World Health Organisation (WHO) defines OA as a joint presenting with osteophyte formation, joint space narrowing, sclerosis, and cysts [5]. These radiographic changes are typically graded using a scheme devised by Kellgren and Lawrence [6], referred to as the K/L grading system, in which a score over two (Grade 2) is indicative of OA. A Grade Two is assigned where there is 50–75% joint space narrowing without secondary features of osteophytes and subchondral sclerosis [7], although research suggests that wording of the K/L grading system is inexact and open to interpretation [8]. However, and in line with some other pathological conditions, imaging findings do not correlate well with symptoms [4]. For example, Anderson and Felson [9] found that individuals with what was considered to be ‘moderate’ knee OA on imaging were symptomatic in only 40% of cases, whereas those considered to have ‘severe’ OA based on imaging results were symptomatic in only 60% of cases.

The prevalence of OA is increasing, and this is thought to be at least in part due to increasing rates of overweight and obesity associated with increasingly sedentary lifestyles [3]. OA of the hip and knee constitute one of the greatest contributors to global disability from musculoskeletal diseases [1], with an estimated 20% of individuals over 60 years of age having already undergone, or seeking, a hip or knee joint replacement due to severe pain from OA [10]. Reported risk factors for the development of OA in the general population include older age, female gender, being overweight or obese, previous injury, involvement in competitive sports, and high levels of exposure to occupational factors that load, or may cause trauma to, joints [10–13]. Given the physically demanding nature of military service, the common military requirement to carry heavy loads [11, 14], and the higher rates of acute injury observed in military populations when compared with the general population [15], it could be expected that military personnel will be at greater risk of developing OA than are members of general public. Recent reviews [11, 16–18] have indicated a disproportionately high incidence of OA, which is rising, among military service members when compared with the general population.

The knee is the most commonly affected joint in military personnel [11, 19] and issues arising from OA have presented as the most common or second most common (depending on the year) cause of discharge from United States (US) military service for over a decade [20]. US figures indicate that across all active duty service members, incidence rates for OA are approximately 7.9 cases per 1,000 person-years [19], with higher incidence rates in the Army (9.9 per 1,000 person-years) than in the Air Force (7.0 per 1,000 person-years), Navy (4.6 per 1,000 person-years), and Marine Corps (4.0 per 1,000 person-years) [16].

Given the extent to which OA affects military personnel, the follow-on effects for medical discharge and physical readiness, and the preponderance of lower-limb joints affected by OA in military personnel, the aim of the current narrative umbrella review was to identify, critically appraise, and synthesise findings from previous literature reviews where the researchers examined risk factors for development of OA in the lower limb (OLL) in physically demanding occupations to inform future research, prevention, and management of OLL in the military context.

3.2 Method

A systematic search for published literature reviews in the PubMed, Cumulative Index of Nursing and Allied Health Literature (CINAHL), and Elton B Stevens Company (EBSCO) databases was conducted (November 2018) using dedicated but comparable search terms for each database. See Table 3.1. Search results were screened by title to remove reviews that were clearly not relevant. For the reviews remaining, abstracts and full texts were subsequently obtained and subjected to eligibility appraisal using dedicated inclusion criteria. Articles were included if they:

a. were a literature review (either narrative or systematic),
b. were published within the preceding 15 years,
c. were written in English,
d. were reviews of studies involving human participants,
e. had been subjected to peer review, and
f. involved an investigation of risk factors for development of OLL in people engaged in physically demanding occupations.

Table 3.1: Databases, search terms, and filters used in literature search.

Database	Search terms	Filters
PubMed	("arthritis"[Title/Abstract] OR "osteoarthritis"[Title/Abstract]) AND ("ankle"[Title/Abstract] OR "knee"[Title/Abstract] OR "hip"[Title/Abstract] OR "foot"[Title/Abstract] OR "lower limb"Title/Abstract]) AND ("risk"[Title/Abstract] OR "prevalence"[Title/Abstract] OR "cause"[Title/Abstract])	Full text, 2003–2018, in English, on humans, reviews
CINAHL	(AB) Arthritis OR osteoarthritis AND (AB) ankle OR knee OR hip OR foot OR lower limb AND (AB) risk OR prevalence OR cause	Human, peer reviewed, from 2003, in English, reviews
EBSCO	Arthritis OR osteoarthritis AND ankle OR knee OR hip OR foot OR lower limb AND risk OR prevalence OR cause	Human, peer reviewed, from 2003, in English.

The methodological quality of the included reviews was critically appraised using A MeaSurement Tool to Assess systematic Reviews (AMSTAR) 2 [1]. The AMSTAR 2 is a 16-question instrument for assessing the methodological quality of systematic reviews of both randomised and nonrandomised studies. The instrument is not designed to give an overall score, but, rather, an overall rating of the level of confidence in the results of a review (i.e., critically low, low, moderate, or high). To minimise scoring bias, two raters independently (BS & EC) scored each review on the AMSTAR 2. To determine the final score, discrepancies in scoring were discussed and, in most cases, a final score was determined by consensus. When consensus in score differences could not be obtained, a third author (RO) adjudicated to establish a final score. Given that the AMSTAR 2 was designed for systematic reviews, narrative reviews were not rated.

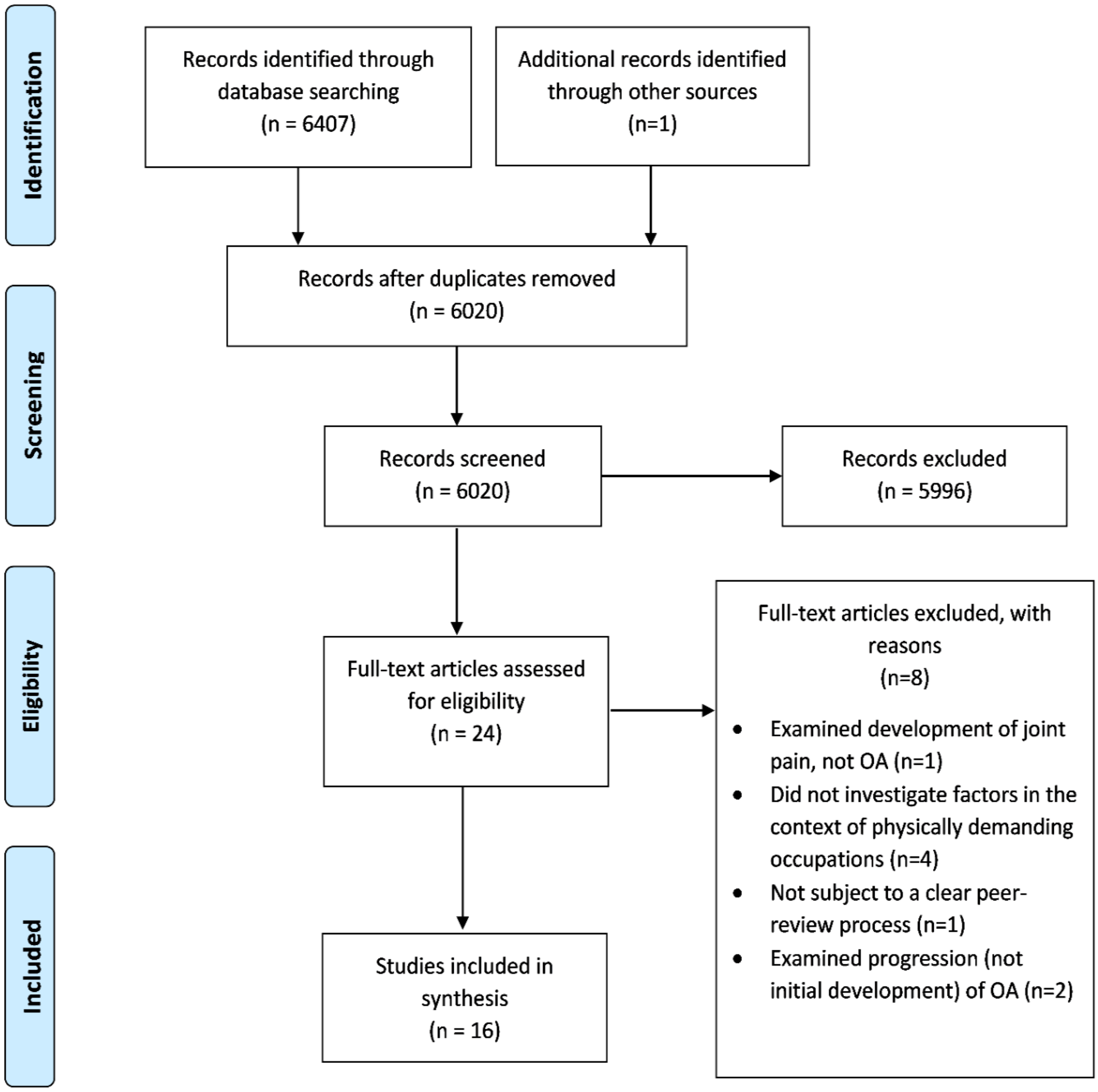
The main findings of the reviews of relevance to the aims of this umbrella review were extracted, summarised in tabular form, and synthesised using a structured, narrative synthesis approach. Types of data extracted from the reviews included author and year, type of review, number of studies included, the focus of the review, and the main findings of the review. Findings were weighted in the narrative synthesis based on the methodological quality of each source.

3.3 Results

3.3.1 Search, screening, and selection outcomes

From an initial 6,408 identified articles, 388 duplicates were removed along with an additional 6,004 that did not meet the eligibility criteria for inclusion, resulting in 16 reviews being retained for analysis. See Figure 3.1.

Figure 3.1: PRISMA diagram showing results of the search, screening and selection processes for the umbrella review.



The main findings from these 16 reviews are summarised in Table 3.2. Fourteen of the reviews were systematic reviews; the remaining two [22, 23] were narrative reviews. Seven reviews [22, 24–29] provided findings for knee OA and were published between 2005 [26] and 2014 [24], with the studies included in those reviews published between 1952 and 2011. Four reviews [30–33] provided findings for hip OA and were published between 2008 [31] and 2018 [32], with the studies included in those reviews published between 1985 and 2014. Three reviews [10, 12, 34] provided findings for both knee and hip OA and were published between 2006 [34] and 2013 [12], with included studies published between 1987 and 2011.

Table 3.2: Eligible publications and key extracted data.[a]

Author(s), Year	Review type; number of included studies, years of publication of included studies	Types of studies included	Focus	Key findings	Methodological rating (AMSTAR 2)
McWilliams et al., 2011 [27]	Systematic review and meta-analysis of 66 studies (1955–2010)	Cross sectional, case control, & cohort	Occupational risk factors for OA of the knee.	Occupational activities incorporating kneeling, lifting, carrying, squatting, or other knee bending activities are associated with increased risk of knee OA.	High
Aluoch & Wao, 2009 [35]	Systematic review of 16 studies (1987–2008)	Cross sectional & case control	Occupational risk factors associated with development of OA in any joints of the body.	There is a strong relationship between physical strain experienced while performing physically demanding jobs and the incidence of OA of the knee and hip.	Moderate
Bergmann et al., 2017 [30]	Systematic review and meta-analysis of 23 studies (1991–2014)	Case control & cohort	Relationships of heavy lifting and carrying with hip OA	An association exists between years of heavy lifting and carrying and risk of developing hip OA. The effects were lower for females, possibly due to females being underrepresented in studies.	Moderate
Ezzat & Li, 2014 [24]	Systematic review of 32 studies (1952–2011)	Cross sectional, case control, & cohort	Relationships of occupational physical loading of various types with knee OA	There is moderate evidence that combined heavy lifting and kneeling constitute a risk factor for knee OA and limited evidence for heavy lifting, kneeling, stair climbing, or occupational groups being individual occupational risk factors for knee OA. Elevated BMI and previous injury have a role in the development of knee OA. There was a moderate level of evidence for males but limited evidence for females.	Moderate
Jensen, 2008 [31]	Systematic review of 19 studies (1985–2004)	Cross sectional, case control, & cohort	Occupational risk factors for development of hip OA	There is moderate to strong evidence for heavy lifting being a risk factor for hip OA in farmers and limited evidence for climbing stairs or ladders as risk factors for hip OA. The evidence was stronger for males than for females.	Moderate

[a] Entries in this table are made in descending order of methodological rating as determined by the AMSTAR 2 instrument [21].

Table 3.2: Eligible publications and key extracted data (cont.).[a]

Author(s), Year	Review type, number of included studies, years of publication of included studies	Types of studies included	Focus	Key findings	Methodological rating (AMSTAR 2)
Jensen, 2008 [25]	Systematic review of 25 studies (1952–2005)	Cross sectional, case control, & cohort	Occupational risk factors for development of knee OA	There is moderate evidence for kneeling and heavy lifting as risk factors for knee OA, with the combination of both associated with greater risk. Stair and ladder climbing were also associated with increased risk of knee OA. The evidence was stronger for males than for females.	Moderate
McMillan & Nichols, 2005 [26]	Systematic review of 19 studies (1952–2000)	Case control & cohort	Occupational risk factors for knee OA in miners.	Work involving kneeling and or squatting is associated with increased risk of knee OA. Frequent or prolonged kneeling or squatting is associated with double the risk of knee OA observed in the general population. Lifting with squatting/kneeling is associated with further increases in risk.	Moderate
Palmer, 2012 [28]	Systematic review of 43 studies (1968–2010)	Cross sectional, case control, & cohort	Occupational risk factors for OA of the knee	Good evidence exists that physical work activities incorporating kneeling, squatting, lifting, or climbing increase risk of, and can aggravate, knee OA. High BMI is also independently related to knee OA.	Moderate
Richmond et al., 2013 [12]	Systematic review with meta-analysis of 43 studies (1977–2008)	Cross sectional, case control, cohort, & case series	Occupational risk factors for OA in the lower limb.	Occupational activity including heavy lifting, squatting, kneeling, and climbing stairs is associated with an increased risk of OA at the knee and hip. No evidence exists for occupational activity and ankle OA. Other factors including obesity and previous joint injury are also associated with an increased risk of hip and knee OA.	Moderate
Seidler et al., 2018 [32]	Systematic review with meta-analysis of 23 studies (1991–2014)	Case Control	Dose response relationship between different types of physical workload and OA of the hip.	An increased risk of hip OA is associated with heavy lifting, and, as heavy lifting increases, risk of OA increases. A linear association was found between manual handling of weights and hip OA in males but not in females.	Moderate

Table 3.2: Eligible publications and key extracted data (cont.).[a]

Author(s), Year	Review type, number of included studies, years of publication of included studies	Types of studies included	Focus	Key findings	Methodological rating (AMSTAR 2)
Silverwood et al., 2015 [29]	Systematic review with meta-analysis of 46 studies. (1991-2011)	Cohort	Evidence of risk factors for knee OA in older adults.	Kneeling and lifting were significantly related to knee OA. Heavy physical workload and knee bending were not significantly related to knee OA. Previous knee injury, female sex, overweight, and obesity are also risk factors for knee OA	Moderate
Sulsky et al., 2012 [33]	Systematic review of 30 studies (1984-2009)	Case control & cohort	The relationships between physical workloads and hip OA.	Heavy lifting is a risk factor for hip OA and long-term exposure to standing may also increase the risk of hip OA.	Moderate
Vignon et al., 2006 [34]	Systematic review of 76 studies (1988-2004)	Cross sectional & case control	The relationships between specific occupational activities and knee and hip OA.	There is high level of evidence of a positive relationship between physically demanding occupational activity, including heavy lifting and climbing, and knee and hip OA.	Moderate
Fransen et al., 2011 [10]	Systematic review of 22 studies (2007-2010)	Cross sectional, case control, & cohort	The role of occupational risk factors in the development of knee and hip OA.	Men involved in farming or construction are at increased risk of developing chronic hip and knee pain and OA. The risk of knee and hip OA from regular lifting, kneeling, and crawling is increased with concomitant obesity.	Critically low
Reid et al., 2010 [22]	Narrative review of 7 studies (1988-2008)	Cross sectional, case control, & cohort	Occupational risk factors for musculoskeletal disorders of the knee, including knee OA.	Kneeling and squatting are primary risk factors for knee OA, with crawling, stair/ladder climbing, lifting/carrying/moving, walking, and standing up from a knee/squat/crawl are also associated with an increased risk of knee OA.	Not applicable – narrative, not systematic, review
Yucesoy et al., 2015 [23]	Narrative review of 30 studies (1988-2011)	Cross sectional & case control	Occupational risk factors for OA	Heavy physical workload is the most common risk factor for OA in several anatomical locations including the knee and hip. Other risk factors include kneeling, regular stair climbing, crawling, bending, whole-body vibration, and repetitive movements.	Not applicable – narrative, not systematic, review

[a] Entries in this table are made in descending order of methodological rating as determined by the AMSTAR 2 instrument [21].

In the final two reviews [23, 35], OA was considered across a variety of joints. These reviews were published in 2009 and 2015, with included studies published between 1977 and 2008. For these latter two reviews, only data pertaining to lower-limb joints were extracted. Only one review [12] included a study that examined risk factors for ankle OA in physically demanding occupations, and another review reported on a single article for foot OA [23]. None of the included reviews reported on other lower-limb sites of OA, such as sacro-illiac joint or pubic symphysis.

Studies within the 16 included reviews employed cross-sectional, case-control, cohort study, and case-series designs. Both reviewers agreed on the methodological quality on all but one included review, which was settled by the third reviewer. Based on AMSTAR 2, one systematic review [27] was deemed to be of high methodological quality, one [10] to be of critically low methodological quality, and the remainder [12, 24–26, 28–35] of moderate methodological quality.

Two reviews were not rated because they were narrative (not systematic) reviews.

3.3.2 Synthesis

Physically demanding jobs have been strongly associated with an increased risk of OA of the hip and knee. However, many studies investigating these relationships have been limited by nonresponse bias, small sample sizes, and retrospective exposure assessments [35]. The physically demanding jobs most often associated with OA of the hip and knee joints are those that entail frequent knee bending, heavy lifting, stair climbing, and prolonged squatting [12, 23, 35]. On this basis, the synthesis of evidence from the retained reviews is primarily structured around the affected joints and the types of tasks that have been associated with development of OA in those joints.

3.3.3 OA of the knee

Seven reviews [22, 24–29] reported on occupational risk factors for the development of knee OA, with a further three [10, 12, 34] combining OA of the knee and hip (see Table 3.2). Heavy physical work is one of the most common risk factors for the development of knee OA [23]. Physical work activities including kneeling, squatting, lifting, and climbing have been associated, by a good level of evidence, with development or aggravation of knee OA [28, 34]. Occupational activities that exert high loads on the knee joints or require unnatural body positions (either at end of range or sustained) and cumulative exposures to these sorts of loads and positions may all contribute to OA development [34]. In one meta-analysis [27], involving 51 studies with 526,343 participants, McWilliams et al. concluded that occupational factors (e.g., heavy lifting, kneeling/squatting, climbing) could increase the risk of OA by up to 61%, although there was considerable heterogeneity among studies ($I^2 = 84\%$) and evidence of publication bias. That analysis was the only review assessed to be of high methodological quality.

3.3.3.1 Heavy lifting and OA of the knee

In four reviews [10, 24, 25, 28], the researchers examined the relationship between occupational heavy lifting and the development of knee OA. In Jensen's 2008 review [25], a moderate level of evidence was found for a relationship between heavy lifting and the development of knee OA (odds ratio [OR] heavy lifting / no heavy lifting 1.9–7.31). A total of nine of 17 included studies in that review showed that a significantly increased risk of knee OA was associated with heavy lifting, with a dose-response relationship evident whereby higher risks were found among those who had greater exposure to heavy lifting (either heavier weight or more frequent lifts) than among those with less exposure. In the studies that Jensen reviewed, lift loads were varied, including > 10 kg, > 25 kg, and > 50 kg.

In 2011, Fransen et al. [10] updated Jensen's 2008 review with the addition of another eight studies, in six of which significant associations were found between heavy lifting and the development of symptomatic knee OA (OR heavy lifting / no heavy lifting = 1.4–5.0), but Fransen et al. provided no mention of the frequency or duration of these lifts [10]. In their 2014 review, Ezzat and Li [24] found only limited evidence for the relationship between heavy lifting and development of knee OA, although the ORs ranged from 1.4–7.3 when comparing exposed with nonexposed subjects in the 32 studies that they reviewed. Ezzat and Li considered the evidence to be 'limited' because of a lack of cohort studies, bias, confounders, and methodological flaws in the studies they reviewed.

In Palmer's 2012 review [28] there was reasonably good evidence indicating occupational lifting caused or aggravated knee OA, with eight of 14 included studies demonstrating significant risk ratios greater than 1.5 when comparing exposed with nonexposed subjects. Silverwood et al. [29] found lifting to be significantly related to knee OA in one of the three studies in their review. Cumulative tonnages of lifting that need to occur for knee OA risk to increase were not provided in any of the reviews.

3.3.3.2 Heavy lifting with kneeling and squatting and OA of the knee

Fransen et al. [10] further explored the interaction of occupational heavy lifting with concurrent kneeling or squatting in relation to the development of knee OA and found exposure to the two factors together (heavy lifting with either kneeling or squatting) increased the risk of developing knee OA, with a mean increase in ORs from 2.4 [1.1–5.0] for exposure to lifting alone to 3.4 [1.8–6.3] for exposure to lifting combined with squatting or kneeling. Ezzat and Li [24] also investigated the interaction between heavy lifting and kneeling and found moderate-level evidence indicating that exposure to these combined occupational tasks contributed to the development of knee OA, with the associated ORs in their review ranging from 1.8–7.9 when comparing exposed with nonexposed personnel. In their 2005 review, McMillan et al. [26] found similar interactions between heavy lifting and prolonged knee bending or squatting, or repeated knee bending, in increasing the risk of knee OA, noting that these factors together were associated with a greater risk of developing knee OA than were knee-bending activities alone. This relationship was further supported by Palmer's later review [28], which indicated that risks of developing knee OA were elevated three- to eight-fold when lifting was combined with kneeling or squatting.

3.3.3.3 *Kneeling, squatting, and crawling and OA of the knee*

Silverwood et al. [29] deemed occupational kneeling to be an important risk factor for OA, but only limited evidence supported the relationship between occupational kneeling alone and the development of knee OA in the review by Ezzat and Li [24]. Despite 11 of the 16 studies in that review in which occupational kneeling was examined showing significant associations between occupational kneeling and development of knee OA (OR exposed / nonexposed 1.5–6.9), only nine studies were believed to be of high methodological quality and six of those showed positive associations of this nature, with the other three not showing significant relationships. Jensen [25] found that eight of 12 reviewed studies indicated a significant association between squatting for greater than 1 hour per day and development of OA in the knee. She concluded exposure to squatting led to a two- to seven-fold increase in the odds of developing knee OA, based on what she regarded to be a moderate level of evidence [25]. The subsequent update of Jensen's review [25] by Fransen et al. [10] supported a significant two-fold increase in the risk of people developing painful knee OA when exposed to kneeling or crawling at work. The exposures in the studies reviewed by Fransen et al. [10] were squatting for more than 30 mins per day or, in total, for more than 15% of the work day.

In their review, McMillan et al. [26] sought to determine the occupational risk factors for knee OA in miners. They concluded that kneeling and squatting are causally associated with an increased risk of developing OA of the knee, and they estimated that occupations that required frequent or prolonged kneeling or squatting doubled the risk of people developing OA of the knee when compared with the risk observed in the general population [26]. In Palmer's review [28], 11 of 17 studies reported significant relationships between work activity involving kneeling or squatting and the risk of developing knee OA, with associated relative risks greater than 1.5. It should be noted, however, that only one of the 17 studies was a cohort study, with the rest case-control or cross-sectional studies.

3.3.3.4 *Climbing and OA of the knee*

Jensen's review [25] provided only limited evidence to support the relationship between climbing stairs at work and the development of knee OA, and the evidence for a relationship between climbing ladders and development of knee OA was considered to be inconclusive. The associations identified in that review, despite being significant, were all from case-control studies, with the retrospective nature of this methodology making the studies prone to recall bias and selection bias. Jensen [25] nevertheless acknowledged that climbing stairs might be an aggravating factor for those who have stairs at work. When updating Jensen's earlier review [25], Fransen et al. [10] concluded that little evidence remained that climbing stairs or ladders was associated with the development of symptomatic knee OA. In line with those findings, Ezzat et al. [24] concluded that there was only limited evidence to suggest stair climbing was a risk factor for knee OA (OR exposed / non-exposed 1.6–5.1), with one study in their review suggesting a protective effect of stair climbing against the development of knee OA.

3.3.4 OA of the hip

Seven of the reviews [10, 12, 30–34] reported on occupational risk factors for the development of hip OA (see Table 3.2). Similar to the results of the reviews focused on the knee, occupations that entail specific types of physical strain while completing physically demanding tasks have been found to have a strong relationship with the incidence of hip OA [12, 23, 34, 35]. In a similar manner to the evidence pertaining to the knee, some evidence supports the relationship between occupational activity including heavy lifting and the development of hip OA [34]. In contrast to the knee, however, hip OA seems predominantly related to forces exerted on the hip joint through heavy lifting as opposed to high loads on the joint from other mechanisms, unnatural body positions, and other types of cumulative exposures that are associated with occupational knee OA [34].

3.3.4.1 Heavy lifting and OA of the hip

Occupational lifting has been found to be associated with the development of hip OA. Bergmann et al. [30] found an approximately 150% increase in risk (relative risk = 2.46) of developing hip OA for men who were exposed to heavy occupational lifting, with a dose-response relationship indicating that greater exposures to lifting were associated with greater levels of risk. Among the studies included in their review, loads ranged from 4 kg to more than 40 kg, with a minimum loading dose of 20 kg lifted regularly required to increase the risk of hip OA over 20 years of exposure. Risk of developing hip OA was found to increase after only 10 years of lifting loads of around 50 kg, or 20 years for regular lifts of 20 kg. The cumulative loading threshold was reported to be 3,000–5,000 tonnes to increase the risk of hip OA significantly [30]. No indication was given about how many lifts per day were required. However, if using 3,000 tonnes lifted, 20 kg at a time, this would equate to 150,000 lifts. Over a 20-year period this would equal 7,500 lifts per year or, if using 220 work days per year, 34 lifts per work day.

Seidler et al. [32] used a similar approach in that an external reference population was used to determine the dose response relationship between physical workload and hip OA. They found three types of cumulative exposure that would double the risk of developing hip OA when compared with the risk if not exposed to lifting. These included lifting 10,100 tonnes of weight comprising loads greater than 20 kg, 9,500 tonnes of loads greater than or equal to 20 kg lifted more than 10 times per day, or 321,400 movements of weights greater than or equal to 20 kg. Findings from the review by Seidler et al. can be summarised as follows: assuming a 40-year career duration, a doubling of risk of hip OA would result from lifting between 6,100 and 14,000 cumulative tons of weights greater than 20 kg, lifting 6,000 to 105,000 cumulative tons of weights greater than 20 kg lifted more than 10 times per day, or between 218,000 and 514,000 cumulative lifting and/or carrying operations involving loads of any weight.

In Jensen's review [31], moderate to strong evidence was found for a positive relationship between occupational heavy lifting and the risk of developing hip OA if the burden of lifting involved loads of 10–20 kg lifted repeatedly for at least 10–20 years. There were, however, few studies in that review that mentioned the frequency of these lifts. A total of 12 of the 14 studies included in that review showed that a significantly increased risk of hip OA was associated with such heavy lifting, with OR (exposed/ nonexposed) ranging from 1.97 to 8.5. In addition, a dose-response relationship was found, such that those who were considered to have high exposure to lifting, reported either by interview or questionnaire, had a higher risk of developing hip OA (OR 1.5–12) than did those who reported medium exposure to lifting (OR 1.1–4.1). This risk differential was related to the loads lifted, the frequency with which the loads were lifted, and the duration of lifting. For example, those who lifted more weight were at higher risk of developing hip OA, with ORs of 1.2–1.9 for lifts more than 10 kg, ORs of 1.5–2.7 for lifts greater than 25 kg, and ORs of 3.2–8.5 for lifts greater than 50 kg, when compared with lifting loads that were less than 10 kg.

The update to Jensen's review by Fransen et al. [31] included an additional eight studies, again indicating a significant association between heavy lifting and hip OA (ORs exposed/nonexposed 1.7–6.7). The lifting exposures sufficient to increase the risk of hip OA have been reported to be as low as 10 kg or more lifted from one to 10 times per week (no threshold duration reported) [35]. In their review, Sulsky et al. [33] identified evidence for the relationship between heavy lifting and risk of developing hip OA, but they failed to identify the dose-response relationship reported by Seidler et al. [32] and Jensen [31] within the literature they reviewed. Only six of the 30 studies reviewed by Sulsky et al. [33] contained quantitative exposure data, and only three of those six studies were deemed to be of good methodological quality.

3.3.4.2 Lifting with squatting or standing and OA of the hip

No significant association was found between hip OA and combined lifting and squatting in the review of Fransen et al. [10]. The combination of occupational heavy lifting and standing was explored in the review of Sulsky et al. [33] in which an increased risk of hip OA was associated with standing and heavy lifting (10–25 kg) at work over the long term, but this increase in risk was determined to be small and the reviewers drew attention to high variability in the results reported in the included studies.

3.3.4.3 Climbing and OA of the hip

Jensen [31] also examined the relationship between climbing stairs or ladders and the risk of subsequently developing hip OA. Despite three of five studies demonstrating a significantly increased risk of hip OA with climbing (ORs exposed/nonexposed 2.3–2.5), the high quality study in the review did not show a significant association, and therefore the evidence for a causal relationship was deemed to be limited [31]. These findings were mirrored in the review by Fransen et al. [10], with only one of three studies demonstrating a significant association between climbing and the risk of developing hip OA. In their review, Sulsky et al. [33] similarly reported that long-term exposure to stair climbing may be associated with hip OA, but they noted that the results were inconsistent across studies.

3.3.4.4 Crawling, kneeling, squatting and sitting and OA of the hip

Limited evidence was provided by one review for a relationship between occupational crawling and the development of hip OA [10]. There was no evidence reported in any of the reviews that permitted us to explore the potential relationship between sitting, kneeling, or squatting without lifting and the development of hip OA.

3.3.5 OA of the ankle

A single study that reported on associations between OA of the ankle and occupational activity was found in the review by Richmond et al. [12]. In that study, no association was found between the number of descents performed by military parachutists and development of ankle OA.

3.3.6 OA of the foot

The narrative review by Yucesoy et al. [23] reported on a single article pertaining to occupational risk factors for foot OA. Stair climbing was reported to be associated with foot OA. However, no exposure duration or loading dosage was provided.

3.3.7 Additional factors

In addition to occupational factors, other factors were demonstrated in the included reviews to contribute to an increased risk of personnel developing lower-limb OA in physically demanding occupations. Gender, increasing age, obesity or high body mass index (BMI), previous injury, and sporting activity have all been linked to the development of knee OA [22, 24, 26, 28, 29, 36], hip OA [35], and both knee and hip OA [12, 34]. In two of the included reviews [25, 37], males appeared to be at greater risk of developing knee OA. Despite Silverwood et al. [29] reporting that females were found to be at a higher risk for knee OA than were males, it should be noted that this was in the general population and not due to occupational tasks. Most reviews indicate that females are underrepresented in the occupational literature at this point in time, which may explain the apparent elevated risk among males [24, 30].

Increases in age have also been associated with occupational settings, with a sharp increase in incidence of knee OA, particularly between the ages of 50 and 75 years, and a levelling off above the ages of 75 to 80 [29]. Overweight or obesity, typically reported as a high BMI > 25, was associated with an increased risk of OA in several of the reviews [10, 12, 24, 28, 29], with ORs of 2.10–2.66 reported when comparisons were made with 'normal' BMI.

Previous injury is a known risk factor for OA [12, 24], with a pooled OR of 2.83 when previously injured personnel in physically demanding occupations were compared in one of the included reviews with those who had not previously been injured [29], although the level of heterogeneity was high (I^2 = 89.1%). The association of sporting activity with OA is contentious in these occupational populations, with mixed results in reviews [12], various sports studied [34], high levels of heterogeneity [12, 34], and at least some of the risk being explained by previous injury within sport [34]. The OA risk associated with sports participation appears to be far less than the OA risks associated with previous injury and being overweight [34]. Estimates are that high BMI in conjunction with previous injury may increase the risk of developing knee OA 5 to 15-fold [28], a much greater increase in risk than the 2–4 times risk increase associated with sporting activity and dependent on the sport [12].

3.3.8 Limitations of included reviews

There are several possible reasons for the varying results, where these occurred, across the included reviews. These are summarised at the end of this subsection. Issues related to differing diagnostic criteria for OA were by far the most prevalent, with included studies from reviews variably using a radiographic diagnosis, a clinical diagnosis or a combination of both [28, 34]. Within radiographic diagnoses there have also been differences, with a K/L score of 2–4 or a K/L score of 1–4 used, and this variation has been reported to dilute the true rates of OA [25]. In addition, the nature of the studies within the reviews examined in this umbrella review has likely impacted our findings. Despite prospective cohort studies being ideal, they are expensive and take considerable time to implement [22, 27]. Numerous retrospective studies, cross-sectional studies, and case-control studies are therefore found in these reviews, with a subsequent loss in methodological quality and hence in the need to maintain reservations about the validity of study findings [22].

A further reason for variations in findings of the included reviews may be the sampling approaches used in studies that were reviewed. For example, some studies used convenience samples at orthopaedic clinics [35], which may result in biased samples involving, for instance, ethnic groups with a lower prevalence of OA [31] or large proportions of farmers who undertake high physical workloads and may not be representative of the general population. In addition, using samples of those who are on a waitlist for surgery or those who have already undergone joint replacement surgery may also give rise to bias [33]. Some reviews included studies in which authors did not control for the individuals' activities of daily living, sport participation, age, BMI, or previous injury—all of which are known to influence results—and the reviews themselves did not contain sensitivity analyses to explore how findings might have been affected by inclusion of these studies [22, 35]. One review had only one reviewer for the study selection, data extraction, and quality assessment elements, and the search was limited to only two databases [24]. In this same review, 'occupation' and 'occupational exposure' were poorly defined [24]. For example, despite a homemaker role possibly requiring heavy lifting, squatting, and carrying, it was not recorded as an occupation, despite representing a similar exposure to a paid job involving manual labour [24].

Studies considered in the included reviews demonstrated discrepancies in what were considered to be heavy with respect to lifting (10 kg, 25 kg, 50 kg, etc.) and in whether lifting frequency was reported per day, per week, or over a lifetime of work. Some studies considered in the reviews classified exposures to lifting as low, moderate, or high when determining associations between heavy lifting and risk of developing OA, without adequately defining these levels [24]. Likewise, quantification of climbing varied across studies considered in the reviews, and it has been variably reported in terms of duration (e.g., > 30 mins/day), absolute numbers of times each day that stairs are climbed (e.g., > 30 times per day), or numbers of flights of stairs climbed (e.g., 15 flights of stairs/day), making direct comparisons difficult [25]. Because of latencies in the development of symptoms or radiographic change associated with OA, there are also inherent difficulties in associating exposures to specific occupational activities, which may vary over time, with development of OA. Other difficulties relate to poor definition of the retrospective timeframes in which exposures have occurred and recall bias that occurs in retrospective accounts of exposed groups, which tends to inflate reported exposures, especially if participants have been tasked with recalling decades of exposures [33, 34].

In addition, the healthy worker survivor effect should be acknowledged, whereby exposure data may be influenced by the early departure from the workforce of those who developed OA early in their careers, leaving personnel in the workforce who were less affected by OA but contributed many more years of exposure in the overall workforce-exposure calculations [38]. Likewise, those who gravitate to physically demanding jobs may be fitter, with less joint disease than those in more sedentary occupations with which they are typically compared [28]. Conversely, those who are tasked with physically demanding jobs may be affected more by their OA and subsequently seek treatment earlier than do those in more sedentary occupations [28]. These factors may have affected the findings of many of the reviews.

The limitations of studies in the reviews can be summarised as follows:

1. Diagnostic criteria for OA
    a. Clinical vs radiographic vs both
    b. K/L scoring variations

2. Study design
    a. Mostly retrospective
    b. Few prospective cohort studies
3. Sampling
    a. Convenience samples often used
    b. Potentially biased groups (e.g., clinical groups awaiting knee replacement)
4. Lack of control for covariates known to affect OA, e.g., BMI, previous injury, and participation in sport
5. Varying definitions of occupation and exposures
6. Few reporting a minimum exposure duration

3.4 Discussion

The reviews indicated moderate to good evidence that heavy occupational lifting is associated with an increased risk of OA at the knee [10, 24, 26–28, 35] and the hip [10, 30–33, 35]. The definition of heavy has ranged from 10 kg [35] to 50 kg [31]. Despite no cumulative lifting threshold being found for knee OA, cumulative tonnes of lifting associated with significantly increased risks of hip OA have been reported to be between 3,000 [30] and 14,000 [32] tonnes of weight for lifts of 20 kg. In addition, the combination of heavy lifting and physically demanding occupational tasks such as kneeling [25] or squatting [39] appears to further increase the risk of developing knee OA.

The results of several of the reviews [22, 26–28, 34, 35] suggest that squatting is associated with knee OA when excessive exposures exist in occupations. The concerns with squatting are for estimated peak external moments created at the knee during squatting, which are up to 2.5 times greater than those experienced when walking [40]. These forces can have long-term implications for both mechanical function of the knee joint and for structural integrity of cartilage within the joint [41].

In a similar manner, activities that require knee bending or kneeling have been well investigated and overall appear likely to be related to the development of knee OA [10, 22–28, 34, 35]. Kneeling focuses around 70% of body weight on a small surface of the tibia and patella, which may damage articular cartilage [25]. Workplace interventions have therefore been suggested to minimise the frequency and duration of knee-bending activities. However, the difficulties associated with implementation of these interventions have been acknowledged [28].

Climbing has been identified as a factor that contributes to knee OA [23, 24, 28, 34, 35]. However, the evidence suggesting that climbing ladders or stairs influences development of knee OA is limited [24]. Climbing has also been implicated in the development of hip OA in several reviews [10, 31, 34, 35]. Forces of up to six times body weight are experienced during stair climbing [25], with an element of rotational loading

[42]. Difficulty remains in quantifying the threshold, if any, beyond which climbing may contribute to development of knee or hip OA because some studies have found it to have a protective effect [43, 44]. Furthermore, the addition of loads carried while climbing in military contexts may be an important consideration.

There are some military-specific tasks that may give rise to knee pain and/or injuries that then have a potential to lead to longer-term issues such as OA. In soldiers undertaking prolonged mounted patrolling in Afghanistan, up to 33% reported knee pain, with significant associations between this pain and the amount of time they spent on vehicles each week [45]. If this pain reflects underlying joint injury, the findings of this umbrella review, which indicate that prior injury is a risk factor for development of lower-limb OA, suggest that exposure to such tasks may increase the longer-term risk of military personnel developing lower-limb OA. A potential source of knee symptoms and contributor to knee OA among naval personnel is the steep inclination angles of naval ladders, which have been shown to increase knee flexion angles and expose the knee to joint forces equal to up to 6.6 times body weight [46].

Given that military occupations typically require carrying heavy loads, heavy lifting, walking, crawling, kneeling, and squatting, often for extended periods of time under conditions of caloric and sleep deficit, it is not surprising that there are relatively high rates of OA among military personnel [14, 18, 45]. Control of risk is a difficult concept in this context because military training must mimic occupational demands, with chronic physical and mental conditioning vital for achieving mission tasks. Given that load carriage, crawling, kneeling, and squatting are essential requirements in the military domain, avoiding these activities is neither possible nor desirable because training must closely replicate expected combat/occupational activities. Primary prevention could more reasonably be focused on attempting to decrease loads where appropriate [47], minimising initial injuries where possible [48] by ensuring adequate strength around affected joints [49], maximising fitness [50], and ensuring complete rehabilitation from injuries when they do occur. Additional risk factors could include gender (females) [51], age (older) [29], years of service (longer) [18], BMI (high) [24], aerobic fitness (low) [2], and strength (low), all of which may negatively affect the relationship between occupational risk factors and the risk of developing lower-limb OA or experiencing injuries that may predispose personnel to lower-limb OA.

Military-specific risk factors for development of OA appear to include ground-based service and higher rank [11, 19]. Given the length of service required to reach higher ranks and the greater exposure to physically demanding tasks that might be expected during this time, rank may be associated with an increased risk of OA as a proxy measure for length of service [18]. Ground-based service often involves navigating difficult terrain while wearing heavy fighting loads and being physically engaged in conflict or simulated conflict during training. These features of ground-based service may help explain and contribute to the increased risk of developing OA associated with such service.

Quantifying what constitutes protective rather than detrimental exposure is a vital step in minimising the impact of OLL in military personnel. Further scrutiny of specific thresholds of weights lifted and carried, and cumulative durations spent crawling, squatting, or kneeling over the time period in specific military occupations is required given that, based on the findings of this review, there are few military-specific studies.

3.5 Conclusion

The results of this umbrella review suggest that occupations that involve heavy physical workloads, like many military occupations, increase the risk of developing OLL. Occupational tasks of heavy lifting, squatting, knee bending, kneeling, and climbing may all increase the risk of developing OA both in knees and hips, and given that these kinds of tasks are routine requirements for military personnel, it is not surprising that service members experience greater rates of OA than do members of the general population. Where possible, effort should be made to decrease the quantity and durations of these tasks, and to pursue preventive measures such as muscle strengthening as well as ensuring optimal BMI, injury minimisation, and complete rehabilitation from previous injuries.

3.6 References

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4. RISK FACTORS FOR DEVELOPMENT OF LOWER-LIMB OSTEOARTHRITIS IN PHYSICALLY DEMANDING OCCUPATIONS: A CRITICAL REVIEW AND META-ANALYSIS

4.1 Introduction

Osteoarthritis (OA) is a common chronic and debilitating musculoskeletal condition. In 2015, over two million Australians were reported to suffer from OA [1]. Recently, Ackerman et al. [2] estimated the projected burden of OA to affect 3.1 million Australians in 2030. This increase in OA presentations was estimated to cost the healthcare system over 2.9 billion Australian dollars [2]. The total financial burden of OA is, however, much greater because these figures do not account for costs other than healthcare costs, including those arising in occupational contexts from loss of working days, job reallocation, and staff repurposing.

OA has a multifactorial aetiology, including genetic [3], biological, and bio-mechanical elements [4]. Clinically, OA may present itself with persistent pain, restricted movement, limited morning stiffness, crepitus, bony enlargement, and reduced joint function [5]. Pathological features observed in radiographic imaging include loss of hyaline cartilage (leading to reduced joint space) and alterations to the subchondral bone (e.g., subchondral bone sclerosis, subchondral cysts, and osteophyte formation). OA diagnosis can be made using either clinical evidence (indicating presence of three out of the six signs and symptoms listed above) or radiological evidence. However, a recent study has shown that in particular articulations such as the hip, OA may be undetected if the diagnosis relies solely on radiographs [6]. Therefore, diagnosis of knee and hip OA should include both radiographic and clinical features, in accordance with the American College of Rheumatology radiological and clinical criteria for OA of the knee and hip [7–9].

The risk factors associated with development of OA have been researched in many studies. The intrinsic factors include older age, female gender, overweight and obesity, inflammation, dyslipidaemia, and prior injury [10–14]. Obesity induces not only biochemical alterations (i.e., increase in proinflammatory adipokines and cytokines) but also contributes to a mechanical overload, particularly in lower-limb joints [15–17]. Adding to this increased biomechanical demand, extrinsic factors such as participation in trauma-prone sports [18] and arduous occupational tasks (e.g., heavy lifting, kneeling/squatting, climbing) have been found to increase the risk of lower-limb OA [19].

The umbrella review within this report (Chapter 3) providing an overview of previous literature reviews and examined risk factors for the development of lower-limb OA in physically demanding occupations such as the military. The umbrella review demonstrated a proportional increase in the risk of developing OA in occupations involving heavy physical workloads. Unfortunately, when reporting on lifting and carrying tasks, the studies in the umbrella review contained varying definitions of heavy loads, ranging from 10 kg to more than 50 kg [20–22], and comparable exposure frequencies and durations have seldom been adopted, if these have been reported at all.

Given the burden of OA and its complex epidemiology, particular attention to extrinsic factors such as occupational demands contributing to OA is warranted. Building on the umbrella review, the primary aim of this systematic review was to identify and critically review the findings of recent studies regarding the relationships between physically demanding occupations or occupational tasks and the development of lower-limb OA. Additionally, the review aimed to determine factors other than occupational tasks that are associated with development of lower-limb OA in personnel engaged in such occupations.

4.2 Method

4.2.1 Systematic literature search, screening, and selection

The databases PubMed, Cumulative Index to Nursing and Health care Literature (CINAHL), and Elton B Stevens Company (EBSCO) were searched systematically using the search terms listed in Table 4.1. The reference lists of included articles were also searched manually and colleagues with expertise in the subject area were approached to identify additional studies of relevance. The criteria adopted for inclusion in this systematic review were that the study:

a. reported original research conducted in humans,
b. was published in the English language,
c. was published within the last 15 years,
d. involved an investigation of risk factors for development of lower-limb OA in personnel engaged in physically demanding occupations, and
e. included both clinical and radiological diagnostic criteria for OA in the participant inclusion criteria.

Titles and abstracts of studies identified in the systematic search were screened, and duplicates and studies that were clearly ineligible were removed. Full text copies of all remaining studies were obtained and subjected to the inclusion criteria, with ineligible studies excluded and reasons recorded independently by two authors (EC and BS). The search, screening, and selection processes were documented in a PRISMA flow diagram [23].

Table 4.1: Databases, search terms, and filters used in literature search.

Database	Search terms	Filters
PubMed	("arthritis"[Title/Abstract] OR "osteoarthritis"[Title/Abstract]) AND ("ankle"[Title/Abstract] OR "knee"[Title/Abstract] OR "hip"[Title/Abstract] OR "foot"[Title/Abstract] OR "lower limb"[Title/Abstract]) AND ("risk"[Title/Abstract] OR "prevalence"[Title/Abstract] OR "cause*"[Title/Abstract])	Full text, 2003–2018, in English, on humans
CINAHL	(AB) Arthritis OR osteoarthritis AND (AB) ankle OR knee OR hip OR foot OR lower limb AND (AB) risk OR prevalence OR cause	Human, peer reviewed, from 2003, in English,
EBSCO	Arthritis OR osteoarthritis AND ankle OR knee OR hip OR foot OR lower limb AND risk OR prevalence OR cause	Human, peer reviewed, from 2003, in English.

4.2.2 Methodological quality assessment

Eligible publications identified through the literature search, screening, and selection processes were appraised to assess their methodological quality using the Critical Appraisal Skills Programme (CASP) toolkit [24, 25] or the AXIS tool for appraising cross-sectional studies [26]. The CASP toolkit provides checklists to facilitate accurate and fair appraisal of each study based on method design but does not include a tool to appraise cross-sectional studies; therefore the CASP toolkit was supplemented by the AXIS tool [26]. The included studies were all suitable for appraisal using the CASP cohort study checklist, the CASP case-control study checklist, or the AXIS tool.

The CASP cohort study checklist [25] contains 12 questions for study quality assessment. The first two questions relate to screening and the following 10 questions guide the reviewer through the assessment of validity, relevance, methodology, and result quality. The CASP case-control checklist [24] contains 11 questions, the first three of which are focused on screening, and the following eight questions assess validity, design effectiveness, power, and applicability. The AXIS [26] is a 20-question checklist encompassing 11 questions regarding objectives and methodology, seven questions to guide the assessor through the study's findings and discussion, and two questions pertaining to ethical considerations such as consent and conflicts of interest.

Questions in each of the three tools were rated on a binary scale, with 1 point awarded for questions that can be answered 'yes' and 0 points awarded for those that are answered 'no' or are indeterminable. An exception to this method was Question 19 in the AXIS tool, where a 'no' answer was awarded 1 point, because answering "yes" to that question affirms that there are funding sources or conflicts of interest that may affect the authors' interpretation of results. Questions 7–9 on both the CASP cohort study checklist and the

CASP case-control checklist were condensed into one item because they are all closely related, and items 7 and 8 cannot be answered numerically. Therefore, cohort studies were scored out of 12 possible points and case-control studies were scored out of nine possible points, but cross-sectional studies were scored out of 20 points, with scores from each tool then converted to a percentage score to derive the final scores considered in the review from all three tools. To ensure validity of score reporting, studies were assessed by two authors (EC & BS) independently. If the scores assigned to a study by the two raters varied by more than 1 point, the article was re-assessed by a third author (RO). When differences remained and consensus could not be reached, the third author (RO) adjudicated to determine the final score. The overall level of agreement between the initial two raters, measured by Cohen’s kappa, was 0.70 and considered a ‘substantial agreement’ [27].

4.2.3 Data extraction and synthesis

Relevant data were subsequently extracted from each included study and tabulated. Extracted information included authors, year of publication, number and characteristics of participants, methods used in the diagnosis of OA and quantification of the exposure to risk factors, and results—the latter with particular emphasis on odds ratios (OR) for risk of developing OA and associated 95% confidence intervals (CIs) where these could be extracted or derived. If CIs were unavailable but relative risks (RRs) or hazard ratios (HRs) were provided, these were extracted instead. Funding information of included studies were recorded when disclosed but not reported in this review. Following data compilation, key findings from the included studies were initially synthesised using a critical narrative approach. Following the critical narrative synthesis, meta-analyses were conducted where appropriate and these are described below.

4.2.4 Statistical and meta analyses

Where possible, ORs and 95% CIs were calculated (along with standard errors) according to Altman [28] to obtain estimates of comparative levels of risk associated with specific occupational exposures and other risk factors for lower-limb OA. Findings from the included studies were then further analysed through meta-analyses using the Cochrane Collaboration’s software package, Review Manager (RevMan, Version 5.3). This provided pooled estimates of the contributions of the reported risk factors to the development of lower-limb OA using all available studies.

When studies contained multiple values for comparative levels of risk associated with particular occupational risk factors (e.g., values based on different exposures or weights handled), the minimum significant comparative risk value was used in the meta-analysis. When other risk factors were subclassified (e.g., sports participation subdivided into soccer, tennis, and others) and numbers of cases exposed and nonexposed were presented, the subclassifications were grouped and the calculated OR for the overall factor (e.g., sports participation) was included in the analysis.

Heterogeneity was assessed using the standard χ^2 test and I^2 value and was considered statistically significant at $p < 0.10$ [29]. I^2 values between 0% and 30% were considered minimal, 30%–50% moderate, 50%–90% substantial, and > 90% considerable heterogeneity [29]. Within subgroup sensitivity assessment was performed with regard to heterogeneity, and studies that single-handedly increased subgroup I^2 by more than 30% were excluded from the respective analyses. Values were recorded as OR and 95% CI [lower limit, upper limit] unless stated otherwise.

Forest plots were generated from the meta-analyses, where appropriate, to aid in visualisation and interpretation of the results. Publication bias was assessed using funnel plots and the trim-and-fill procedure [30, 31]. Funnel plots used here were graphs of standard errors (SE) and ORs. Studies with larger sample sizes tend to cluster near the top of the plot and near the pooled SE, while smaller studies are generally near the bottom of the graph. If publication bias is present, the bottom of the plot tends to show a higher concentration on one side because studies with smaller samples are more likely to be published if they had larger SEs [30]. The trim-and-fill procedure adjusts the funnel plot through an iterative process, removing studies concentrated on one side of the plot, reinserting the trimmed studies on the other side of the plot, and imputing their counterparts on the original side of the plot [31]. A new SE and 95% CI is produced with imputed values.

4.3 Results

4.3.1 Included studies

The systematic search resulted in identification of a total of 6,407 articles and a further three articles were identified from other sources. Once the screening and selection processes were complete, 28 articles remained for inclusion in the systematic review. The PRISMA diagram outlining the identification, screening, eligibility assessment, and selection of articles is shown in Figure 4.1.

Among the included studies, there were two cohort studies [32, 33], 10 case-control studies [34-43], and 16 cross-sectional studies [44-59]. Eleven studies [32–35, 40, 41, 50, 54, 55, 57, 59] reported on comparative risks of developing hip or knee OA associated with particular occupations without analysing or specifying occupational tasks as risk factors. See Table 4.2.

Two studies reported on both occupations and occupational tasks as risk factors [38, 53] for hip or knee OA (see Table 4.2). A further 15 studies reported on occupational tasks but not occupations as risk factors for knee or hip OA (see Table 4.2). Only one of the 28 studies [46] included in the review reported on risk factors for OA of a lower-limb joint other than the knee or hip (specifically, the first metatarsophalangeal joint).

Figure 4.1: PRISMA diagram showing results of the search, screening, and selection processes for the systematic review.

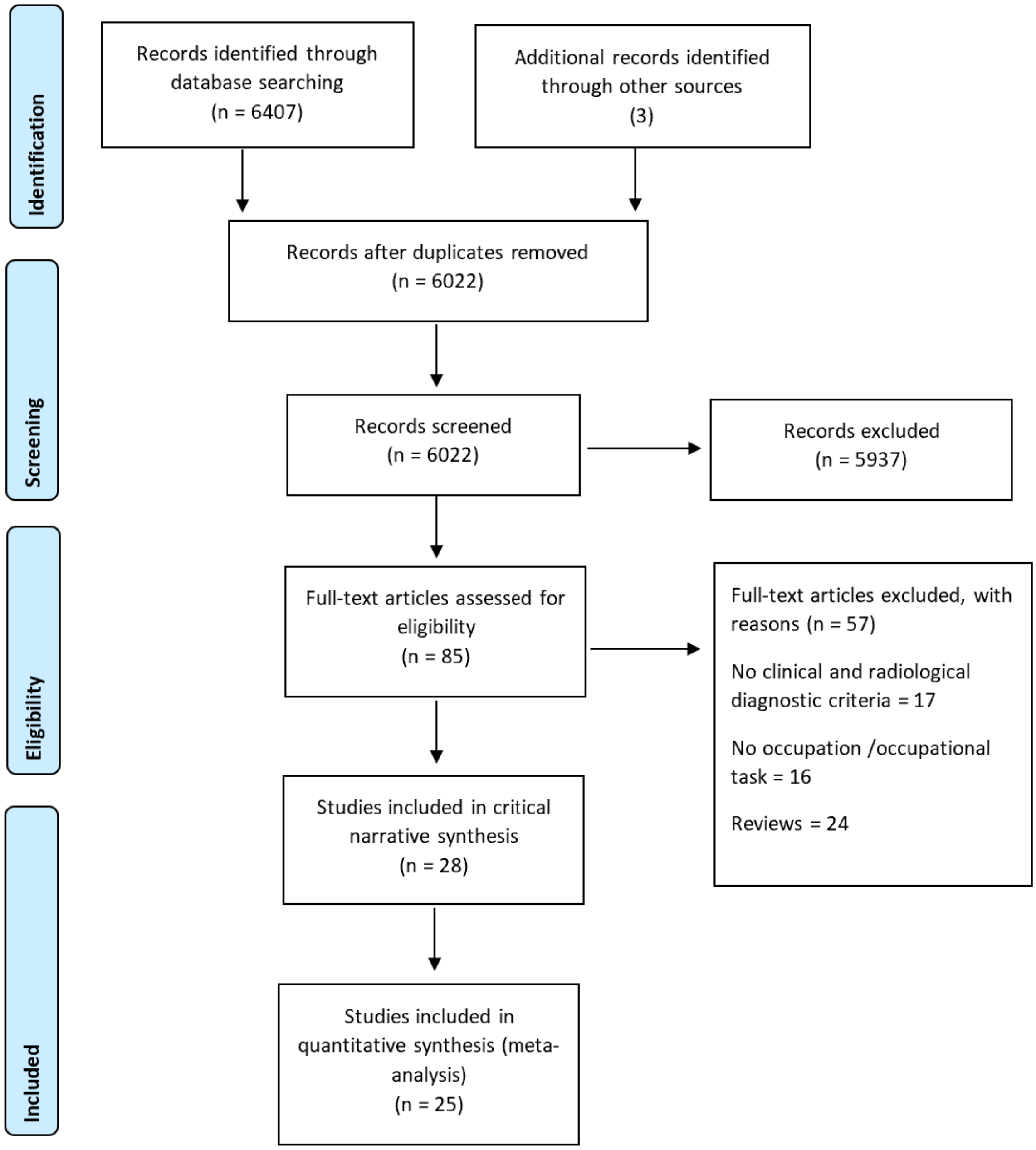


Table 4.2: Occupational risk factors for knee or hip OA in the included studies.[a]

Outcome	Number of studies	References
Occupation	11	30-33, 38, 48, 52, 53, 55, 57
Occupational task	17	
Squatting / knee bending	13	34-37, 40, 42-45, 47, 50, 54, 56
Kneeling	7	34, 35, 40, 45, 46, 50, 56
Lifting/carrying	13	34-37, 40-43, 45, 49-51, 56
Standing	9	34, 35, 40-42, 44, 45, 50, 56
Walking	7	34, 35, 40, 42, 45, 50, 56
Sitting	8	34, 35, 39, 40, 42, 45, 50, 56
Crawling	1	42
Bending, twisting, reaching	1	42

[a] The two studies that reported on both occupations and occupational tasks [38, 53] as risk factors for knee or hip OA were added to the occupational task row.

Key data from the included studies are presented in a structured manner in Table 4.3 and Supplementary Table 1 (located at the end of this chapter), which provide measures of OA risk associated with exposure to specific occupations and specific occupational tasks, respectively. In addition, Supplementary Table 1 identifies other risk factors (for example, high BMI, previous injury, older age, and female sex) that appear to affect the relationships between exposure to specific occupational tasks and risk of developing OA.

Table 4.3: Occupations as risk factors for OA

Reference	Joint	Study type	Participants	Methods (OA diagnosis / exposure to risk Factors)	Occupations as risk factors: Comparative levels of risk			Methodological Quality[#]
Andersen et al. [32]	Hip and Knee	Prospective Cohort	Integrated database for labour market research (1996-2006) (n=2,117,298 workers in wide ranging occupations; cases: ♂hip OA=8,358; ♂ knee OA=4,014; ♀hip OA= 8,059; ♀ knee OA=5957)	Diagnosis of OA according to the Nordic Classification of Surgical Procedures (requirement of the National Patient Register) and had a hip/knee replacement (X-ray required) in the same year.	**Knee**	♂ HR (95%CI)	♀ HR (95%CI)	54%
					Farmers	1.14 (1.04-1.28)	0.95 (0.85-1.06)	
					Construction workers	1.27 (1.17-1.38)	1.37 (1.14-1.64)	
					Floor/Brick layers	1.49 (1.28-1.73)	N/A	
					Healthcare Assistants	1.42 (1.23-1.64)	1.34 (1.27-1.42)	
					Hip	♂	♀	
					Farmers	1.96 (1.84-2.08)	1.22 (1.12-1.33)	
					Construction workers	1.23 (1.15-1.31)	1.21 (1.03-1.43)	
					Floor/Brick layers	1.35 (1.20-1.52)	N/A	
					Healthcare Assistants	1.11 (0.99-1.25)	1.12 (1.07-1.18)	
					Reference: Office workers			
Franklin et al. [34]	Knee and hip	Case-control	2490 participants 1408 cases with knee and/or hip OA (832 ♀) 1082 age- and genetically matched (i.e. > 60 years old and relatives of participants) controls (592 ♀)	X-ray (Kellgren & Lawrence grades) Questionnaire	Knee	♂ OR [95%CI]	♀ OR [95%CI]	67%
					Farmers	5.1 [2.1, 12.4]	1.4 [0.67, 2.7]	
					Fisherman	3.3 [1.3, 8.4]	N/A	
					Craft Workers	2.5 [1.0, 6.2]	1.2 [0.59, 2.5]	
					Hip	♂	♀	
					Farmers	3.6 [2.1, 6.2]	0.62 [0.36, 1.0]	
					Service and Shop Workers	2.1 [1.0, 4.2]	0.79 [0.48, 1.3]	
					Reference: Managers and professionals (i.e. teachers, doctors and nurses)			

Table 4.3: Occupations as risk factors for OA (cont.).

Reference	Joint	Study type	Participants	Methods (OA diagnosis / exposure to risk Factors)	Occupations as risk factors: Comparative levels of risk			Methodological Quality#
Holmberg et al. [35]	Knee	Case-Control	1473 participants 778 cases (440 ♀ and 338 ♂) 695 matched (age, sex and county) controls (402 ♀ and 293 ♂).	X-ray (Kellgren & Lawrence grades) Questionnaire	Knee	♂ OR [95%CI]	♀ OR [95%CI]	89%
					Farmers (11-30 years)	0.8 [0.3, 2.1]	2.1 [1.0, 4.5]	
					Building and construction (11-30 years)	3.7 [1.2, 11.3]	N/A	
					Reference: Matched controls with no OA			
Jarvholm et al. [33]	Knee and Hip	Prospective Cohort	204,741 males from wide-ranging occupations (including 9136 in control group - white-collar workers)	X-ray (Kellgren & Lawrence grades) Questionnaire	Knee	RR (95% CI)		75%
					Asphalt workers	2.81 (1.11-7.13)		
					Brick layers	2.14 (1.08-4.25)		
					Drivers	2.01 (0.89-4.54)		
					Floor layers	4.72 (1.80-12.33)		
					Plumbers	2.29 (1.19-4.43)		
					Rock workers	2.59 (1.18-5.69)		
					Sheet metal workers	2.60 (1.06-6.37)		
					Wood workers	2.02 (1.11-3.69)		
					Reference: White-collar workers			
Jensen [49]	Knee	Cross sectional	Floor layers (n=133) Carpenters (n=509) Compositors (n=327)	Questionnaire Video analysis of occupational tasks X-ray (Kellgren & Lawrence grades)	**Knee complaints: >30 days in 1 year**	OR [95%CI]		65%
					Low-moderate exposure	2.1 [1.1, 4.4]		
					High exposure	3.95 [2.2, 7.3]		
					Very high exposure	6.85 [3.6,13.0]		
					Knee complaints + radiographic OA			
					Low-moderate exposure	1.39 [0.3,3.6]		
					High exposure	3.07 [0.6,16.8]		
					Very high exposure	4.47 [1.1, 18.9]		
					Reference: No exposure to knee-stressing work positions			

Table 4.3: Occupations as risk factors for OA (cont.).

Reference	Joint	Study type	Participants	Methods (OA diagnosis / exposure to risk Factors)	Occupations as risk factors: Comparative levels of risk		Methodological Quality#
Jensen et al. [50]	Knee	Cross sectional	Floor layers (n=134) Graphic designers (n=120)	X-ray (Kellgren & Lawrence grades) Questionnaire (Knee Injury and Osteoarthritis Outcome Score – KOOS) + MRI	Symptomatic tibiofibular OA	OR [95%CI]	70%
					Floor layers	2.6 [0.99,6.9]	
					Reference: Graphic designers		
Jensen et al. [59]	Knee	Cross sectional	Floor layers (n=92) Graphic designers (n=49)	X-ray (Kellgren & Lawrence grades) Questionnaire (Knee Injury and Osteoarthritis Outcome Score – KOOS) MRI	Tibiofibular OA	OR [95%CI]	65%
					Floor layers	2.46 [0.8, 7.3]	
					Seniority		
					<20 years in trade	0.7 [0.1, 7.4]	
					21-30 years in trade	1.89 [0.3, 12.3]	
					>30 years in trade	4.82 [1.4, 17.0]	
					Patellofemoral OA		
					Floor layers	0.44 [0.1, 1.5]	
					Seniority		
					<20 years in trade	1.30 [0.3, 6.3]	
					>30 years in trade	0.48 [0.1, 1.9]	
					Reference: Graphic designers		
Kim et al. [57]	Knee	Cross sectional	Participants from a range of occupations (n= 504 ♀ 274, ♂ 230)	X-ray (Kellgren-Lawrence OA (≥2 = all, 3-4 = severe) Interviewer- administered questionnaire (Knee pain/aching/stiffness lasting ≥1 month)	**Symptomatic knee OA**	OR [95%CI]	82%
					Manual occupations (i.e. farmer, construction worker, labourer)	2.39 [1.35, 4.22]	
					Radiographic knee OA		
					Manual occupations (i.e. farmer, construction worker, labourer)	2.14 [1.19, 3.84]	
					Reference: non-manual occupations		

Table 4.3: Occupations as risk factors for OA (cont.).

Reference	Joint	Study type	Participants	Methods (OA diagnosis / exposure to risk Factors)	Occupations as risk factors: Comparative levels of risk		Methodological Quality#
Rytter et al. [54]	Knee	Cross sectional	Male floor layers (n=134) Male graphic designers (n=120)	OA on modified Ahlback scale - joint space narrowing ≥1 grade (scored for tibiofemoral and patellofemoral compartments) + questionnaire	**Radiographic tibiofemoral OA**	OR [95%CI]	63%
					Floor layers (age)		
					≤ 49 years	1.1 [0.1, 13.1]	
					50-59 years	3.6 [1.1, 12.0]	
					≥ 60 years	1.9 [0.4, 7.8]	
					Reference: graphic designers		
					Seniority in trade		
					21-30 years	1.4 [0.1, 21.4]	
					≥ 31 years	1.6 [0.1, 17.5]	
					Reference: ≤ 20 years		
Showery et al. [55]	Knee	Cross sectional	21,318 US military active duty servicemembers with diagnosis of primary or secondary knee OA (Defence Medical Epidemiological Database retrospective 2005-2014)	Dependent and based on patient history, physical examination, and pertinent radiographic imaging	**Primary knee OA**	RR (95%CI)	70%
					Rank		
					Senior Enlisted	1.49 (1.39-1.60)	
					Junior Officer	1.00 (0.94-1.06)	
					Senior Officer	1.59 (1.39-1.60)	
					Reference: Junior enlisted		
					Service		
					Army	1.21 (1.13-.128)	
					Air Force	1.38 (1.30-1.47)	
					Navy	0.85 (0.80-0.91)	
					Reference: Marines		

Table 4.3: Occupations as risk factors for OA (cont.).

Reference	Joint	Study type	Participants	Methods (OA diagnosis / exposure to risk Factors)	Occupations as risk factors: Comparative levels of risk		Methodological Quality#
Thelin et al. [40]	Hip	Case-control	Farmers with OA (n=369) Controls (n=369) matched by occupation, age, gender and residential area	X-ray and questionnaire	**OA among farmers**	OR [95%CI]	83%
					Milk > 40 cows/daily	4.5 [1.86, 10.97]	
					Work > 5h/daily in animal barns from age 30	13.3 [1.22, 144.98]	
					Reference: not exposed to work with animals/ in animal barns		

Methodological quality percentage score is based on the critical appraisal tool specific to each study design, described in the methods section of this review.

Kellgren & Lawrence grades: Grade 1: doubtful narrowing of joint space and possible osteophytic lipping; Grade 2: definite osteophytes and possible narrowing of joint space; Grade 3: moderate multiple osteophytes, definite narrowing of joint space and some sclerosis and possible deformity of bone ends; Grade 4: large osteophytes, marked narrowing of joint space, severe sclerosis and definite deformity of bone ends. OA: osteoarthritis. KOOS: Knee injury and Osteoarthritis Outcome Scores. MRI: magnetic resonance imaging. OR: odds ratio. HR: hazard ratio. RR: relative risk. CI: confidence interval. N/A: not available. ♂: male. ♀: female.

4.3.2 Occupations

Occupations considered to be physically demanding, such as construction workers, floor layers, bricklayers, fishermen, farmers, and service personnel (including, but not limited to, salespersons, healthcare workers, and police officers) [32, 34, 35, 40, 44], were associated with an increased risk for the development of both hip and knee OA. Some occupations showed a dose-dependent relationship between OA and years worked [32, 35, 49, 54, 59]. For example, farmers had an increased risk of hip OA after 1 to 5 years of work (hazard ratio [HR], when compared with office workers, 1.63 [1.52, 1.74]), which increased substantially (HR 4.20) in those who had worked for more than 20 years [32]. Due to such high comparative risks, Thelin et al. [40] investigated specific occupational tasks within farming, such as working more than 5 hours per day in an animal barn, which was shown to increase the risk of hip OA substantially (OR [95% CI] exposed / not exposed = 13.3 [1.2, 145.0]). In another study [35], construction workers who had worked in the industry for 11–30 years had 3.7 [1.2, 11.3] times the odds of developing knee OA compared with matched controls. However, although they were at greater risk when compared with matched controls, a dose-response relationship could not be established between exposure and development of OA because construction workers who had been in the profession for over 30 years had a lower risk (OR 1.6 [0.6, 4.6]) than had those exposed for 11–30 years [35]. The authors hypothesised that such findings could be explained by the healthy worker survivor effect in which workers who have developed knee OA may have left the workforce and therefore only those who are healthy remain.

Franklin et al. [34] found that, compared with controls in managerial occupations, farmers were at a greater risk of having both a total knee replacement (TKR) and total hip replacement (THR; OR 5.1 [2.1, 12.4] and 3.6 [2.1, 6.2], respectively). This was presumed by the authors to be due to their heavy workload. Likewise, when compared with managers and professionals, male fishermen were at significantly greater risk of having a TKR for OA (OR 3.3 [1.3, 8.4]) [34]. The increased risk of having surgery due to knee OA in occupations with heavy physical workloads was also found by Jarvholm et al. [33], who reported that floor layers had 4.7 [1.8, 12.3] times the risk observed in white-collar workers of having surgical treatment for their knee OA. The authors concluded that across all construction industry workers, 50% of the cases of severe OA of the knee could be prevented by addressing occupational risk factors (i.e., decreasing exposure to occupational tasks such as squatting/kneeling), and that, despite a positive correlation between hip and knee OA ($r = 0.62$, $p = 0.01$), the knee appears to be more affected than is the hip [33].

Floor layers were also the focus of a study by Jensen et al. [50] due to the substantial amount of time they spend kneeling. Compared with graphic designers, floor layers had higher rates of symptomatic knee OA (OR 2.6 [0.99, 6.9]), significantly lower knee injury and OA outcome scores (KOOS; indicating substantial knee issues) [60] on all subscales (i.e., pain, symptoms, activity of daily living functions, sport and recreation function, and knee-related quality of life), and higher rates of medial meniscal tears on MRI (OR 2.04

[0.77, 5.5]) [50]. In a separate study with the same cohort of floor layers, Jensen et al. [59] found that, compared with graphic designers, length of time in the specific work trade was associated with an increased risk of tibiofibular knee OA (> 30 years of exposure OR 4.82 [1.38,17.0]).

Large cross-sectional surveys have found that OA is prevalent in 40% of physically demanding, heavy-labour occupations that require uncomfortable positions or constant lifting or carrying of heavy objects. These include occupations associated with agriculture workers, housekeepers, truck drivers, and labourers [33, 34, 49, 53]. These large studies have indicated that OA is linked to occupation and is not simply an inevitable disease of ageing. There are consequently calls for an increased number of occupation-specific studies that develop and evaluate preventative strategies [55, 57]. Likewise, individuals in military occupations were found to be at increasing risk of knee OA as their age or rank increased [55]. Given the length of service required to reach higher ranks, length of service may also therefore be associated with an increased risk of OA. In addition, service type predicted level of lower-limb OA risk [55], with service in the Army or Air Force being associated with an increased risk of knee OA ($p < 0.001$) when compared with service in the Marines.

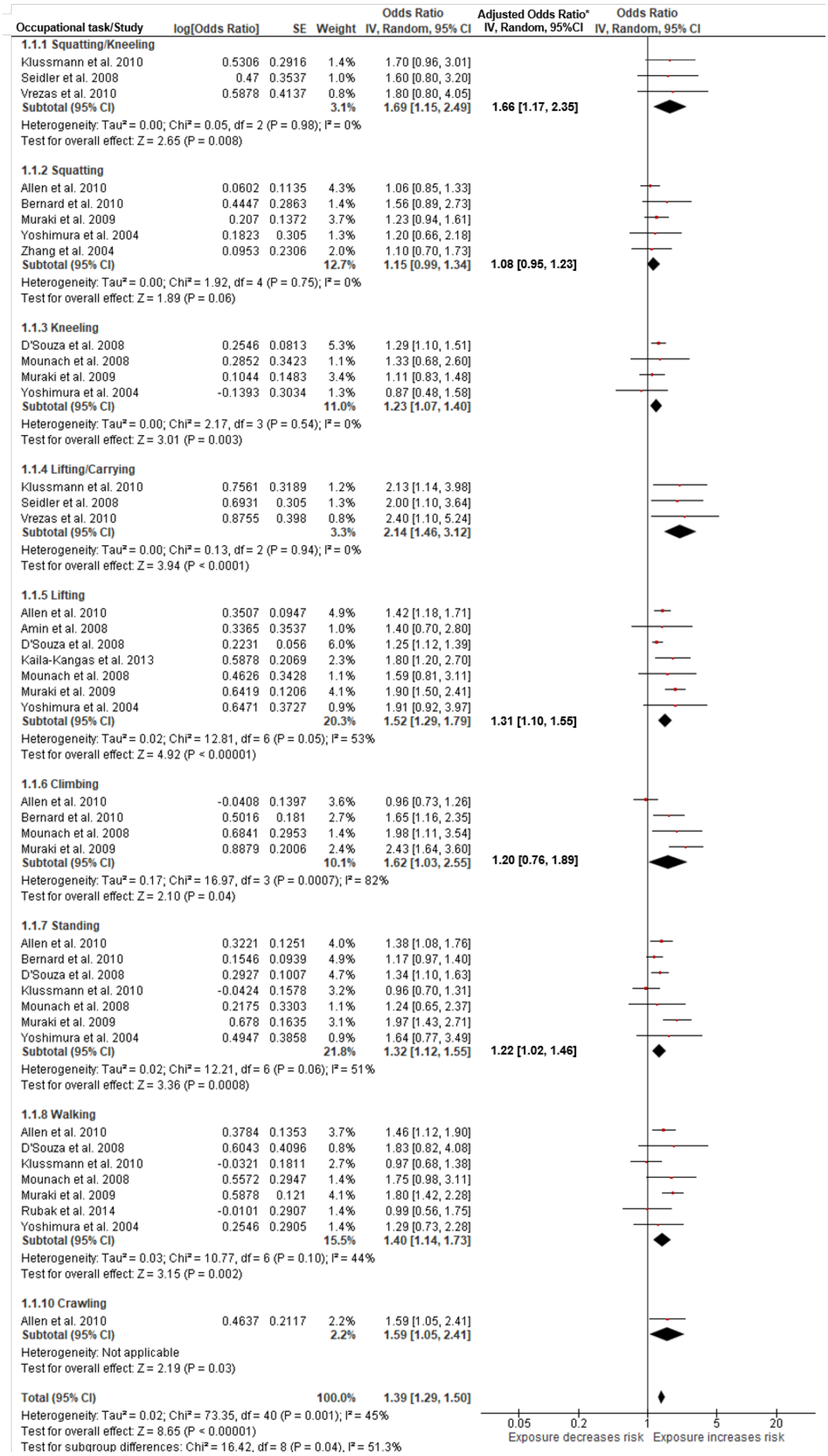
4.3.3 Occupational tasks

4.3.3.1 Occupational tasks associated with knee OA

The occupational tasks considered in many studies as risk factors for development of knee OA are depicted in Figure 4.2. Five of the 17 studies that reported on occupational tasks associated with development of knee OA were excluded from the final meta-analysis for knee OA risk because they either failed to identify the exclusive contribution of a particular task (i.e., exposure indexes or self-reported time spent in task and/or years in the occupation) or did not provide enough information for estimating data. The 12 studies included in the final meta-analysis revealed a significant, though modest, overall contribution of exposure to these physically demanding tasks, to the risk of developing knee OA (Figure 4.2).

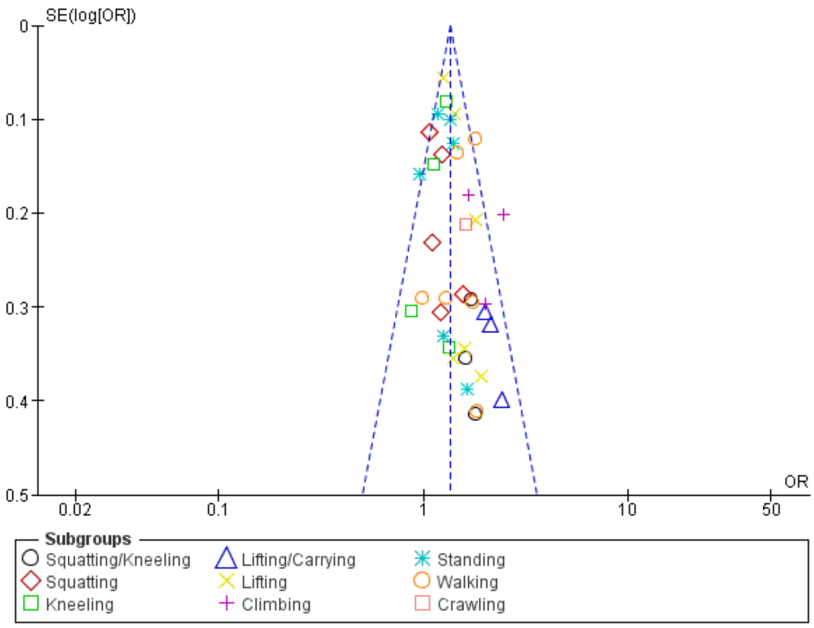
Contributions of exposure to individual task categories in increasing knee OA risk (Figure 4.2) were generally modest, although in most instances statistically significant. There was moderate overall heterogeneity among the task categories that were analysed, so a random model was used. Trim-and-fill adjustments [31] were performed because visual inspection of a funnel plot revealed likely publication bias (Figure 4.3). Trim-and-fill adjustment resulted in the input of 11 values, all to the left of the funnel plot (i.e., lower effect size). The adjusted ORs and 95% CIs were still significant in most task categories apart from squatting and climbing (Figure 4.3).

Figure 4.2: Occupational tasks and associated comparative risks of developing knee OA following task exposure.



*Values obtained after trim-and-fill adjustment

Figure 4.3: Funnel plot for studies of associations between occupational task exposures and knee OA.



4.3.3.1.1 Lifting/carrying

Ten studies assessed the association between exposure to lifting/carrying and risk of developing knee OA. Of these studies, three combined the actions of lifting and carrying [36, 38, 39], and the remaining seven assessed lifting separately. The reported weights lifted ranged from 4.5 kg to > 25 kg, and, when reported, frequency of lifting ranged from once to 10 times per week. Meta-analysis results showed a significant association between exposure to lifting/carrying tasks and risk of developing knee OA (Figure 4.2).

Lifting 4.5 kg 10 times/week (OR of 1.42 [1.13, 1.80]) [44] and > 10 kg/week was reported to increase the risk of OA in both men (OR 2.26 [1.52, 3.40]) and women (OR 1.68 [1.24, 2.26]) [52]. Substantial cumulative exposure to lifting and carrying (ranging from 5,120 to 37,000kg*hour) resulted in an increase in the risk of knee OA in men (OR 2.0 [1.1, 3.9]) [38] and a 2.6-fold increased risk in men with BMI > 25 kg/m^2 [39]. In women, the cumulative exposure to lifting/carrying more than 1,088 tonnes/lifetime (mean reported lifetime 59.6 years [+ 9.8 years of age]) was a significant contributing factor to the development of knee OA (OR 2.13 [1.14, 3.98]) [36].

4.3.3.1.2 Squatting / knee bending / kneeling

Twelve studies reported specifically on squatting, kneeling, and knee-bending tasks as risk factors for the development of knee OA. Combined, these studies indicated that squatting, kneeling, and other knee-bending tasks were significantly associated with the development of knee OA, although the comparative risk for people exposed to these tasks was only a little higher than for those who were not exposed (OR 1.21 [1.10, 1.33], $z = 3.82$, $p < 0.001$). The associations between individual task categories (i.e., squatting, kneeling, and knee bending) and the development of knee OA are provided in Figure 4.2.

Among the twelve studies, authors of three case-control studies [36, 38, 39] and one cohort study [45] reported on the three tasks without acknowledging the biomechanical differences between them. These three studies, grouped for meta-analytic purposes, demonstrated a significant association between the three task categories combined and the development of knee OA (Figure 4.3). Exposure to kneeling/squatting for 3,574 to 12,244 hours/life was associated with a substantial increase in the occurrence of symptomatic knee OA in male patients when they were compared with apparently healthy controls (OR 2.16 [1.24, 3.77]) [36]. A similar exposure range (4,757–10,800 hours/life) was reported to contribute to the risk of knee OA development in male patients (OR 1.6 [0.8,3.4]) [38] and to further increase risk in male patients with a BMI > 25kg/m^2 when they were compared with controls who had normal BMI (OR 8.9 [4.4, 17.9]) [39].

Lifetime exposures to these tasks for more than 10,800 hours/life were associated with a significant increase in the risk of knee OA in men—approximately a 2-fold [36] to 4-fold [38] increase. Similarly, for women, a lifetime exposure of > 8,934 hours/life was associated with more than a two-fold increase in the risk of knee OA [36]. Amin et al. [45] reported that a combined exposure of squatting/kneeling (> 30 min/day) and lifting (> 10 kgs/day) was associated with an increased risk of poor cartilage morphology at the patello-femoral joint (OR 1.6 [1.0, 2.7]) in male workers when they were compared with other male workers who did neither of these activities. This finding was corroborated in a separate study, where lifetime exposure of kneeling/squatting > 10,800 hours and lifting/carrying > 37,000 kg*hours was associated with a significant increase in the risk of symptomatic knee OA in men (OR 7.9 [2.0, 31.5]) [38].

Although the results of most individual studies were not statistically significant, the pooled results from the meta-analyses suggested that kneeling, but not squatting, contributed significantly to the development of knee OA (see Figure 4.2).

4.3.3.1.3 Standing

Seven studies reported on standing as a risk factor for the development of knee OA. Results of the meta-analysis showed a significant association between exposure to this task category and development of knee OA (see Figure 4.2). Two studies [46, 47] indicated that for women (but not for men), standing for more than 2 hours/day increased risk of knee OA. Conversely, Monauch et al. [37] described no significant association between standing for > 5 hours per day and development of knee OA when comparing exposed cases with controls. These differences may be due to study design, sample size, or participants' occupations. The two studies in agreement were cross-sectional studies, each with more than 2,000 participants [43, 44], whereas the third, a case-control study, included only 95 cases [34]. Further, more than half of the cases and controls in the case-control study were housewives, whereas the two cross-sectional studies encompassed a greater variety of trades including farmers, construction workers, labourers, machinery operators, and retail workers.

4.3.3.1.4 Climbing, walking, and crawling

Four studies reported on climbing as a risk factor for the development of knee OA. Although three individual studies indicated a statistically significant contribution of climbing for the development of knee OA [37, 46, 52], trim-and-fit adjusted pooled results, did not (Figure 4.2).

The contribution of walking to the development of knee OA was reported in seven studies [36, 37, 42–44, 47, 52]. Of these, only two studies identified a statistically significant risk of walking for more than 50% of the time in their occupation (OR 1.46 [1.12, 1.90]) [44] or when walking distance exceeded 3 km per day (OR 1.80 [1.48, 2.28]) [52]. Only one study reported on occupational crawling as a risk factor for the development of knee OA [44], with the overall risk of climbing in relation to knee OA found to be 1.39 [1.05, 2.41].

4.3.3.1.5 Physical load (without specifying task)

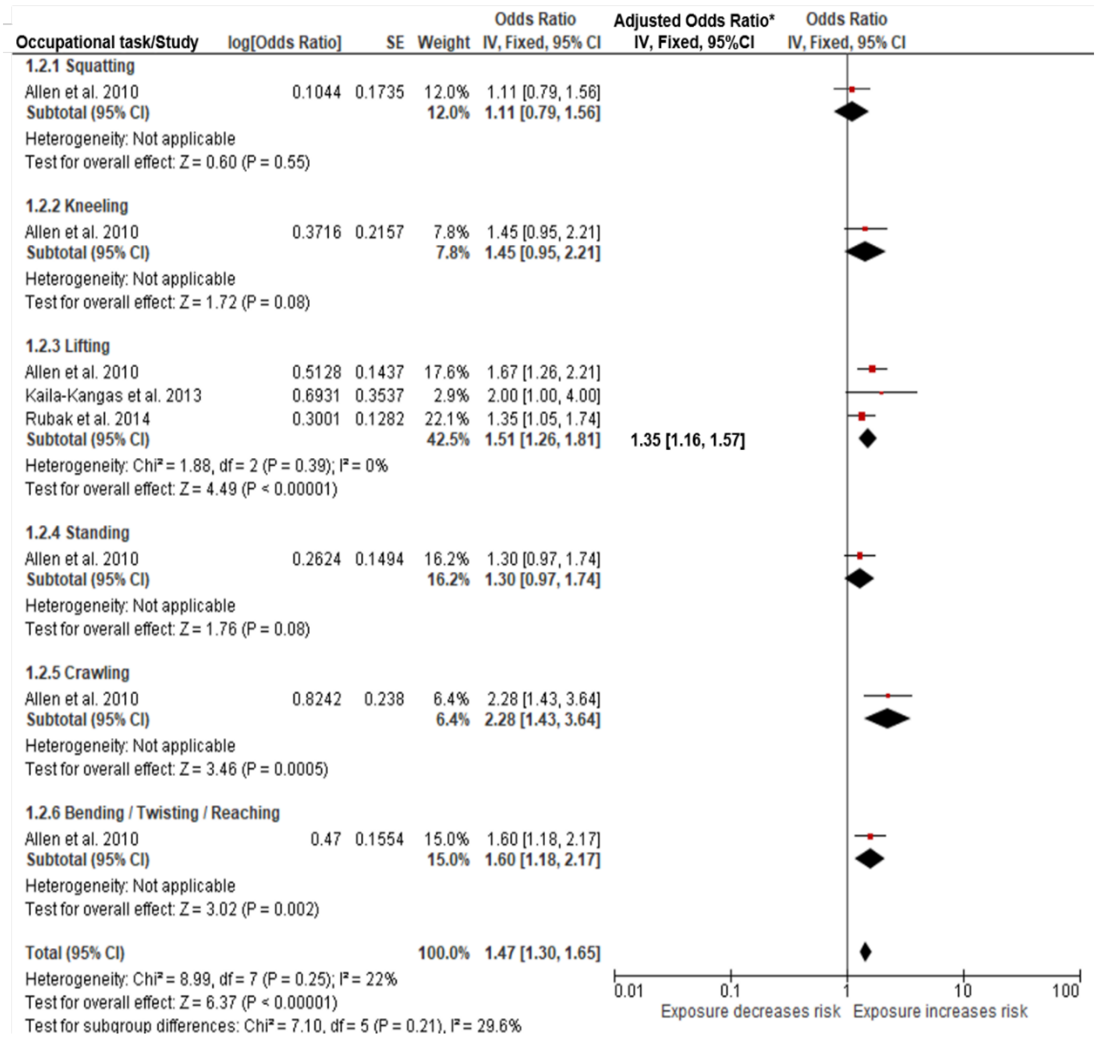
Two studies created a physical load-exposure index by coupling occupational tasks with other variables, such as time and/or years [48, 49]. The first of these two studies [48] involved two population-based cohorts and a physical load index (i.e., product of the number of years in the job, activity level, and knee bending or kneeling score) categorising cumulative physical load exposures into quartiles. Individuals in the highest physical loading quartile had higher risk of knee OA (OR 8.16 [1.89, 35.27], $p < 0.05$) when compared with the lowest quartile, as did the second highest quartile when compared with the second lowest quartile (OR 5.73 [1.36, 24.12], $p < 0.05$). Both MRI-diagnosed and symptomatic OA were found to have dose-response relationships with occupational activity level, but radiographically diagnosed knee OA did not. Jensen [49] highlighted a dose-response relationship between an exposure index (product of video assessment, self-reported time performing knee-straining occupational tasks and self-reported years in the trade) and self-reported chronic (> 30 days in 12 months) knee complaints. This group reported a higher risk of knee OA in participants with high exposure when compared with those with no exposure to such tasks (OR 7.06 [3.7, 13.4]) [49]. The same trend was observed for radiographically diagnosed OA, as those with very high exposure to knee-straining tasks were at increased risk of radiographically diagnosed knee OA when compared with those not exposed (OR 4.92 [1.1, 21.9]) [49].

4.3.3.2 Occupational tasks associated with hip OA

Only three of the included studies [43, 44, 51] provided information about occupational tasks associated with the risk of developing hip OA. Despite the small number of studies, meta-analysis of findings revealed a significant association between exposure to most of these tasks and risk of developing hip OA (Figure 4.4). Inspection of the funnel plot (Figure 4.5) suggested publication bias for studies of lifting tasks. Trim-and-fill adjustments resulted in two values being located to the left of the funnel plot (i.e., lower effect size). The adjusted OR and 95% CIs still demonstrated significant contribution of lifting to the development of hip OA (Figure 4.4).

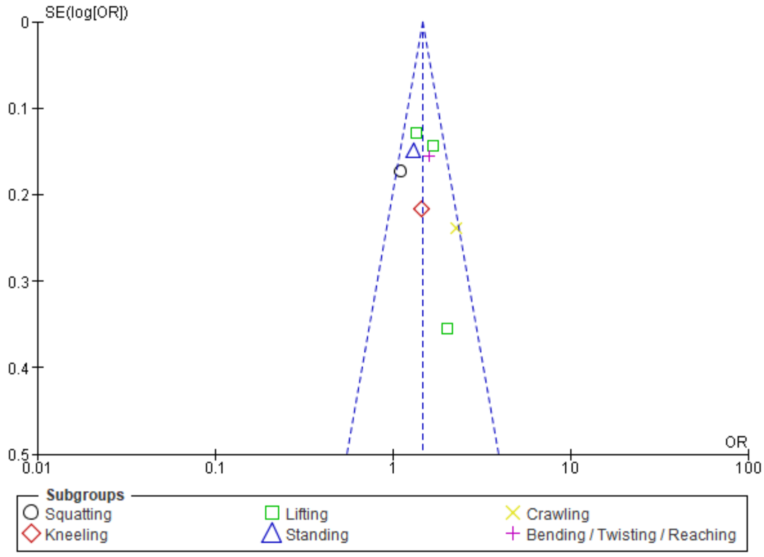
Three studies reported on the contribution of lifting to the development of hip OA [43, 44, 51]. Allen et al. [44] provided strong evidence of increased risk of hip OA development associated with a lifetime exposure to lifting > 10 kg (OR 1.71 [1.28, 2.29]), 20 kg (OR 1.63 [1.15, 2.30]) or 50 kg (OR 1.88 [1.20, 2.92]) > 10 times per week, in agreement with findings from Kaila-Kangas et al. [51].There was only one study [44] in which squatting, crawling, bending/twisting/reaching, standing, and kneeling were examined. As shown in Figure 4.4, only lifting, crawling, and bending/twisting/reaching significantly increased the risk of hip OA.

Figure 4.4: Occupational tasks and associated comparative risks of developing hip OA following task exposure.



*Values obtained after Trim-and-Fill adjustment

Figure 4.5: Funnel plot for studies of associations between occupational task exposures and hip OA.

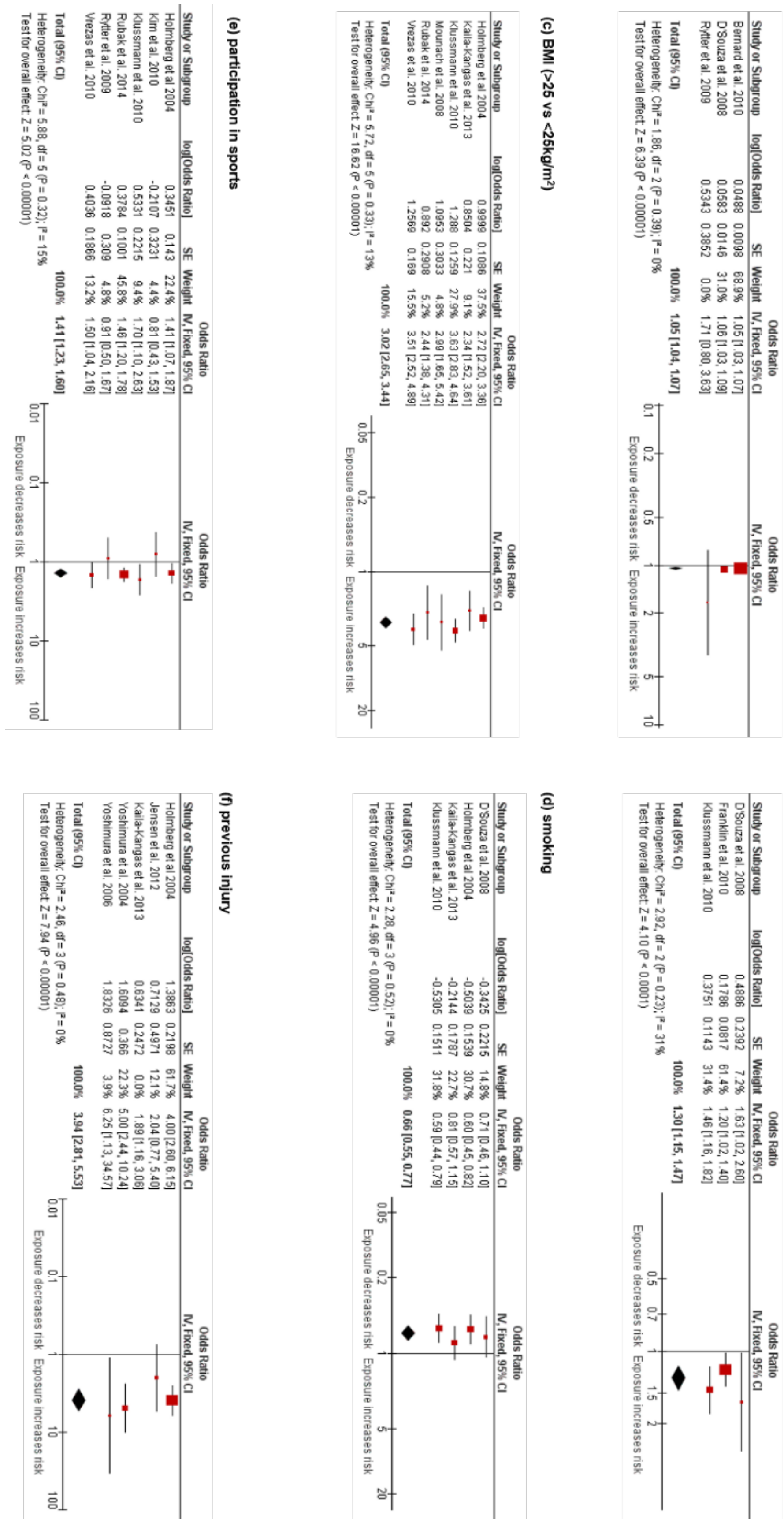


4.3.4 Other factors that may interact with occupational task exposures to increase risk of lower-limb OA

The secondary aim of this review was to determine factors other than occupational tasks that may interact with occupational task exposures in affecting the risk of developing lower-limb OA. Gender, age, BMI, smoking habits, participation in sport, and previous injuries have all been reported as additional risk factors for the development of lower-limb OA in occupational populations. All the included studies reported on at least one of these risk factors. Forty six percent of the 28 studies reviewed (n = 13) provided enough information to allow quantification of the influence of such additional factors associated with the risk of lower-limb OA. The unique contribution of these factors reported in the studies investigating the association between occupations/occupational tasks and the risk of OA are depicted in Figure 4.6 (a–f).

The well-established associations of intrinsic risk factors such as gender, age, and BMI with OLL have been confirmed through this review for occupations with high physical demands. The meta-analysis revealed increased risk of developing lower-limb OA for persons > 50 years of age when compared with people < 50 years old (Figure 4.6a), for females compared with males (Figure 4.6b), and for persons with a BMI greater than 25 kg/m^2 when compared with those who have a normal BMI (Figure 4.6c). There was an inverse relationship between smoking and lower-limb OA in the physically demanding occupations (Figure 4.6d).

Figure 4.6a-f: Other factors contributing to lower-limb OA additional to occupational task exposures.



Participation in sport and previous injury were significant extrinsic risk factors for development of lower-limb OA. Participation in sport, reported by five studies, was a significant contributor to knee OA (Figure 4.6e). Cumulative exposures to injury-prone sports (not defined) of more than 1,440 hours/life increased the risk of knee OA in females when compared with controls not involved in sports (OR 2.5 [1.3, 4.6], $p < 0.01$) [36]. Similarly, in males, participation in sport for 3,232 hours or more throughout a lifetime produced an OR of 2.5 [1.6, 4.2] ($p < 0.01$) for risk of developing knee OA [34].

Of the sports reported, participation in soccer, ice hockey, or tennis increased the risk of lower-limb OA (OR exposed / not exposed 1.6 [1.1, 2.2], OR 1.9 [1.2, 3.0], OR 2.0 [1.1, 3.8], respectively). Five studies highlighted the contribution of previous injury to increasing the risk of OLL (Figure 4.6f). Holmberg et al. [33] distinguished between injuries, highlighting that among fractures, knee injuries, and meniscus injury, with the latter contributing more than did the other two categories in increasing the risk of OA in men (OR exposed/not exposed 6.7 [4.5, 10.1]) and women (OR 5.5 [3.4, 8.9]).

4.4 Discussion

Results from this review indicate that individuals in physically demanding occupations or exposed to specific types of physically demanding tasks were at increased risk of OLL. The most frequently reported occupations in which workers were at an increased risk of OLL were farming, floor laying, and bricklaying. Squatting with kneeling [36, 38, 39], kneeling alone [37, 42, 47, 52], lifting/carrying [36, 38, 39], lifting alone[44, 47, 51, 52], climbing [37, 46, 52], standing [44, 47, 52], walking [44, 52], and crawling [44] constituted specific tasks associated with risk of knee OA. The data on hip OA were limited, but three studies [43, 44, 51] found that hip OA was associated with lifting tasks.

With regard to occupations, Andersen et al. [32] reported incidence rates of surgically treated hip OA and knee OA in farmers of 157 and 47 per 100,000 person-years, respectively. Other occupations, such as military service, have been identified with high incidence rates of OA [55, 61-63], reporting 786 cases of OA per 100,000 person-years across all active duty service members in the US military [61]. Only one of these military studies was included in this review [55] because the others failed to meet the criteria of image-based OA diagnosis [61-63].

Physically demanding occupational tasks such as lifting/carrying heavy weights and kneeling/squatting, routinely performed by farmers and floor layers, have been frequently associated with increased risk of lower-limb OA [36–39, 42, 47, 49, 52, 58]. Exposures to lifting and carrying that have been associated with increased risks vary and have included > 1,088 tons/life, > 10 kgs for 8–20% of work day, and > 5,120 kg*hour. Exposures to kneeling/squatting (without an external load) that have been associated with increased risk have ranged from > 1 hour/day to cumulatively > 4,757 hours.

Interestingly, only one of the included studies reported on military personnel [55], who, during training and duty are required to kneel, squat, and march long distances (> 10 km) carrying loads of up to 60% of their body weight [64, 65], with the higher loads in this range exceeding loads reported in other occupations. Simpson et al. [66] reported on US recruits undertaking their 44-day army basic combat training and noted that, in 7 nonconsecutive days, they carried external loads ranging from 23–34 kgs for a cumulative 5.4 (+ 3.8) hours. Orr et al. [67] reported on the incidence and distribution of injuries among Australian Army soldiers, highlighting that 56% of the injuries affected the lower-limb and 62% of load carriage injuries occurred while marching. Marching with external load has been reported to increase ground reaction forces incrementally because load is increased in increments of 8 kgs [68], decreasing stability and altering gait patterns [69], thus exposing all joints in the kinetic chain to risk of injury.

Many tasks that have been consistently identified in the literature and confirmed in this review as risk factors for OA, such as squatting/kneeling and standing, were similar in that they comprise closed kinetic chain movements because the distal aspect (in this case the foot) is fixed or stationary on the ground while other joints can move.

Thus, anomalies in one joint in the chain could influence other joints in the chain and multi-joint symptomatology is a possibility. For example, Rytter et al. [54] demonstrated that workers with radiographically confirmed hip alterations had an increased likelihood of knee complaints. Recently, Paterson et al. [70] identified a significant association between foot and ankle symptoms (i.e., pain, ache, stiffness) and an increase in risk of developing knee OA as well as the worsening of symptomatic knee OA [71].

Contralateral foot/ankle symptoms have been associated with significantly increased risk of developing radiographically confirmed knee OA (OR 3.08 [1.06, 8.98]) [70]. Interestingly a significant risk of worsening knee pain was also identified in patients with ipsilateral (OR 1.5 [1.07, 2.10] $p = 0.017$), contralateral (OR 1.44 [1.02, 2.06] $p = 0.038$), or bilateral (OR 1.61 [1.22, 2.13] $p < 0.001$) ankle pain [71].

None of the studies included in this review alluded to pain in any other joints than the knee and hip. However, data from military personnel have identified that the incidence of ankle injuries (e.g., sprains) is 45.14 per 1,000 person-years [72]. Given the biomechanical adaptations to load carriage and the high incidence of injuries in the kinetic chain, it can be postulated that military personnel are at a higher risk of developing or further aggravating conditions affecting the lower limb, particularly knee and hip OA.

The contribution of other risk factors (e.g., BMI, age, and gender) to risk of developing lower-limb OA in association with occupation or occupational tasks has been reaffirmed in this review. Interestingly, smoking has been demonstrated to have an inverse association with lower-limb OA, in agreement with a recent systematic review [73]. Disregarding the possible biochemical effects of nicotine (found to upregulate glycosaminoglycan (GAG) and collagen synthetic activity of articular chondrocytes [74]) and other cigarette components, this 'protective' effect may stem from lower BMI in current smokers compared with never smokers [75-77] or the increased number of breaks from work accessed by smokers (i.e., de-loading). Borland et al. [78] reported an average of 9.25 cigarettes smoked among smokers who left work two or more times a day for a cigarette break. Considering the time to smoke a cigarette is five minutes, these workers would have almost an extra 50 minutes per day of 'breaks' from usual work, not considering regular work breaks (e.g., lunch).

Curiously, little association was found between physical activity or fitness levels and lower-limb OA in the studies included in this review. The limited mention of physical activity was restricted to seven studies [34, 36, 37, 40–42, 48] whereas fitness status (i.e., aerobic capacity) failed to be acknowledged as a potential modifier of risk for developing lower-limb OA. Among the seven studies that mentioned it, the frequency of physical activity was only described by two studies in which there were vague criteria such as < or > 3 times per week [57] or none, light, regular, or high [34], without attributing informative characteristics such as duration and intensity. Hootman et al. [79] have demonstrated that adequate isokinetic quadriceps strength was associated with lowering the risk of lower-limb OA by up to 64% in women. Moderate aerobic exercise and individually progressed weight-bearing strengthening exercises (one hour, 3x/weekly for 4 months) have also been shown to improve knee-cartilage GAGs, pain reduction, and function in participants at risk of knee OA (3–5 years post partial medial meniscectomy) [80]. Moreover, a lack of aerobic fitness (measured by the 20 m shuttle run test [81] and by VO_2 peak [82]) has been identified as a strong predictor of risk of musculoskeletal injury.

Thelin et al. [83] suggested that the association between participation in sport and the risk of developing knee OA may be attributed to the injuries sustained during participation in sport. Once the model assessing the association between sport participation and the risk of knee OA was adjusted for previous knee injuries, the positive association lost its statistical significance (from OR 1.52 [1.04, 2.20] to OR 0.94 [0.61, 1.44]) [83]. This supposition has been corroborated by recent research demonstrating an increased likelihood of knee replacement surgery up to 15 years after a sports-related injury (hazard ratio 2.41 95% CI [1.73, 3.37]) [84]. Interestingly, 50% of the 338 cases of knee OA in the study by Thelin et al. [83] had suffered meniscal injury, highlighting the association between meniscal injury and knee OA (OR 6.73 [4.49, 10.1]) when compared with matched controls. Jones et al. [85] identified an overall incidence rate of 8.27 [8.22, 8.32] per 1,000 person-years for meniscal injuries among active-duty US military service members, 10 times more than reported in the general population. This reported incidence may be explained by high exposure of this population to risks associated with meniscal injuries. Acute injuries may be related to participation in sports while degenerative meniscal tears have been associated with occupational kneeling and squatting (OR 2.69 [1.64, 4.40] when compared with no exposure to these tasks) [86]. Therefore, it is not surprising that incidence rates and rate ratios of meniscal injuries in US military service members have been found to increase as age increased [85]. The investigators also highlighted that those in the Army and Marine Corps suffered the highest rates of injury among the different service branches [85]. Thus, the physically demanding nature of defence occupations coupled with the high exposure to knee-straining occupational tasks and high incidence of injuries places military personnel at a high risk of developing lower-limb OA.

4.4.1 Limitations

This review is not without its limitations. The methodological quality of the studies was rated on scales that differed depending on study design. Most of the studies were of a cross-sectional design, which may create a population bias and prevent definitive identification of causal relationships [87]. Further, self-report questionnaires were used in most studies to obtain information about exposure to occupational tasks, and therefore recall bias could have influenced the results. This methodological approach (i.e., self-report questionnaires), has been found to provide, at times, an overestimation of workload of up to 45% [36]. Such issues are also common in case-control studies [88], which make up 36% (n = 10) of the studies reviewed.

4.5 Conclusion

This review indicates a degree of consensus that highly physical occupational demands contribute to the development of knee and hip OA. Further, when compared with single tasks, combinations of arduous occupational tasks (i.e., kneeling/squatting and heavy lifting/carrying) seem to impose a greater risk of lower-limb OA development. The disparity in reporting of cumulative loads poses a challenge when attempting to suggest exposure thresholds. Studies have reported exposure using different measures (e.g., kg/week, tonnes, kg*hour, tonnes/lifetime), often failing to provide duration of the exposure (e.g., years worked, lifetime in years). Without such information, it is difficult to determine whether the risk of OA is linked to the weight of the load, frequency of the task, duration of the task, or a combination of all three. Future studies assessing risk of OA development based on occupational task exposures should aim to disclose all information about the data captured and aim to standardise exposure assessment, thus allowing direct comparisons between exposures. Moreover, participation in sport and a history of previous injuries were found to be two of the strongest extrinsic risk factors for lower-limb OA. This review provides evidence that exposure to knee-straining occupational tasks, in particular lifting / carrying and kneeling / squatting, is associated with an increased risk of developing lower-limb OA.

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Supplementary Table 1: Occupational tasks contributing to lower limb OA

Reference	Joint	Study type	Subjects	Methods (OA Diagnosis / Exposure to Risk Factors)	Occupational Tasks as Risk Factors: Comparative levels of risk	OR [95%CI]	Other Risk Factors: Comparative levels of risk	Study Quality#
Allen et al. [44]	Hip and Knee	Cross-sectional	n=2729; ♂=933 ♀=1796 Mean (SD) age 63.3 (10.5) years	Interviewer administered questionnaire + Kellgren-Lawrence OA, ≥grade 2	**Knee**		All values were adjusted for age, gender, race, body mass index, smoking (ever and current vs never), prior knee injury, and household tasks. Authors do not disclose unadjusted value or comment on differences in findings based on adjusting.	70%
					Lift > 4.5kg ten times/weekly	1.42 [1.13, 1.80]		
					Stand	1.38 [1.08, 1.77]		
					Bend, twist, reach	1.26 [0.99, 1.60]		
					Crawl	1.59 [1.05, 2.41]		
					Heavy work, standing	1.44 [1.03, 2.02]		
			(Participants from Johnston County Osteoarthritis Project)	Frequency of exposure: Rated 5-pt scale 0=never, 4=always	*Lifetime Exposure*			
					Heavy work while standing >50% of job	1.32 [1.02, 1.72]		
					Hip			
					Lift > 4.5kg ten times/weekly	1.67 [1.26, 2.23]		
				Activities graded as life time exposure= *Lifetime Exposure (>50% of time in job)*	Bend, twist, reach	1.60 [1.18, 2.17]		
					Crawl	2.28 [1.43, 3.65]		
					Heavy work, standing	1.75 [1.17, 2.61]		
					Lifetime Exposure			
					Heavy work while standing >50% of job	1.39 [1.01, 1.91]		
					Lifting 10 kg ≥ 10×/week	1.71 [1.28, 2.29]		
					Lifting 20 kg ≥ 10×/week	1.63 [1.15, 2.30]		
					Lifting 50 kg ≥ 10×/week	1.88 [1.20, 2.92]		
					Reference: No exposure			

Supplementary Table 1: Occupational tasks contributing to lower limb OA (cont.)

Reference	Joint	Study type	Subjects	Methods (OA Diagnosis / Exposure to Risk Factors)	Occupational Tasks as Risk Factors: Comparative levels of risk			Other Risk Factors: Comparative levels of risk			Study Quality#
Amin et al. [45]	Knee	Cross sectional	192 ♂ Heavy lifting group n=40 (age 69±9 years) Squatting/kneeling and heavy lifting n=47 (age 64±9 years) Control n=97 (age 70±9 years)	Questionnaire + MRI	Squatting/kneeling and heavy lifting associated with worse cartilage morphology (MRI) than men who did either or none of these activities						53%
						OR [95%CI]					
					Patellofemoral Joint	1.8 [1.1, 3.2]					
					Tibiofemoral Joint	1.6 [0.9, 3.0]					
Bernard et al. [46]	Knee	Cross sectional	n=3458 (2450 ♀ and 1098 ♂) Database of the Clearwater Osteoarthritis Study with demographic, historical, clinical and radiological data of individuals over 40 years old.	Questionnaire + X-ray (Kellgren & Lawrence grades)	**Knee**	♂ OR [95%CI]	♀ OR [95%CI]	**Knee**	♂ OR [95%CI]	♀ OR [95%CI]	63%
					Stair climbing > 5 times/day	1.61 [1.11, 2.32]	1.14 [0.87, 1.49]	Age	1.05 [1.03, 1.07]	1.07 [1.06, 1.08]	
					Jolting of feet and legs	2.39 [1.38, 4.15]	1.39 [0.78, 2.45]	BMI	1.12 [1.08, 1.16]	1.12 [1.10, 1.15]	
					Standing on a rigid surface (≥2h/day)	1.12 [0.81, 1.55]	1.36 [1.06, 1.73]				
					Squatting	1.56 [0.89, 2.75]	0.89 [0.50, 1.61]				
					Foot	♂	♀	**Foot**	♂	♀	
					Stair climbing > 5 times/day	1.41 [1.01, 1.97]	0.88 [0.68, 1.13]	Age	1.04 [1.02, 1.05]	1.06 [1.04,1.07]	
					Jolting of feet and legs	0.97 [0.56, 1.69]	1.14 [0.68, 1.94]	BMI	1.05 [1.02,1.09]	1.03 [1.01, 1.05]	
					Standing on a rigid surface (≥2h/day)	1.00 [0.75, 1.34]	1.14 [0.91, 1.43]				
					Squatting	1.00 [0.59, 1.68]	1.05 [0.65, 1.70]				
					Reference: not exposed			*Reference: not stated*			

Supplementary Table 1: Occupational tasks contributing to lower limb OA (cont.)

Reference	Joint	Study type	Subjects	Methods (OA Diagnosis / Exposure to Risk Factors)	Occupational Tasks as Risk Factors: Comparative levels of risk			Other Risk Factors: Comparative levels of risk		Study Quality#
						♂ OR [95%CI]	♀ OR [95%CI]		OR [95%CI]	
D'Souza et al. [47]	Knee	Cross-sectional	n= 1970 participants (916 ♀ and 1054 ♂) Cohort from the Third National Health and Nutrition Examination Survey (NHANES III)	Questionnaire + Kellgren-Lawrence OA (≥2 = all, 3-4 = severe) + Knee pain	**Sitting** (>54% v <22% of workday)	0.46 [0.17, 1.22]	0.60 [0.19, 1.93]	Age (per year)	1.06 [1.03, 1.08]	65%
					Standing (30-36% v <26% of workday)	1.53 [0.66, 3.55]	2.28 [1.09, 4.77]	♀ Sex	1.63 [1.02, 2.62]	
					Walking (>30% v <16 of workday)	1.59 [0.48,5.23]	2.00 [0.84, 4.75]	Current BMI (per kg/m^2increased)	1.19 [1.13, 1.25]	
					Kneeling (14% v >4% of workday)	3.08 [1.31, 7.21]	1.31 [0.56, 3.07]	BMI 10 years ago (per kg/m^2 increased)	1.15 [1.10, 1.19]	
					Heavy lifting (>10kg) (>20% v <4% of workday)	2.72 [1.14, 6.50]	1.40 [0.51,3.82]	BMI at age25years (per kg/m^2 increased)	1.11 [1.06, 1.16]	
					Reference: lowest quartile of exposure (% of work day)					

Supplementary Table 1: Occupational tasks contributing to lower limb OA (cont.)

Reference	Joint	Study type	Subjects	Methods (OA Diagnosis / Exposure to Risk Factors)	Occupational Tasks as Risk Factors: Comparative levels of risk			Other Risk Factors: Comparative levels of risk		Study Quality[#]
Ezzat et al. [48]	Knee	Cross-sectional (Population-based cohort)	n=327 (167♀ and 160 ♂)	Survey + MRIs		OR [95%CI]			OR [95%CI]	73%
					Radiographic OA (ROA) v no ROA			**ROA v no ROA**		
					QCOPL3 v 1*	4.19 [1.55, 11.34]		Age (> 50 years old)	1.07 [1.04, 1.11]	
					QCOPL4 v 1*	3.15 [1.02, 9.70]		♀ Sex	2.15 [1.05, 4.39]	
								BMI	1.01 [0.94, 1.09]	
					Symptomatic OA (SOA) v no SOA					
					QCOPL3 v 1*	5.73 [1.36, 24.12]		**SOA v no SOA**		
					QCOPL4 v 1*	8.16 [1.89, 35.27]		Age (> 50 years old)	1.05 [1.01,1.09]	
					*Cumulative occupational load - COPL (# years in job x activity level x knee bending or kneeling score). Divided into quartiles of exposure (QCOPL), with 4 being highest.			♀ Sex	1.56 [0.67, 3.63]	
								BMI (reference not stated)	1.07 [0.98, 1.16]	
Kaila-Kangas et al. [51]	Hip	Cross sectional (Population-based cohort)	Total n=6556 Cases (♀ 71, ♂ 85) Control (♀ 3446, ♂ 3110)	Survey + interview	**Lifting, carrying or pushing heavy objects (>20kg) for minimum average of 10x per day/years**					58%
						♂ OR [95%CI]	♀ OR [95%CI]			
					1-12y	1.1 [0.4, 3.2]	1.6 [0.7, 3.5]			
					13-24y	3.8 [0.8, 5.9]	3.8 [1.7, 8.1]			
					Reference: no exposure					

Supplementary Table 1: Occupational tasks contributing to lower limb OA (cont.)

Reference	Joint	Study type	Subjects	Methods (OA Diagnosis / Exposure to Risk Factors)	Occupational Tasks as Risk Factors: Comparative levels of risk			Other Risk Factors: Comparative levels of risk			Study Quality#
Klussmann et al. [36]	Knee	Case control	739 cases (♀ 438, ♂ 301)	Questionnaire X-ray (Kellgren & Lawrence grades)		♂ OR [95%CI]	♀ OR [95%CI]		♂ OR [95%CI]	♀ OR [95%CI]	89%
					Kneeling and squatting			**Played Injury-prone sports**	2.58 [1.59, 4.17] (>3,232h/ life)	2.47 [1.31, 4.65] (>1,440h/life)	
			571 Controls (♀ 303, ♂ 268)		< 3,574	1.7 [0.96, 3.00]	1.5 [0.83, 2.69]				
					3,574-12,244h/life	2.16 [1.24, 3.77]	N/A	**BMI**			
					>8,934h/life	N/A	2.52 [1.38, 4.68]	Overweight	2.2 [1.43, 5.57]	3.2 [2.09, 4.96]	
					>12,244h/life	2.47 [1.41, 4.32]	N/A	Obese GI	4.0 [2.30, 6.94]	3.5 [2.12, 5.94]	
					Lifting and carrying			Obese GII	12.5 [4.40, 36.86]	11.5 [4.38, 30.63]	
					>1,088 tons/life	N/A	2.13 [1.14, 3.98]	Obese GIII	N/A	17.65 [4.50, 69.23]	
					Reference: no exposure			*Reference: BMI <25kg/m²*			
Mounach et al. [37]	Knee	Cohort	95 cases (♀69, ♂ 26), matched controls (n=95)	X-ray and questionnaire		OR [95%CI]			OR [95% CI]		56%
					Sitting (> 3h/day)	0.58 [0.44,0.75]		**BMI >30kg/m²**	3.12 [1.67,5.81]		
					Standing (> 5h/day)	0.80 [0.42, 1.53]					
					Kneeling (> 1h/day)	0.75[0.38,1.46]					
					Walking (> 2km/day)	0.57 [0.32,1.02]					
					Climbing (> 50 steps/day)	0.50 [0.20, 0.90]					
					Lifting weights (>25kg)	0.63 [0.32,1.23]					
					Reference: matched controls no exposure			*Reference: BMI <25kg/m²*			

Supplementary Table 1: Occupational tasks contributing to lower limb OA (cont.)

Reference	Joint	Study type	Subjects	Methods (OA Diagnosis / Exposure to Risk Factors)	Occupational Tasks as Risk Factors: Comparative levels of risk	Other Risk Factors: Comparative levels of risk	Study Quality#
Muraki et al. [52]	Knee	Cross sectional (population-based cohort)	1,471 participants (♀940, ♂ 531)	X-ray and questionnaire	OR [95%CI] Standing (> 2 h/day) 1.97 [1.43, 2.72] Walking (> 3 km/day) 1.80 [1.42, 2.29] Climbing (>1 h/day) 2.24 [1.65, 3.04] Lifting weights (> 10kg at least once/week 1.90 [1.50, 2.42] *Reference: no exposure*		75%
Muraki et al. [58]	Knee	Cross sectional (population-based cohort)	1,402 participants (♀896, ♂ 512)	X-ray and questionnaire	- **Tasks contributing to decreased medial minimum space of the tibial plateau:** Standing $\geq$ 2 hour/day Kneeling $\geq$1 hour/day - **Tasks contributing to increased osteophyte area in the tibial plateau:** Kneeling $\geq$1 hour/day *Data not shown: reported as regression coefficients*		80%
Rossignol et al. [53]	Hip and knee	Cross sectional	2842 Cases (no control group)	X-ray and questionnaire (physician)	**Occupational Task (% of cases)** **Lift or carry heavy objects** **Hip**: ♂ (of 478): 71.8; ♀ (of 272): 50.4 **Knee**: ♂ (of 862): 74.5; ♀ (of 537): 50.1 **Work in vibrating vehicle or with vibrating tools** **Hip**: ♂ (of 478): 38.5; ♀ (of 272): 3.7 **Knee**: ♂ (of 862): 35.5; ♀ (of 537): 5.4 **Uncomfortable position of the joint which later developed OA** **Hip**: ♂ (of 478): 71.3; ♀ (of 272): 65.1 **Knee**: ♂ (of 862): 76.8; ♀ (of 537): 65.4 **Repeat same movements continuously** **Hip**: ♂ (of 478): 51.5; ♀ (of 272): 55.9 **Knee**: ♂ (of 862): 56.1; ♀ (of 537): 55.7		60%

Supplementary Table 1: Occupational tasks contributing to lower limb OA (cont.)

Reference	Joint	Study type	Subjects	Methods (OA Diagnosis / Exposure to Risk Factors)	Occupational Tasks as Risk Factors: Comparative levels of risk			Other Risk Factors: Comparative levels of risk	Study Quality#
Rubak et al. [43]	Hip	Case control	1776 control sets (at least 1 control and 1 case) (861 sets ♀ and 915 sets ♂	Questionnaire (cohort of first-time THR due to primary hip OA – X-ray diagnosis required for surgical procedure)		♂ OR [95%CI]	♀ OR [95%CI]		89%
					Lift or carry				
					20 –115 ton-years	1.35 [1.05, 1.74]	1.00 [0.72, 1.41]		
					Standing/Walking				
					20–29 standing years^	0.99 [0.77, 1.28]	1.03 [0.78, 1.35]		
					^Standing-years were standardised to standing/walking 6 hours/day for 1 year				
					Reference: no exposure				
Seidler et al. [38]	Knee	Case control	295 male patients aged 25-70 and 327 population-based random sample control	Questionnaire + Interview + X-ray (Kellgren & Lawrence grades)			OR [95%CI]	When values were adjusted in combination for age, region, BMI, jogging/athletics, kneeling/squatting, and lifting/carrying (excluding the considered variable at time), all factors displayed in the previous column remained associated with the development of knee OA	83%
					Kneeling and squatting combined				
					>0 – <870 h		0.7 [0.3, 1.5]		
					870 – <4,757h		1.4 [0.8, 2.5]		
					4,757 – <10,800 h		2.8 [1.5, 5.4]		
					≥ 10,800h		4.0 [2.1, 7.6]		
					Cumulated lifting and carrying combined				
					630 – <5,120 kg*h		2.0 [1.2, 3.4]		
					5,120 – <37,000 kg*h		3.6 [2.1, 6.0]		
					> = 37,000 kg*h		3.5 [1.7, 7.2]		
					Kneeling/squatting and lifting/carrying combined				
					Kneeling/squatting 4,757 – <10,800 hrs. or lifting/carrying 5,120 – <37,000 kg*hrs		3.5 [2.0, 6.0]		
					Either kneeling/squatting >10,800 hrs. or lifting/carrying >37,000 kg*hrs		3.8 [2.1, 6.8]		
					Both kneeling/squatting >10,800 hrs. and lifting/carrying >37,000 kg*hrs		7.8 [2.1, 28.3]		
					Reference: no exposure				

Supplementary Table 1: Occupational tasks contributing to lower limb OA (cont.)

Reference	Joint	Study type	Subjects	Methods (OA Diagnosis / Exposure to Risk Factors)	Occupational Tasks as Risk Factors: Comparative levels of risk		Other Risk Factors: Comparative levels of risk		Study Quality#
Vrezas et al. [39]	Knee	Case-control	295 ♂ patients aged 25-70 and 327 population-based random sample control	Questionnaire + Interview + X-ray (Kellgren & Lawrence grades)	**Interaction of tasks and other factors**			OR [95%CI]	78%
						OR [95%CI]	Age ≥ 65years old (reference <35yo)	19.0 [6.1, 58.7]	
					Kneeling/Squatting (>4,757h) + Overweight	8.9 [4.4-17.9]	Overweight (reference *BMI <25kg/m²)*	10.8 [4.8, 24.3]	
					Lifting/Carrying (>5,120kg*h) + Overweight	6.8 [3.6-12.9]			
					Reference: no exposure and BMI <25kg/m²		**Physical Activity**		
							Cycling (>7,000h)	3.7 [1.7, 7.8]	
							Soccer (4,00-7,800h)	2.2 [1.0, 5.0]	
							Handball/ Basketball /volleyball (>2,100h)	4.0 [1.8, 8.9]	
							Gymnastics (400-2,200h)	3.2 [1.0, 9.8]	
							Reference: no participation in these activities		
Yoshimura et al. [42]	Knee	Case control	101 ♀ cases 101 matched controls	Questionnaire + Image		OR [95%CI]		OR [95%CI]	78%
					Sitting (> 2h/day)	0.77 [0.45, 1.32]	Previous injury *(reference no injury)*	5.0 [2.44, 10.23]	
					Standing (> 5h/day)	1.64 [0.77, 3.46]	Weight ≥ 62.kg *(reference <55kg)*	3.10 [1.26, 7.58]	
					Kneeling (> 1h/day)	0.87 [0.48, 1.58]			
					Squatting (>1h/day)	1.20 [0.66, 2.17]			
					Driving (>4h/day)	0.50 [0.05, 5.51]			
					Walking (> 2km/day)	1.29 [0.73, 2.27]			
					Climbing (> 30 steps/day)	1.19 [0.61, 2.31]			
					Lifting Weights (>25kg)	1.91 [0.92, 3.96]			
					Reference: matched controls no exposure				

Supplementary Table 1: Occupational tasks contributing to lower limb OA (cont.)

Reference	Joint	Study type	Subjects	Methods (OA Diagnosis / Exposure to Risk Factors)	Occupational Tasks as Risk Factors: Comparative levels of risk			Other Risk Factors: Comparative levels of risk		Study Quality#
Yoshimura et al. [41]	Knee	Case control	37 ♂ cases (>45 years old) ≥ 3 grade in Kellgren & Lawrence x-ray) 37 matched controls	Questionnaire + image		OR [95%CI]			OR [95%CI]	78%
					Risk of OA with physical work*	2.8 [1.01,7.77]		Previous injury	2.5 [0.78, 7.97]	
					Risk of OA with physical work (adjusted for weight and previous injury)	6.2 [1.40, 27.5]		Previous injury (adjusted for weight and work)	6.25 [1.12, 34.5]	
					* based on occupations – factory, construction, agriculture or fishery work) without specifying occupational tasks.			Weight: ≥72kg (compared to <55kg)	4.22 [1.13,15.8]	
								Weight (adjusted for previous injury and work)	6.01 [1.18, 30.5]	
Zhang et al. [56]	Knee	Cross sectional	1,858 participants (♀ 1103, ♂ 755)	Tibiofemoral - Kellgren-Lawrence grade ≥2; patellofemoral, osteophyte or joint space narrowing >2) + Interviewer-administered questionnaire	Squatting at age 25 (in minutes/day)	♂ OR [95%CI]	♀ OR [95%CI]			58%
					Tibiofemoral OA					
					30-59	1.1 [0.7, 1.9]	1.4 [0.9, 2.2]			
					60-120	1.0 [0.6, 1.6]	1.3 [0.9, 2.0]			
					120-179	1.7 [0.8, 3.5]	1.2 [0.8, 1.9]			
					≥180	2.0 [0.9, 4.3]	2.4 [1.3, 4.4]			
					Patellofemoral OA					
					30-59	0.9 [0.6, 1.5]	1.5 [1.0, 2.4]			
					60-120	1.2 [0.8, 1.8]	1.3 [0.9, 2.0]			
					120-179	1.2 [0.6, 2.4]	1.2 [0.8, 1.8]			
					≥180	1.4 [0.6, 3.0]	1.7 [0.9, 3.0]			
					Reference: squatting 0-29 minutes/day					

#Study quality percentage score is based on the critical appraisal tool specific to each study design, described in the methods section of this review. BMI was categorised into the groups of normal weight (BMI = 18.5 to <25 kg/m^2), overweight (BMI ≥25 to <30 kg/m^2), obesity grade I (BMI ≥30 to <35 kg/m^2), obesity grade II (BMI ≥35 to <40 kg/m^2), and obesity grade III (BMI ≥40 kg/m^2) according to the definitions of the World Health Organization. BMI: body mass index. OA: osteoarthritis. OR: Odds ratio. CI: confidence intervals.

5. METHODS: DESKTOP ANALYSIS, OBSERVATIONS, SURVEYS, AND JOB EXPOSURE MATRIX

In this chapter, we describe the methods employed for the desktop analysis of selected initial training programs, the observations and surveys undertaken within the same training programs, and the construction of a job exposure matrix for osteoarthritis (OA) of the lower limbs (JEM-OLL) within each service. Methods employed for other project components (e.g., critical narrative review and historical review) are detailed in their respective chapters of this report.

5.1 Desktop Analysis

5.1.1 Research design

The desktop analysis of initial, entry-level training undertaken by full-time personnel from selected occupations of the ADF involved a cross-sectional survey design, examining training programs from the calendar year 2018. The levels of exposure experienced by full-time personnel from these initial training courses to factors that are known to increase the risk of developing osteoarthritis of the lower limbs (OLL) were estimated using a systematic approach, detailed below.

5.1.2 Data collection

Complete documentation of the selected initial training programs undertaken by full-time personnel within each service were requested and obtained from each service of the ADF and formed the basis for this desktop analysis. The initial training programs selected from each of the three services for analysis were as follows:

Air Force

RAAF Wagga (NSW)

- Air Force recruit training

RAAF Sale (VIC)

- Air Force Initial Officer Course

RAAF Amberley (QLD)

- Airfield Defence Guard Initial Employment Training
- Loadmaster Initial Employment Training

Latchford Barracks (VIC)

- Australian Defence Force Medic Training Continuum

Navy

HMAS Creswell (NSW)

- Navy New Entry Officers' Course

HMAS Cerberus (Victoria)

- Navy Recruit School
- Boatswain's Mate Course
- Marine Technician Initial Technical Training
- Maritime Logistics - Personnel Operations Course

Army

Army Recruit Training Centre (Kapooka, NSW)

- Army Recruit Training Course

Royal Military College - Duntroon (Canberra, ACT)

- Initial officer training

School of Infantry (Singleton, NSW)

- Infantry Initial Employment Training

Road Transport Wing, Army Logistic Training Centre (Puckapunyal, VIC)

- Driver Specialist Initial Employment Training

Army School of Health, Latchford Barracks (Bonegilla, VIC).

- Australian Defence Force Medic Training Continuum

These programs were purposively selected in order to:

1. include the entry-level training courses undertaken by all full-time Australian Defence Force personnel (i.e., to cover the starting points in initial training for all Air Force, Navy, and Army full-time occupations, including recruit training and officer training); and

2. include three occupation-specific initial training courses (which are undertaken after entry-level training courses have been completed, for example, occupation-specific Initial Employment Training [IET] courses) that are known to involve:

a. a relatively low physical activity loading level (e.g., Australian Defence Force Medic Training Continuum and Maritime Logistics – Personnel Operations Course);

b. a relatively high physical activity loading level (e.g., Airfield Defence Guard Initial Employment Training, Boatswain's Mate Course, and Infantry Initial Employment Training); or

c. a high level of specific exposure concern (e.g., Driver Specialist Initial Employment Training and Marine Technician ITT exposure to vibration and Loadmaster Initial Employment Training exposure to vibration and heavy lifting and carrying).

The purposive sampling was designed to ensure that each of the selected initial training courses was reasonably representative of other occupation-specific initial training courses from the ADF that involved similar levels of physical demands or specific exposure types. The selection of these occupation-specific initial training courses was informed by consultation with senior physical training instructors and other subject matter expert advisers from across the ADF.

In most cases, the training program documentation included standard core data elements, including a session-by-session breakdown of the respective training program, details of the physical training regime encompassed within it, and information on time set aside for participation in sport, where this occurred. Generally included were details of all activities undertaken within the program, venues in which they occurred, apparel and loads worn or carried by the trainees, and session start and finish times. In some instances, additional details were provided, for example details of equipment used, staffing details, or detailed instructions for the activities. Where required data elements were not initially provided, these data were gathered through consultation with program coordinators and other subject matter experts.

5.1.3 Data analysis

5.1.3.1 Estimates of exposures

The methodology employed to derive the estimates of exposures to factors that may increase risk of OLL, described below, is based on previous Australian Army recruit training research undertaken by members of the research team with the Defence Science and Technology Group and the United States Army Research Institute of Environmental Medicine. The data analysis is descriptive in nature, and involved quantifying, through extraction of data from program documentation (e.g., session timings, loads carried, equipment lists, distances traversed) and well-informed estimation, the exposures of trainees to activities, positions, and other factors (such as loads and vibration) that are known to increase the risk of developing OLL. Exposures of trainees to other, lower risk, types of activities, positions, and factors were also quantified, in order to establish context for the higher risk exposures and ensure that all time spent in training was accounted for in the analysis. Estimates were measured in terms of durations of exposure (minutes or hours) to particular activities, positions, or other factors (e.g., vibration), numbers of repetitions of lifting specific loads, numbers of stairs or ladder rungs ascended or descended, actual loads lifted or carried (kg), and distances traversed. These measures of exposure were used to ensure consistency with the measures of exposure used to quantify exposure to recognised factors by the Repatriation Medical Authority (RMA) in its Statements-of-Principles (SoPs) for OLL.[1] All exposure estimates derived in the analysis were recorded in Microsoft Excel 2013 (Microsoft Corporation 2013) workbooks and spreadsheets and summarised in exposure summary sheets.

The estimates of exposures were derived based on data provided in the documentation for each training program, on objective data provided in military manuals (for example, the F88 Steyr Weapon Training Manual), and on first-hand, expert knowledge of the activities being analysed and the contexts in which those activities were undertaken. In many instances, the researchers undertaking this component of the analysis possessed the required first-hand, expert knowledge of the training activities and contexts, having undertaken, instructed and/or observed the activities and contexts as serving members of the ADF or while consulting, conducting training, or researching in this context. Where this was not the case and where the training program documentation and available military manuals provided insufficient information, subject matter experts from the respective service who had extensive experience and expertise in the specific areas of training were consulted to inform the estimates of exposures derived by the research team. A list of subject matter experts who informed the desktop analysis for each service and consented to having their contributions formally acknowledged is provided in Appendix 1.

All estimates were based on the principle of typicality in that they reflected what was typical for the cohort as a whole. Outliers, for example, personnel who did not participate in an activity due to injury on a particular day, or personnel who went off-base for dinner instead of eating at the mess, where the latter was more typical, were disregarded. Where activities were undertaken by different groups of trainees in variable sequences, one group was selected and documented or the total cumulative exposures across all activities and the timeframe across which they were completed were used to derive average weekly exposures. Although these approaches may have affected the documented timings of exposures within specific training programs, they did not affect the total exposures estimated to have been accumulated by any group across the respective training program.

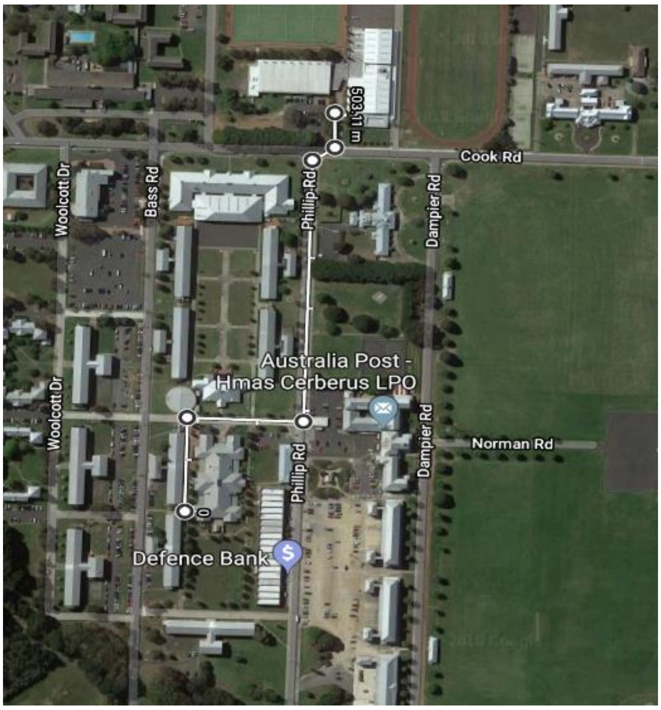
Given the variability in the locations of accommodation buildings and instructional venues used by different groups (e.g., different accommodation blocks or different levels

[1] These SoPs may be found at www.rma.gov.au/sops/condition/osteoarthritis

of the accommodation blocks, resulting in some personnel routinely climbed more stairs than did other personnel), all distances were estimated based on the average of the possible locations. For example, if accommodation Block A was 200 m from the mess and accommodation Block B was 400 m from the mess, a mean distance of 300 m was used as the estimate of typical distances moved between the accommodation block and mess. A similar approach was used to estimate the numbers of stairs or ladder rungs personnel typically ascended or descended during any given time period in the program.

Distances traversed were estimated from scale maps of the respective military area depicting key venues and roadways, by use of Google Maps measuring tools (see Figure 5.1), from previous experience of the researchers having traversed these distances on bases, or, where these options were not feasible, from local knowledge of the military area possessed by subject matter experts. Reference distances within local military areas are usually well known to staff because they are measured and used by military personnel as routes for fixed-distance run tests, marches, and similar kinds of activities.

Figure 5.1: Example of use of Google Maps measuring tools, measuring the distance from the male trainee accommodation to the HMAS Cerberus gymnasium.



Some minor variability in lifted and carried loads was anticipated, so loads were recorded and estimated in discrete load ranges, or 'bins', each representing a 5 kg range. When calculating cumulative lifted loads, the mean of each load bin was used, calculated by summing the lowest and highest loads included in the bin's range and dividing this figure by two. For example, for the bin range of 5–9 kg, a mean load of 7 kg was used. Where more than one person was involved in a lift (e.g., in a 2-person stretcher carry), the total load was divided by the number of lifters to provide an average load per lifter.

Where lifting involved lifting a person, for example in a stretcher carry, the average weight of an Australian (in this instance a load weight of 80 kg was assumed) was used as the estimated load. Military load lists and load weights listed in training program documentation or manuals were consulted to derive weights of military apparel and equipment. Subject matter experts from the respective training program were consulted where load weights could not be ascertained by one of these methods.

5.1.3.2 Program-specific weekly exposure workbooks

Once received, documentation detailing a specific selected training program, including additional information obtained from program coordinators and subject matter experts, was manually translated into a minute-by-minute representation of the activities undertaken during each training day of each week of the respective training program, which was recorded in a Microsoft Excel (Microsoft Corporation, 2013) workbook. Each sheet within the program-specific weekly exposure workbook represented one particular week of the respective training program. Any gaps in the schedule on any given day, for which activity information was not provided, were identified. Further information was then requested from the training establishment to elucidate the activities that occurred in those gaps. This information was subsequently added to the relevant sheet in the workbook. Checks were performed on every sheet within each workbook to ensure those workbooks initially accounted for a total of 1,440 minutes (i.e., 24 hours) for every day it documented. This process was facilitated by the insertion of automated check columns within each sheet, containing formulae that yielded a figure of zero or 1,440 if the sessions listed for each day summed to a total of 1,440 minutes, and some other number (as a flag to the research team) if not. If the program included periods of leave, following initial 24-hour checking, the timescales were adjusted to include only the period of actual military training. For example, if the program commenced at 0600 and concluded at 1700 with the trainees allowed local leave until the following morning parade, the timescale was adjusted to 660 minutes.

Each sheet in the program-specific workbook contained a series of columns for documenting the nature, start and finish times, and duration of each activity undertaken within each training session, and to classify the activities based on a range of parameters, representing key types of exposures. These parameters included activity types, position types, kilograms of loads lifted or carried, durations of load carriage, numbers of lift repetitions, exposure to vibration, and levels of physical effort involved in the activities.

Examples of some of the parameters and associated categories used to classify each activity undertaken within each session on each day of each week of each selected initial training program are as follows:

- Body position:
    - Lying
    - Sitting
    - Kneeling
    - Standing
    - Squatting

- Physical activity:
    - Stationary
    - Walk (distance, strides)
    - March (distance, strides)
    - Run (distance, strides)
    - Crawling
    - Menial tasks
    - Lifting of objects (manually raising and lowering objects)
    - Climbing
    - Combat training
    - Carrying (carrying objects)

- Worn and carried loads, lifted loads
    - 0 kg
    - 1–4 kg
    - 5–9 kg
    - 10–14 kg
    - 15–19 kg
    - 20–24 kg
    - 25–29 kg
    - 30–34 kg

  - 35–39 kg
  - 40–44 kg
  - 45–49 kg
  - 50+ kg

- Whole body vibration
  - Occasional
  - Intermittent
  - Constant

- Physical effort
  - Sleep
  - Rest
  - Light 10%
  - Light 20%
  - Light 30%
  - Moderate 40%
  - Moderate 50%
  - Moderate 60%
  - High 70%
  - High 80%
  - High 90%
  - Max 100%

Duration (minutes) of exposure to each category of activity, position, and other factors were documented in the workbooks for each day and week of the respective training program, along with the numbers of times loads of various weights that were lifted (as opposed to carried) within each session and cumulatively across each day and week. Cumulative hours for which loads of various weights were carried (as opposed to lifted) were similarly documented per session, per day, and per week.

5.1.3.3 Occupation-specific cumulative exposure spreadsheets

Once these week-by-week detailed exposure workbooks were compiled for each of the initial training programs undertaken by personnel within a selected occupation, a separate cumulative exposure spreadsheet was developed in Microsoft Excel 2013 for that occupation. Each occupation-specific cumulative exposure spreadsheet documented, week-by-week, the estimated cumulative exposures of personnel in the respective occupation to activities, positions, and other factors that are known to increase the risk of developing OLL.

The cumulative exposures documented within each spreadsheet were derived directly from the program-specific weekly exposure workbooks for the respective occupation and began at Week 1 of the first training program undertaken by personnel enlisting into the respective occupation and accumulated across all successive weeks of that training program. These exposures continued to accumulate across all weeks of training undertaken in subsequent training programs routinely completed by personnel from that particular occupation as part of their initial training (e.g. Army basic recruit training continuing into Infantry IET).

On this basis, each occupation-specific cumulative exposure spreadsheet encompassed estimated exposures accumulating across all successive initial training courses undertaken by personnel from the respective occupation (for example, both recruit training and initial employment training courses) following enlistment and commencement of service.

5.1.3.4 Occupation-specific cumulative exposure summaries

The weekly cumulative exposures for key types of exposure recognised by the RMA in its SoPs were then extracted from the occupation-specific cumulative exposure spread-sheets and graphed. The resulting graphs (see Chapter 7.1.1. for examples) depict the cumulative exposures that occurred over the sequence of initial training programs undertaken by personnel from a particular occupation. Separate graphs were developed for:

- the cumulative kilograms of loads weighing 20 kg or more that were lifted by personnel while they were weight bearing through their legs,
- the cumulative hours spent carrying loads weighing 20 kg or more while weight-bearing through the legs,
- the cumulative number of days on which personnel ascended or descended 150 or more stairs and/or ladder rungs, and
- the cumulative number of days on which personnel spent a total of 1 hour or more kneeling or squatting.

In some cases, the estimates of exposures to some of these factors reached the threshold exposures set by the RMA in its SoPs for OLL within the timeframe covered by the sequence of initial training programs undertaken by personnel from a particular occupation. When this occurred, the timepoint during initial training at which the threshold level of exposure was estimated to occur was documented. In other cases, where threshold exposures were not reached during the timeframe of initial training, the trajectories for cumulative exposures established during the sequence of initial training programs undertaken by personnel from a particular occupation were used to derive projections of cumulative exposures over time, beyond the timeframe of initial training.

These projections assumed that the average weekly exposure to a particular factor that personnel in the respective occupation experienced during initial training would continue over time as personnel moved into operational roles as trained personnel.

Although it is clearly acknowledged that this may not always be the case, and that future exposures may vary from those experienced during initial training for a particular occupational role, the project team was specifically requested by the DVA to provide these kinds of projections as our best current estimates of longer-term exposures. In making this request, the DVA noted it is likely that exposures occurring during initial training for a particular occupational role will be indicative of exposures that occur within the occupational role for trained personnel because initial training is generally intended to prepare personnel for the specific occupational role they will fulfil.

Although subsequent research is needed to instigate the occupational exposures to key factors experienced by trained personnel after they finish initial training, this was outside the scope of the current project. However, where information was available to enable more accurate estimates of post initial-training exposures (e.g., to injuries, to working on aircraft and being exposed to associated stair climbing for loadmaster personnel, and to climbing steps and ladders while posted to sea or to vessels situated 'alongside' in the Navy), these assessments were made and reported rather than relying on projections.

Projected cumulative exposures were subsequently compared with the threshold exposures set by the RMA in its SoPs for OLL, so that the time points at which the RMA threshold exposures would be reached (if ever) could be estimated, assuming continued similar rates of exposure, while acknowledging the above-mentioned limitations of these estimates. These graphs and projections relative to RMA-specified thresholds were presented in a single-page, occupation-specific cumulative exposure summary for each occupation.

Because the analysis of cumulative exposures occurring during initial training programs was based on only one initial training sequence for each occupation, 'error bars' or 'confidence intervals' could not be calculated around the reported cumulative exposures and projections. Instead, each estimate of cumulative exposure represents our best estimate based on analysis of the single point-in-time iteration of the initial training sequence existing in the year 2018, for the respective occupation.

The research team acknowledges that variation in cumulative exposures may occur due to changes in programming and content of the initial training sequence year-to-year, or due to deviations from the documented program during delivery of the training program, for example due to weather conditions on a particular day (e.g., work:rest ratios required to manage heat stress demand certain changes to ensure safety of personnel) or unexpected nonavailability of particular facilities or equipment. The former issue (how much initial training programs and associated exposures have changed over time) has been addressed through an historical review of initial training programs (Chapter 11).

The latter issue (deviations from the documented program during delivery of the training) is unlikely to change cumulative exposures across a full initial training sequence substantially because such day-to-day deviations from programmed activities are variable and likely to balance out over the entirety of an initial training sequence in order to ensure trainees achieve training objectives. These issues are also further discussed in Chapter 13, in which it is noted that staff conducting a range of initial training reported that 89% of training observed by the research team was conducted in accordance with the planned (programmed) training. The further issue of whether estimates of exposures derived from the desktop analysis are reasonably accurate has been addressed through observations of training undertaken by the research team. These observations were conducted to confirm the estimates derived from the desktop analysis and explore and document any observed deviations from those estimates (Section 5.2).

5.1.3.5 Compilation of exposure findings: Job exposure matrix

Upon completion of data analysis for each occupation, the program-specific weekly exposure workbooks, occupation-specific cumulative exposure spreadsheets, and occupation-specific cumulative exposure summaries associated with that occupation were compiled within the job exposure matrix (JEM) for OLL constructed for occupations within the respective service. The methods used to construct the JEM-OLL for each service and the additional elements included within the JEM-OLL are described in Section 5.3, below.

5.2 Observations and surveys

5.2.1 Ethics approval and research settings

The observations and surveys component of the project, incorporating direct observations of selected parts of initial training programs and conduct of trainee and instructor surveys received ethics approval from the Department of Defence and DVA Human Research Ethics Committee and the Bond University and Charles Sturt University Human Research Ethics Committees. Observations and survey administration occurred during visits to the selected ADF training establishments between September 2018 and February 2019 (Table 5.1).

Table 5.1: Observation and survey visits.

Course	Stage of training observed		Location	N (Trainees)
	Week	Days		
Navy Entry Officers' Course	2	Tue/Wed	HMAS Creswell, NSW	130
Navy Recruit School	2	Tue/Wed	HMAS Cerberus, VIC	138
Navy Boatswain's Mate course	3	Thu/Fri	HMAS Cerberus, VIC	25
Navy Marine Technician ITT	13	Thu/Fri	HMAS Cerberus, VIC	12
Navy Maritime Logistics-Personnel course	3	Thu / Fri	HMAS Cerberus, VIC	16
RAAF Initial Officer Course	4	Thu/Fri	RAAF Base East Sale, VIC	35
RAAF Recruit training		Tue/Wed	RAAF Base Wagga, NSW	55
RAAF Loadmaster IET (C17)	4	Tue	RAAF Base Amberley, QLD	1
RAAF Airfield Defence Guard IET	7	Thu	Greenbank Firing Range, QLD	40
RAAF Airfield Defence Guard IET	2	Thu	RAAF Base Amberley, QLD	40
Army Initial officer training	3	Sat/Sun	Royal Military College, ACT	150
Army Recruit training	3	Tue/Wed	Kapooka, NSW	62
Army Driver Specialist IET	2	Thu/Fri	Puckapunyal, VIC	15
Army Infantry IET	11	Wed/Thu	Singleton, NSW	45
ADF Medic Training Continuum	78	Mon/Tue	Bandiana, VIC	30

5.2.2 Research design

The observations and surveys element of the project employed a cross-sectional design:

1. direct observation of military personnel (recruits, trainees or officer cadets, collectively referred to in this document as trainees) who were undertaking their usual initial training activities as part of a cohort (observations were recorded at the cohort, rather than individual, level); and

2. surveys, administered once only to both trainees and instructors from the initial training programs observed. These surveys sought information regarding training activities observed during the preceding 2 days and, from the trainees but not the instructors, also sought demographic, fitness, and anthropometric (self-reported height and body weight) data as well as data regarding injury history and previous diagnoses of OA.

Observations were limited to external observation of usual training of whole cohorts of trainees without any modification to usual training.

The survey approach was designed to enable triangulation of data regarding training activities and related exposures that had been gathered through the desktop analysis and by each of the three methods employed in this observations and surveys element of the project: direct observation of trainees, surveys completed by trainees, and surveys completed by instructors. Consistent with the research aims, the data derived from each of these approaches was designed to reveal the levels of exposure of personnel from specific military occupations to activities, actions, movements, loads, incidents and other factors (for example, vibration) that are known to increase their risk of developing OLL. The data triangulation was planned to ensure the trustworthiness and representativeness of the findings of the research project, and particularly the comprehensive desktop analyses of initial training programs that examined trainee exposure to factors that may contribute to development of OLL.

The observations enabled the research team to directly observe and document the frequencies and durations of each relevant type of exposure that the trainees experience during the usual course of training. The surveys allowed for additional data (demographic, fitness, anthropometric, injury, and OA) to be collected from each observed cohort of trainees and for observations regarding specific training activities and exposures to be verified, with variations across the trainee cohort also identified by this means.

5.2.3 Participants

Participants who were observed as they undertook usual training included ADF recruits, officer cadets, and initial employment trainees (collectively termed 'trainees') who were undertaking one of the selected ADF initial training programs.

The purposive selection of initial employment training programs from each service was informed by consultation with senior physical training instructors from each service. In similar fashion, the specific training days to be observed within each selected initial training program were chosen to enable a variety of training types to be observed, and to enable sessions for which the desktop analyses required additional clarification to be observed.

Observed cohort numbers varied based on the nature of the training and the standard course sizes. For example, the Air Force Loadmaster conversion course for the C17 Globemaster had a total of two trainees, which was typical for the course. In contrast, the Army Recruit Training Course typically has a cohort of 50–60 recruits. In some instances, multiple cohorts for a particular training course could have been running at the same time. When this was the case, the cohort undergoing a training schedule that could best inform the desktop analysis was selected. For example, rather than follow a cohort that had lectures scheduled all day, a cohort that had lectures, weapons training, and/or drill was selected.

Individuals invited to participate in the trainee surveys were the same trainees who were observed. Individuals invited to participate in the instructor surveys were all instructors of the training activities observed, together with all program training staff who accompanied the observed trainees for one or more observed training activities and thus were aware of what occurred during the training activities.

The numbers of instructors and other staff varied considerably depending on the nature of the course and the stage of training. For example, the Navy Maritime Logistics - Personnel Course had one instructor who was allocated to the trainees for the duration of the day. In contrast, the Army Recruit Training Course had at least three and often up to five staff with the recruits for the duration of the day, although these numbers were smaller at later stages in the training program. In some instances (e.g., the ADF Medical Training Continuum course), the trainees had various instructional staff, some of them nonmilitary, throughout the day, as opposed to a single dedicated instructor.

To be included in the observation or survey components of the research, participants had to be ADF recruits, officer cadets, or initial employment trainees who were undertaking one of the selected training programs, or ADF staff who were instructing or overseeing trainees in one of the selected training programs, within the selected training activities, on the days that observations occurred. Reasons for exclusion from participation in these components of the research were:

- part-time service status (for the survey component, only, of the research project, part-time personnel who were undertaking normal training with full-time personnel were not excluded from the *observation* component of the research project because they were not approached to check their employment status at that time); and

- injury, illness, leave of absence, or other reasons that trainees or staff did not undertake or engage with training within at least one observed activity on the days on which observations occurred (e.g., due to attending medical or dental appointments).

Part-time personnel from the observation component were not excluded because the observations were conducted under an approved Human Research Ethics Committee waiver of the usual requirement to obtain informed consent for participation in this observation component (only) of the research project so that observations could be conducted from the sidelines without interfering with the normal training in any way. Any attempt to exclude part-time personnel from the cohorts to be observed would have disrupted normal training and thus invalidated the observations, which were intended to be of normal training without interference and without any change to the usual composition of the trainee cohort.

In the observation component of the research, all trainees (but not the instructors or staff) who met the inclusion criteria and did not meet exclusion criteria were observed during their usual training activities as part of the training cohort and without being individually identified so that they remained anonymous in the recorded observational data. All trainees, instructors, and accompanying staff from within the training programs and cohorts that were observed were subsequently invited to participate in the respective trainee or instructor survey, which also allowed them to remain anonymous.

5.2.4 Procedures

After obtaining necessary ADF approvals, the research team liaised with assigned points of contact at each of the ADF locations at which the selected initial training programs were to be observed in order to arrange access to trainee cohorts, associated training staff, and training activities discussed in the preceding sections.

Both trainees and training staff from all training activities to be observed by the research team were briefed by the research team prior to the observations about the purpose, nature, risks, and benefits of the research and they were provided with a participant information sheet. The participants were advised that the training would proceed as usual and that the research team would not interfere in the training activities to be observed in any way. The research team would simply be external observers.

The trainees and training staff were also advised that the research team would document their observations of the training activities on paper while they observed the activities, and that no trainees or training staff would be identified in this process, i.e. all trainees and staff involved in the observed activities would be anonymous in the recorded data set, to protect their privacy. No photos or video footage were taken of the trainees undertaking activities or staff supervising them. The trainees and training staff were provided with opportunity to ask any questions they might have about the research.

During the observations, data describing the training activities and relevant exposures of trainees to factors that are known to increase the risk of subsequent development of OLL (e.g., lifting, carrying, and climbing steps) were recorded by the observers at a cohort level on a purpose-designed data-collection form they carried on a clipboard. The variables considered in this dataset matched those derived from the desktop analysis to enable subsequent comparison.

On each day on which observations occurred, the observers shadowed the trainee cohorts for the full day where possible (there were instances where, due to operational safety, the observers were not able to remain with the trainees, e.g. loadmaster trainees during a flight, and in these instances instructors and trainees provided details of what had taken place during the session to populate the data sheet), and they recorded activities and relevant exposures, not only during formal, scheduled training sessions, but also during transitions between sessions (e.g., moving between lessons or venues) and during breaks (e.g., lunch period) and unscheduled time periods.

In the afternoon or evening of the final day of observations for each cohort observed, at a time agreed with senior instructional staff from the observed initial training program, trainees from the observed cohorts and staff who had been instructing or supporting them during the observations were invited to complete a trainee or instructor/staff survey, as appropriate.

The potential participants for each of the trainee and instructor surveys were first briefed by the research team on the surveys and their purpose. It was made clear that trainees who were in part-time service or who did not complete any of the observed training activities on preceding days were ineligible to participate in the survey component of the research, and any such personnel were excluded from further involvement. The trainees and instructors/staff were briefed separately and staff were asked not to attend the trainee briefing in order to minimise risk of coercion of trainees to participate and protect the future working relationships between trainees and staff.

At the time of the briefing, each group was provided with a participant information sheet and a copy of the relevant survey (trainee or instructor), which explained on its cover that participant consent would be implied by completion of the anonymous survey, that participation was voluntary, and that they were not required to identify themselves in the survey.

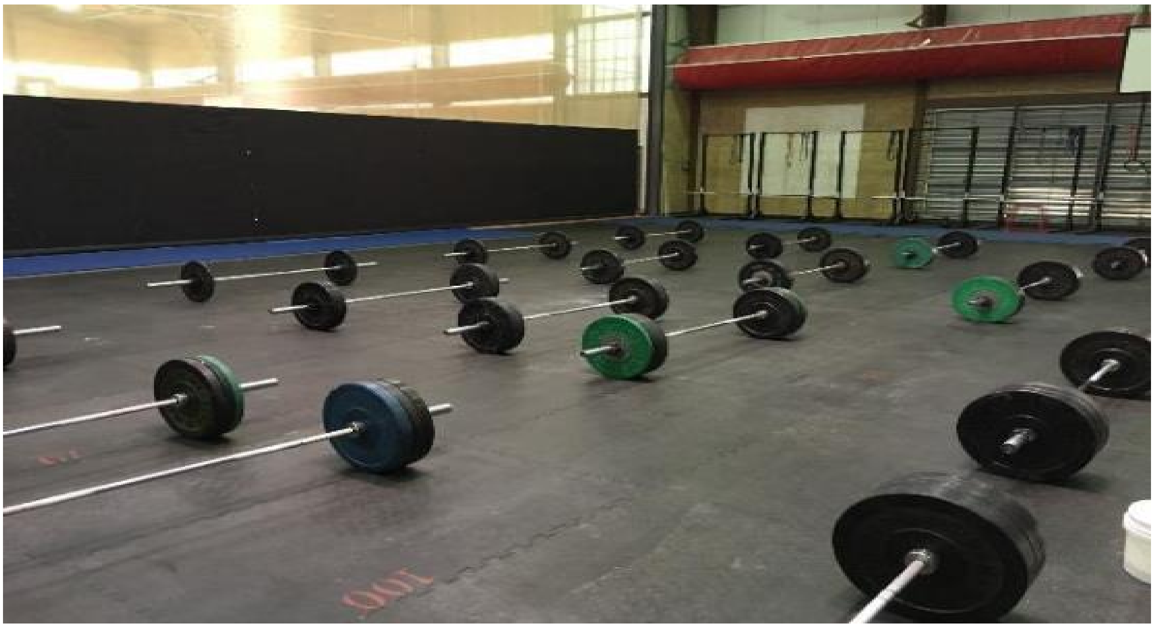
All potential participants were also given a copy of implied consent information with the participant information sheet. Those who chose to complete the survey were asked to return their completed survey, folded in half to hide any writing on it. Nonparticipants were asked to simply return their blank survey, folded in half to hide the fact it was blank. In the case of trainees, return of the surveys was out of the view of staff members.

These processes ensured that no one knew who had completed the survey and who had not, minimised the risk of coercion by both peers and staff, and protected future working relationships between those involved.

5.2.4.1 Observations: Centre of mass and averages

Noting that individuals may not have remained with the main cohort for the duration (e.g., medical appointment, 'restriction of privileges', etc) the observers remained with the main 'centre of mass' of the cohort being observed. Similarly, during PT, although a random individual was observed and each repetition noted, where more than one load option was provided to trainees (See Figure 5.2), the most typical load lifted by the group being observed was recorded as the training load. Considering this, although the load options taken up by trainees may have varied substantially, for example 30–120 kg, it should be noted that all loads in this instance were above the RMA required threshold of ≥ 20 kg.

Figure 5.2: Layout for resistance strength training in Army recruit training.



5.2.4.2 Trainee and instructor surveys

Both the trainee and instructor surveys sought information regarding the training activities observed during the preceding days. In particular, questions asked participants to recall the names of activities undertaken and the types of movements, actions, positions, loadings, and vibration to which trainee participants were exposed on the preceding days, and the cumulative durations of those exposures as percentages of their total day's activities. The trainee survey (but not the instructor survey) also gathered demographic, fitness and anthropometric data (self-reported height, and body weight) and data regarding injury history and previous diagnoses of OA. Paper-and-pencil formats were employed for ease of administration in the field locations associated with training where access to technology is very often challenging.

5.2.4.3 Data analysis

Data analysis was conducted using both Microsoft Excel and SPSS Version 25® (IBM Corp., Armonk, NY, USA). Data (observations and surveys) were first entered into an Excel spreadsheet and checked by the research team against the original. Incomplete or missing data were not imputed or replaced in any way but were simply treated as missing data in the analyses. Once checked, the survey dataset was imported into SPSS.

Analysis of the survey data was designed to describe relevant characteristics (including fitness) of trainees, the numbers of trainees who had been diagnosed with OA, the prevalence, and, where possible, incidence of lower limb injuries of relevance to OLL, and trainee and staff estimates in relation to programmed training that was observed by the research team.

5.3 Job exposure matrix

5.3.1 Design of the job exposure matrix for osteoarthritis of the lower limbs

The JEM-OLL constructed for each service of the ADF was designed to provide a readily searched and browsable list of occupations in the respective service. The listed occupations were indexed according to commonly used job titles as well as formal job titles and codes used to classify ADF jobs in PMKeyS (Personnel Management Key Solution), the personnel management system of the Australian Department of Defence.

The JEM-OLL for each service was further designed to initially provide:

- a description of each listed occupation;
- details of the available pathways for entry to each listed occupation;
- key details of the initial training courses that enlisting personnel have to complete to become eligible for posting to an operational unit within a particular occupational role; and
- details of the cumulative exposures of personnel in selected listed occupations, during initial training courses, to activities, positions, and other factors that are known to increase their risk of developing OLL.

The basis for selection of the occupations is described in detail in Section 5.1, and involved selecting four representative occupations from each service, including officers and three occupations that commenced with recruit training and included occupations characterised by (1) high physical demand, (2) low physical demand, and (3) high levels of exposure to a specific factor (e.g., heavy lifting) believed to be associated with the development of OLL.

The JEM-OLL for each service was constructed in a single Excel spreadsheet, associated with a series of folders, each containing hyperlinked documents, of the types listed below. The JEM-OLL spreadsheet was constructed such that each occupation and entry pathway combination was represented by a single row. Columns contained, for each listed occupation:

- The ADF service within which the occupation exists (i.e., Air Force, Navy, Army)
- The nature of employment in the occupation (full-time, because part-time occupational roles were outside the scope of the current project)
- The common name for the occupation, as used by Defence Jobs Australia (www.defencejobs.gov.au)
- Formal titles, descriptors, and codes for the occupation, and for subfunctions within the occupation, used in PMKeyS (Personnel Management Key Solution), the personnel management system of the Australian Department of Defence.

- Details of the course name, location, and duration for each initial training course that personnel in the occupation must complete
- A hyperlink to an information sheet for the occupation (containing a job overview and information on pathways for entry, salary and benefits, locations, entry requirements, and training requirements), downloaded from the Defence Jobs Australia website (www.defencejobs.gov.au) in 2018
- For each of the three selected, representative occupations:
    - Hyperlinks to program-specific weekly exposure workbooks for the initial training courses associated with the occupation
    - A hyperlink to an occupation-specific cumulative exposure spreadsheet
    - A hyperlink to an occupation-specific cumulative exposure summary for OLL.

Designed in this way, the JEM-OLL for each service constitutes both an indexed data repository for the research project and a ready reference for the DVA to inform policy decisions. Exposure information derived from subsequent research in operational units may be added to the JEM-OLL to extend knowledge about occupational exposures beyond the initial training phase, including exposures occurring during service in operational contexts. The detailed information on occupational exposures provided in the JEM-OLL could also be used to develop JEMs for conditions other than OLL, where a similar SoP from the RMA detailing threshold exposures, exists.

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6. PRELUDE TO AUSTRALIAN DEFENCE FORCE FINDINGS

In Chapters 7, 8, and 9, which follow, we report the main findings from the desktop analysis and observations of the selected Australian Defence Force (ADF) initial training programs. In Chapter 10, we report the findings arising from the construction of a job exposure matrix for the three ADF services. In Chapter 11, we report the findings of the historical review conducted of ADF initial training and associated injury rates. Chapter 12 builds on the detailed review of historical injury rates in ADF initial training programs that were presented in Section 11.4 in order to provide further evidence supporting lower-limb injury as a key risk factor for development of osteoarthritis of the lower limb (OLL) in ADF personnel. Chapter 13 reports findings from the surveys of trainees and instructional staff.

The main findings reported in Chapters 7, 8, and 9 relate to the occupational exposures of ADF personnel undertaking initial training to activities, positions, and other factors that increase their risk of subsequently developing OLL. In particular, findings regarding several types of exposure recognised by the Repatriation Medical Authority (RMA) in its Statements-of-Principles (SoPs) for OLL are detailed for personnel from each service undertaking initial officer training and for those from each service undertaking recruit training and one of the selected initial employment training (IET) programs, for specific occupations (refer to Table 5.1). More extensive results, including findings regarding a range of additional occupational exposures, can be found in the accompanying initial job exposure matrix for osteoarthritis of the lower limb (JEM-OLL) and in the electronic workbooks and spreadsheets linked to it (see Chapter 10) for each of the three ADF services.

As noted in Section 5.1.3, in the findings regarding key occupational exposures presented in Chapters 7, 8, and 9, projections have been made of the cumulative exposures that would occur over time if the trajectory of cumulative exposures remained unchanged. These projections have been compared with the threshold exposures set by the RMA in its SoPs for OLL so that timeframes for reaching the RMA thresholds can be estimated while acknowledging the limitations of these estimates.

All projections are based on the assumption that rates of exposure beyond the respective initial training course remain the same as the rates of exposure estimated to occur during the course. Although it is clearly acknowledged that this may not always be the case and that future exposures may vary from those experienced during initial training for a particular occupational role, the project team was specifically requested by the DVA to provide these projections as our best current estimates of longer exposures. In making this request, the DVA noted that it is likely that exposures occurring during initial training for a particular occupational role will be indicative of exposures that occur within the occupational role for trained personnel because initial training is generally intended to prepare personnel for the specific occupational role they will fulfil and will therefore be likely to involve similar activities and exposures. Often, but not always, rates of exposure to arduous physical activities that constitute risk factors for OLL increase when personnel move from initial training to operational service because training is designed to prepare personnel in a graduated fashion for the roles they will subsequently fill. Therefore, exposures to physical demands during initial training represent the exposures that personnel will experience in the occupation but are often gradually ramped up. If this holds true, personnel may reach thresholds for exposure earlier than predicted following completion of the initial training courses.

The project team has recommended to the DVA that subsequent research be instigated by the DVA to determine the occupational exposures to key factors experienced by trained personnel after they finish initial training. Although that research is outside the scope of the current project, where information was available to enable more accurate estimates of postinitial training exposures (e.g., to working on aircraft and being exposed to associated stair climbing for loadmaster personnel, and to climbing steps and ladders while posted to sea or to vessels situated 'alongside' in the Navy), these assessments were made rather than relying on projections.

7. FINDINGS: AIR FORCE

7.1 Desktop Analysis

7.1.1 Exposures occurring during initial training

Figure 7.1 shows (blue line) the estimated cumulative loads greater than 20 kg that are lifted by trainee Air Force officers during the 17-week Initial Officer Course (IOC). The first row of Table 7.1 identifies the thresholds of exposure set by the Repatriation Medical Authority (RMA) in its Statements of principles (SoPs) for osteoarthritis of the lower limb (OLL), for repeated heavy lifting of this nature to have been a likely contributor to development of diagnosed OLL, under its ‘Reasonable Hypothesis’ and ‘Balance-of-Probabilities’ scenarios.

The exposure thresholds for the two scenarios are also represented in Figure 7.1 by the orange and grey lines, respectively. The final column of Table 7.1 indicates the projected timepoint after enlistment at which the RMA-set threshold for each scenario would be met if the rate of exposure of Air Force officers to such heavy lifting continued as it was during the 17 weeks of the IOC. Table 7.1 indicates that, for this group, it is estimated the RMA-set threshold under its reasonable-hypothesis scenario would be reached by officers 7 years and 31 weeks after commencement of service. However, the RMA-set threshold under its Balance-of-Probabilities scenario would not be reached within any 10-year period.

In Figure 7.2 and the second row of Table 7.1 the same approach is used for estimated cumulative hours of carrying loads greater than 20 kg in this officer population. In this instance, it is apparent that if exposure to carrying such heavy loads continued at the same rate as occurred during the IOC, Air Force officers would never meet the RMA’s threshold specified in the SoPs for OLL within the timeframe set by the RMA.

Figure 7.1: Cumulative kilograms of lifted loads ≥ 20 kg

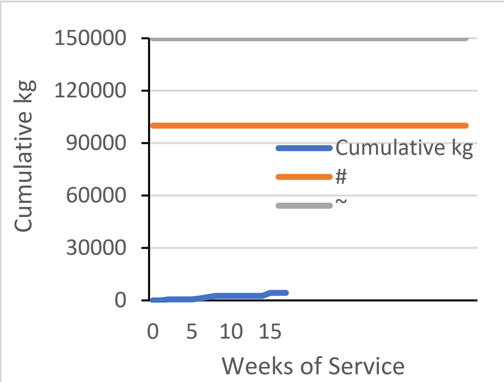
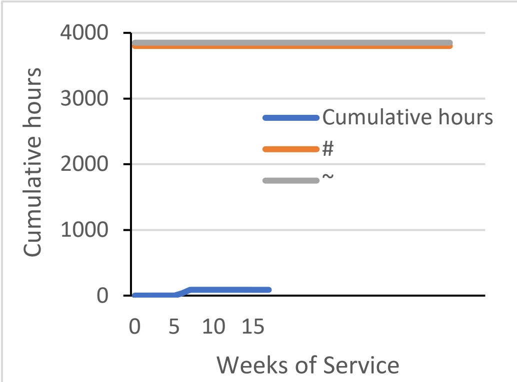


Figure 7.2: Cumulative hours of carrying loads ≥ 20 kg



Reasonable Hypothesis (RMA SoP for OLL)
~ Balance-of-Probabilities (RMA SoP for OLL)

Figure 7.3: Cumulative days ≥ 150 stairs or ladder rungs

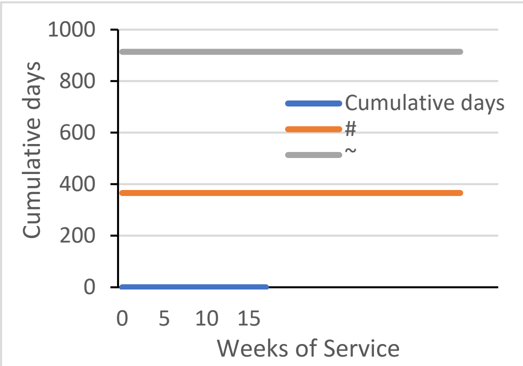
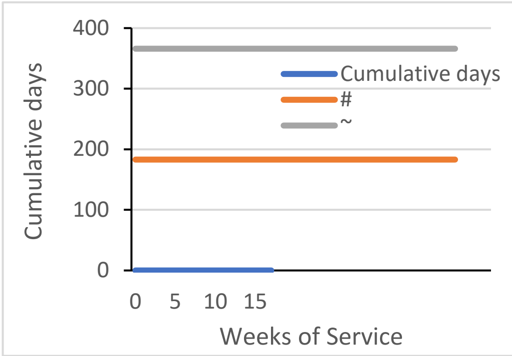


Figure 7.4: Cumulative days kneel/ squat ≥ 1 hr total



\# Reasonable Hypothesis (RMA SoP for OLL)
~ Balance-of-Probabilities (RMA SoP for OLL)

Table 7.1: Projected timeframes for Air Force officers to reach RMA-recognised exposure thresholds.[a]

Exposure type	RMA thresholds	Estimated timepoint at which RMA threshold will be met
Cumulative kilograms of lifted loads ≥ 20kg* while weight bearing through the legs (excl. lifts due to strides) (Figure 7.1)	#[c] 100,000 kg in any 10-yr period of service preceding clinical onset of OLL	7 years + 31 weeks following service commencement
	~ 150,000 kg in any 10-yr period of service that falls within 35 years prior to date of clinical onset of OLL	Never
Cumulative hours of carrying loads ≥ 20kg while weight bearing through the legs (Figure 7.2)	# 3,800 hrs in any 10-yr period of service preceding clinical onset of OLL	Never
	~ 3,800 hrs in any 10-yr period of service that falls within 35 years prior to date of clinical onset of OLL	Never
Cumulative days on which ≥ 150 stairs or ladder rungs ascended or descended (Figure 7.3)	# 366 days in any 2-yr period of service preceding clinical onset of OLL	Never
	~ 914 days in any 5-yr period of service that falls within 30 years prior to date of clinical onset of OLL	Never
Cumulative days on which kneeling and/or squatting was performed for ≥ a cumulative total of 1 hour (Figure 7.4)	# 183 days in any 1-yr period of service preceding clinical onset of hip or knee OA (only)	Never
	~ 366 days in any 2-yr period of service that falls within 27 years prior to date of clinical onset of hip or knee OA (only)	Never

[a] Based on exposure trajectories established during the IOC
[b] Lifting loads means manually raising an object; it excludes lifting of centre of mass and load that occurs with each stride when marching with load
[c] # Reasonable Hypothesis (RMA SoP for OLL) ~ Balance-of-Probabilities (RMA SoP for OLL)

The same conclusion can be drawn for cumulative number of days on which at least 150 stairs or ladder rungs are ascended or descended by Air Force officers (Figure 7.3 and third row of Table 7.1) and for cumulative number of days on which Air Force officers' total time spent kneeling or squatting is one hour or more (Figure 7.4 and fourth row of Table 7.1).

Two further projections were made for Air Force officers based on exposures estimated in the IOC:

- Projected annual cumulative hours of carrying loads ≥ 5 kg while weight bearing through the legs: 988 hours
- Projected annual cumulative kilograms of all lifted loads while weight bearing through the legs (excluding lifts during strides): 107,530 kg

7.1.2 Exposures occurring during initial training for Air Force Airfield Defence Guard Trainees

The Air Force's 10-week Security Forces Common Course and 10-week Airfield Defence Guard Basic Course together comprise the Airfield Defence Guard IET that Airfield Defence Guard trainees undertake after they complete recruit training. This IET for Airfield Defence Guards is representative of Air Force IET characterised by high physical demands. In this section, the exposures of Airfield Defence Guard trainees during recruit training, the Security Forces Common Course, and the Airfield Defence Guard Basic Course are documented.

Figure 7.5 shows (blue line) the estimated cumulative kilograms of loads greater than 20 kg that are lifted by Airfield Defence Guard trainees during recruit training, the Security Forces Common Course, and the Airfield Defence Guard Basic Course. Using a similar approach to that used in Table 7.1, Table 7.2 indicates that, for this group, the RMA-set threshold under its reasonable-hypothesis scenario would be reached within 1 year and 34 weeks of commencement of service. It is similarly estimated the RMA-set threshold under its Balance-of-Probabilities scenario would be reached within 2 years and 20 weeks of commencing service.

Figure 7.5: Cumulative kilograms of lifted loads ≥ 20 kg

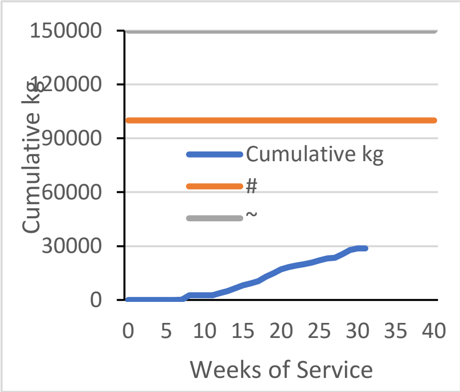


Figure 7.6: Cumulative hours of carrying loads ≥ 20 kg

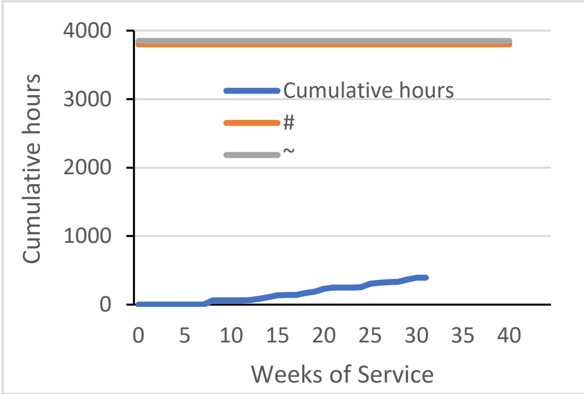


Figure 7.7: Cumulative days ≥ 150 stairs or ladder rungs

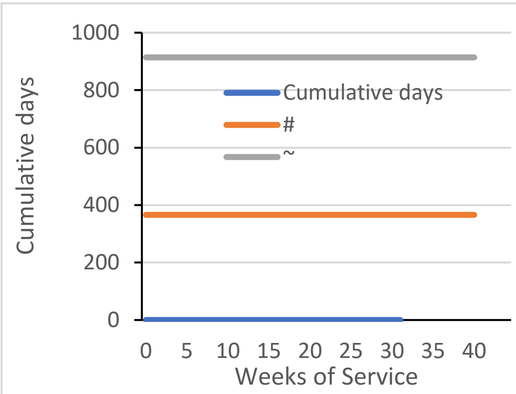
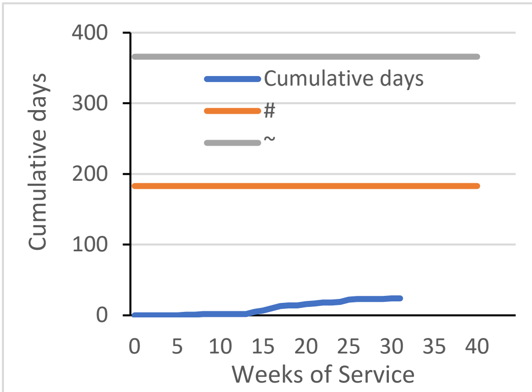


Figure 7.8: Cumulative days kneel/ squat ≥ 1 hr total



Footnote: # Reasonable Hypothesis (RMA SoP for OLL) ~ Balance-of-Probabilities (RMA SoP for OLL)

Table 7.2: Projected timeframes for Airfield Defence Guard personnel to reach RMA-recognised exposure thresholds.[a]

Exposure type	RMA thresholds	Estimated timepoint at which RMA threshold will be met
Cumulative kilograms of lifted loads ≥ 20kg* while weight bearing through the legs (excl. lifts due to strides) (Figure 7.5)	# 100,000 kg in any 10-yr period of service preceding clinical onset of OLL	1 year + 34 weeks following service commencement
	~ 150,000 kg in any 10-yr period of service that falls within 35 years prior to date of clinical onset of OLL	2 years + 20 weeks following service commencement
Cumulative hours of carrying loads ≥ 20kg while weight bearing through the legs (Figure 7.6)	# 3,800 hrs in any 10-yr period of service preceding clinical onset of OLL	5 years + 40 weeks following service commencement
	~ 3,800 hrs in any 10-yr period of service that falls within 35 years prior to date of clinical onset of OLL	5 years + 40 weeks following service commencement
Cumulative days on which ≥ 150 stairs or ladder rungs ascended or descended (Figure 7.7)	# 366 days in any 2-yr period of service preceding clinical onset of OLL	Never
	~ 914 days in any 5-yr period of service that falls within 30 years prior to date of clinical onset of OLL	Never
Cumulative days on which kneeling and/or squatting was performed for ≥ a cumulative total of 1 hour (Figure 7.8)	# 183 days in any 1-yr period of service preceding clinical onset of hip or knee OA (only)	Never
	~ 366 days in any 2-yr period of service that falls within 27 years prior to date of clinical onset of hip or knee OA (only)	Never

[a] Based on exposure trajectories established during recruit training, the Security Forces Common Course, and the Airfield Defence Guard Basic Course

[b] Lifting loads means manually raising an object; it excludes lifting of centre of mass and load that occurs with each stride when marching with load

[c] # Reasonable Hypothesis (RMA SoP for OLL) ~ Balance-of-Probabilities (RMA SoP for OLL)

Figure 7.6 and the second row of Table 7.2 take the same approach for estimated cumulative hours of carrying loads greater than 20 kg in Airfield Defence Guard trainees. In this instance, it is apparent that if exposure to carrying such heavy loads continued at the same rate as occurred during recruit training, the Security Forces Common Course, and the Airfield Defence Guard Basic Course, trainees would meet the RMA's thresholds specified in the SoPs for OLL within 5 years and 40 weeks of commencing service.

In contrast, it is evident the RMA's threshold exposures will *never* be reached by Airfield Defence Guard personnel for risk of developing OLL associated with the projected cumulative number of days on which at least 150 stairs or ladder rungs are ascended or descended (Figure 7.7 and third row of Table 7.2) or the projected cumulative number of days on which total time spent kneeling or squatting is 1 hour or more (Figure 7.8 and fourth row of Table 7.2).

Two further projections were made for Airfield Defence Guard trainees, based on exposures estimated in recruit training, the Security Forces Common Course, and the Airfield Defence Guard Basic Course:

- Projected annual cumulative hours of carrying loads ≥ 5 kg while weight bearing through the legs: 1,063 hours
- Projected annual cumulative kilograms of *all* lifted loads while weight bearing through the legs (excluding lifts in strides): 102,056 kg

7.1.3 Exposures occurring during Air Force Loadmaster IET

Air Force Loadmaster IET is representative of Air Force IET characterised by high levels of exposure to heavy load lifting and carrying. It begins with a 2-week Airman Aircrew Initial Course, followed by a 1-week Aviation Medicine Course, 2-week Aircrew Survival Evade Resist Escape Course, 1-week Dangerous Goods Pack and Accept Air Course, 2-week Loadmaster Basic Course, and 4-8 month Loadmaster Aircraft Conversion Course.

Figure 7.9 shows (blue line) the estimated cumulative kilograms of loads greater than 20 kg that are lifted by loadmaster trainees during recruit training and Loadmaster IET. Using a similar approach to that used in Tables 7.1 and 7.2, Table 7.3 indicates that, for this group, it is estimated the RMA-set threshold under its Reasonable-Hypothesis scenario would be reached by trainees within 30 weeks following commencement of service. It is similarly estimated the RMA-set threshold under its Balance-of-Probabilities scenario would be reached by trainees within 33 weeks following commencement of service.

Figure 7.10 and the second row of Table 7.3 take the same approach for estimated cumulative hours of carrying loads greater than 20 kg in this loadmaster trainee population. In this instance, it is apparent that if exposure to carrying such heavy loads continued at the same rate as occurred during recruit training and Loadmaster IET, trainees would never meet the RMA's threshold specified in the SoPs for OLL within the timeframe set by the RMA.

The same conclusion can be drawn for the cumulative number of days on which at least 150 stairs or ladder rungs are ascended or descended by loadmaster trainees (Figure 7.11 and third row of Table 7.3) and for cumulative number of days on which loadmaster trainees' total time spent kneeling or squatting is 1 hour or more (Figure 7.12 and fourth row of Table 7.3).

Two further projections were made for loadmaster trainees based on exposures estimated in recruit training and Loadmaster IET:

- Projected annual cumulative hours of carrying loads ≥ 5 kg while weight bearing through the legs: 382 hours
- Projected annual cumulative kilograms of *all* lifted loads while weight bearing through the legs (excluding lifts in strides): 342,952 kg

Figure 7.9: Cumulative kilograms of lifted loads ≥ 20kg

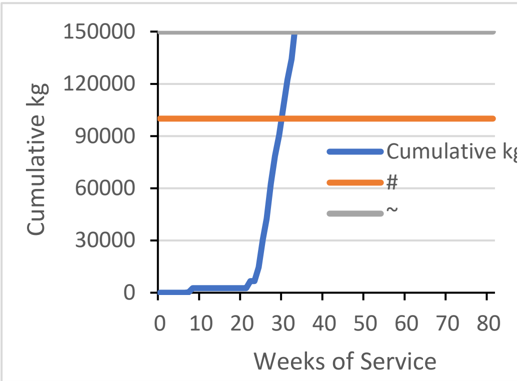


Figure 7.10: Cumulative hours of carrying loads ≥ 20kg

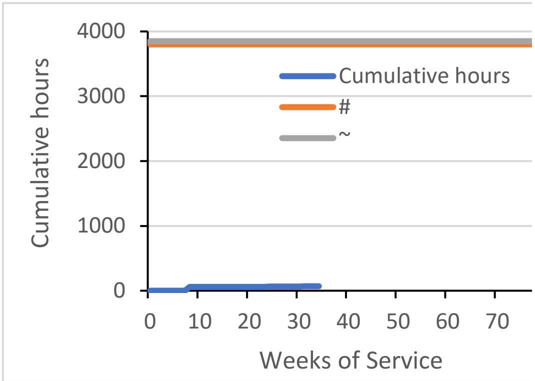


Figure 7.11: Cumulative days ≥ 150 stairs or ladder rungs

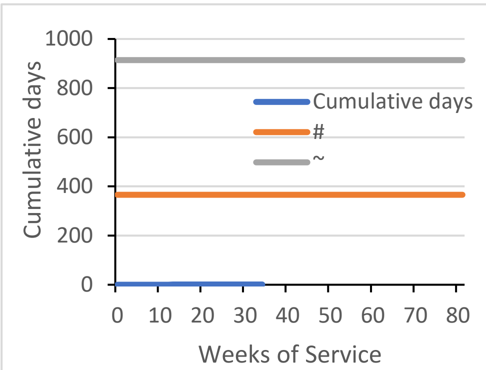
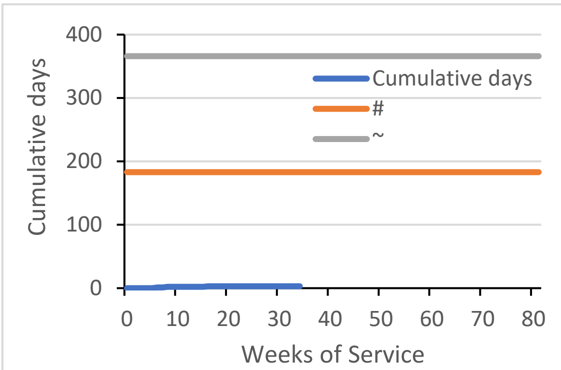


Figure **7.12:** Cumulative days kneel/ squat ≥ 1 hr total



Reasonable Hypothesis (RMA SoP for OLL)

~ Balance of Probabilities (RMA SoP for OLL)

Table 7.3: Projected timeframes for loadmaster personnel to reach RMA-recognised exposure thresholds.[a]

Exposure type	RMA thresholds	Estimated time point at which RMA threshold will be met
Cumulative kilograms of lifted loads ≥ 20kg* while weight bearing through the legs (excl. lifts due to strides) (Figure 7.9)	# 100,000 kg in any 10-yr period of service preceding clinical onset of OLL	30 weeks following service commencement
	~ 150,000 kg in any 10-yr period of service that falls within 35 years prior to date of clinical onset of OLL	33 weeks following service commencement
Cumulative hours of carrying loads ≥ 20kg while weight bearing through the legs (Figure 7.10)	# 3,800 hrs in any 10-yr period of service preceding clinical onset of OLL	Never
	~ 3,800 hrs in any 10-yr period of service that falls within 35 years prior to date of clinical onset of OLL	Never
Cumulative days on which ≥ 150 stairs or ladder rungs ascended or descended (Figure 7.11)	# 366 days in any 2-yr period of service preceding clinical onset of OLL	Never
	~ 914 days in any 5-yr period of service that falls within 30 years prior to date of clinical onset of OLL	Never
Cumulative days on which kneeling and/or squatting was performed for ≥ a cumulative total of 1 hour (Figure 7.12)	# 183 days in any 1-yr period of service preceding clinical onset of hip or knee OA (only)	Never
	~ 366 days in any 2-yr period of service that falls within 27 years prior to date of clinical onset of hip or knee OA (only)	Never

[a] Based on exposure trajectories established during recruit training and Loadmaster IET
[b] Lifting loads means manually raising an object; it excludes lifting of centre of mass and load that occurs with each stride when marching with load
[c] # Reasonable Hypothesis (RMA SoP for OLL) ~ Balance of Probabilities (RMA SoP for OLL)

7.1.4 Exposures occurring during the Tri-Service Medical Assistant IET

Air Force Medical Assistant IET is representative of Air Force IET characterised by relatively low levels of exposure to physical activity. It is conducted over a period of 69 weeks following recruit training and incorporates a nursing module, military module, paramedic module, and several workplace learning placements.

Figure 7.13 shows (blue line) the estimated cumulative kilograms of loads greater than 20 kg that are lifted by medical assistant trainees during recruit training and Medical Assistant IET. Using a similar approach to that used in Tables 7.1 to 7.3, Table 7.4 indicates that, for this group, it is estimated the RMA-set threshold under its reasonable-hypothesis scenario would be reached by trainees within 2 years and 4 weeks following commencement of service. It is similarly estimated the RMA-set threshold under its Balance-of-Probabilities scenario would be reached by trainees within 3 years and 6 weeks following commencement of service.

Figure 7.14 and the second row of Table 7.4 take the same approach for estimated cumulative hours of carrying loads greater than 20 kg in this medical assistant trainee population. In this instance, it is apparent that if exposure to carrying such heavy loads continued at the same rate as occurred during recruit training and Medical Assistant IET, trainees would never meet the RMA's threshold specified in the SoPs for OLL within the timeframe set by the RMA.

The same conclusion can be drawn for the cumulative number of days on which at least 150 stairs or ladder rungs are ascended or descended by medical assistant trainees (Figure 7.15 and third row of Table 7.4), and for cumulative number of days on which medical assistant trainees' total time spent kneeling or squatting is 1 hour or more (Figure 7.16 and fourth row of Table 7.4).

Two further projections were made for medical assistant trainees, based on exposures estimated in recruit training and Medical Assistant IET:

- Projected annual cumulative hours of carrying loads ≥ 5 kg while weight bearing through the legs: 132 hours
- Projected annual cumulative kilograms of *all* lifted loads while weight bearing through the legs (excluding lifts in strides): 84,616 kg

Figure 7.13: Cumulative kilograms of lifted loads ≥ 20kg

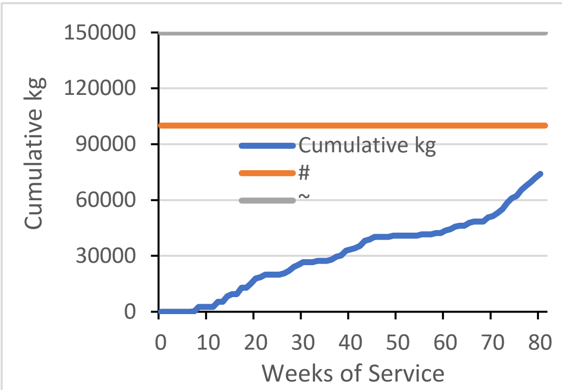


Figure 7.14: Cumulative hours of carrying loads ≥ 20kg

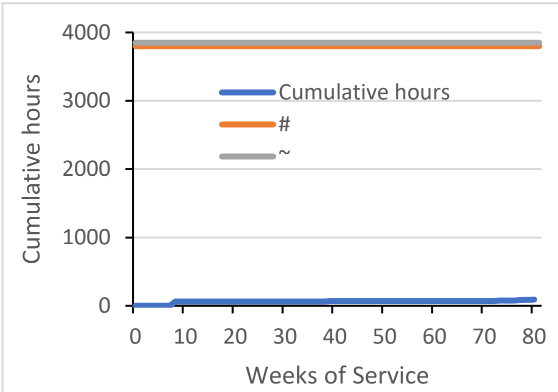


Figure 7.15: Cumulative days ≥ 150 stairs or ladder rungs

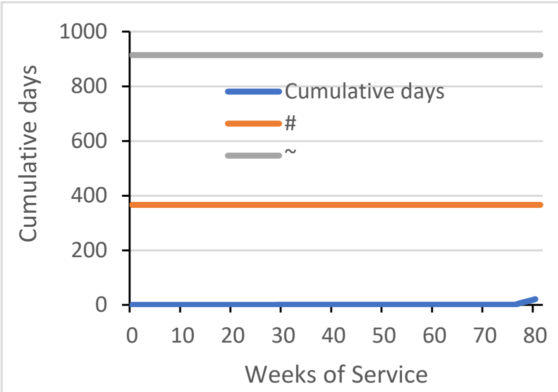
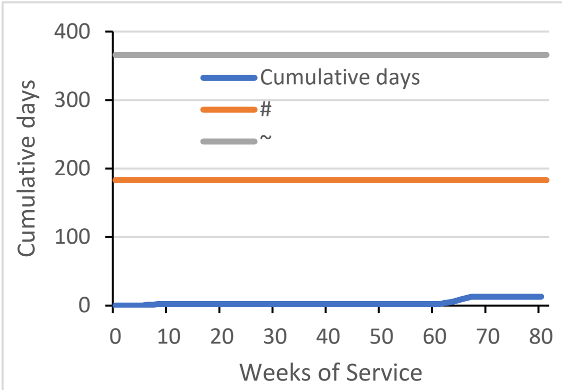


Figure 7.16: Cumulative days kneel/squat ≥ 1 hr total



\# Reasonable Hypothesis (RMA SoP for OLL) ~ Balance-of-Probabilities (RMA SoP for OLL)

Table 7.4: Projected timeframes for Air Force medical assistant personnel to reach RMA-recognised exposure thresholds.[a]

Exposure type	RMA thresholds	Estimated time point at which RMA threshold will be met
Cumulative kilograms of lifted loads ≥ 20kg* while weight bearing through the legs (excl. lifts due to strides) (Figure 7.13)	# 100,000 kg in any 10-yr period of service preceding clinical onset of OLL	2 years and 4 weeks following service commencement
	~ 150,000 kg in any 10-yr period of service that falls within 35 years prior to date of clinical onset of OLL	3 years and 6 weeks following service commencement
Cumulative hours of carrying loads ≥ 20kg while weight bearing through the legs (Figure 7.14)	# 3,800 hrs in any 10-yr period of service preceding clinical onset of OLL	Never
	~ 3,800 hrs in any 10-yr period of service that falls within 35 years prior to date of clinical onset of OLL	Never
Cumulative days on which ≥ 150 stairs or ladder rungs ascended or descended (Figure 7.15)	# 366 days in any 2-yr period of service preceding clinical onset of OLL	Never
	~ 914 days in any 5-yr period of service that falls within 30 years prior to date of clinical onset of OLL	Never
Cumulative days on which kneeling and/or squatting was performed for ≥ a cumulative total of 1 hour (Figure 7.16)	# 183 days in any 1-yr period of service preceding clinical onset of hip or knee OA (only)	Never
	~ 366 days in any 2-yr period of service that falls within 27 years prior to date of clinical onset of hip or knee OA (only)	Never

[a] Based on exposure trajectories established during recruit training and Medical Assistant IET
[b] Lifting loads means manually raising an object; it excludes lifting of centre of mass and load that occurs with each stride when marching with load
[c] # Reasonable Hypothesis (RMA SoP for OLL) ~ Balance-of-Probabilities (RMA SoP for OLL)

7.2 Observations

7.2.1 Commentary

The following observation commentary is based on the observation phase:

7.2.1.1 Air Force Initial Officer Course

Notable observations impacting some estimates from the desktop analysis, but not any of the key estimates that relate to RMA-recognised factors discussed in Section 7.1, are as follows:

- As of 2019, Battle PT was no longer performed at the Officer Training School, and the physical training instructors have been instructed to no longer run the recruits further than 200 m in boots.

- The parade ground was around 750 m from the weapons sheds and lines where recruits were predominantly based, which added to the distances covered per day estimated from the desktop analysis.

- Recent changes in weapons sheds/locations for lessons resulted in distances covered during movements to and from and between lessons being higher than those estimated in the desktop analysis.

7.2.1.2 Air Force recruit training

A notable observation impacting estimates of stairs climbed derived from the observations was that the RAAF recruit ‘flight’ was located on the ground floor of the lines. The observed numbers of stairs climbed when compared with other flights would therefore have been conservative.

7.2.1.3 Airfield Defence Guard IET

A notable observation impacting estimates of loads lifted and carried derived from the desktop analysis for Airfield Defence Guards was that observations made during the Airfield Defence Guard combat shooting training revealed that trainees were required to set up and pack the equipment away at the range. This included lifting and carrying loaded ammunition tins, trunks, and tentage. Although this increased the amount of load lifted and carried above that expected based on the desktop analysis, it was only a minor increase and is not expected to have influenced the overall findings. Nevertheless, it demonstrates that estimates of lifting and carrying derived from the desktop analysis for this occupation are conservative.

7.2.1.4. Loadmaster Initial Employment Course

Notable observations impacting on comparisons between observed exposures and exposures estimated in the desktop analysis for the Loadmaster IET, and impacting estimates of cumulative stairs climbed derived from the desktop analysis, are as follows:

- Observations made during the loadmaster conversion course yielded slightly different findings from those of the desktop analysis because, although the C130 conversion course formed part of the desktop analysis, the observations undertaken were of loadmaster trainees completing similar conversion training on the C17 Globemaster. There was no opportunity to observe trainees completing the C130 conversion course. Nevertheless, discussion with instructional staff indicated any differences in key exposures would be minimal.

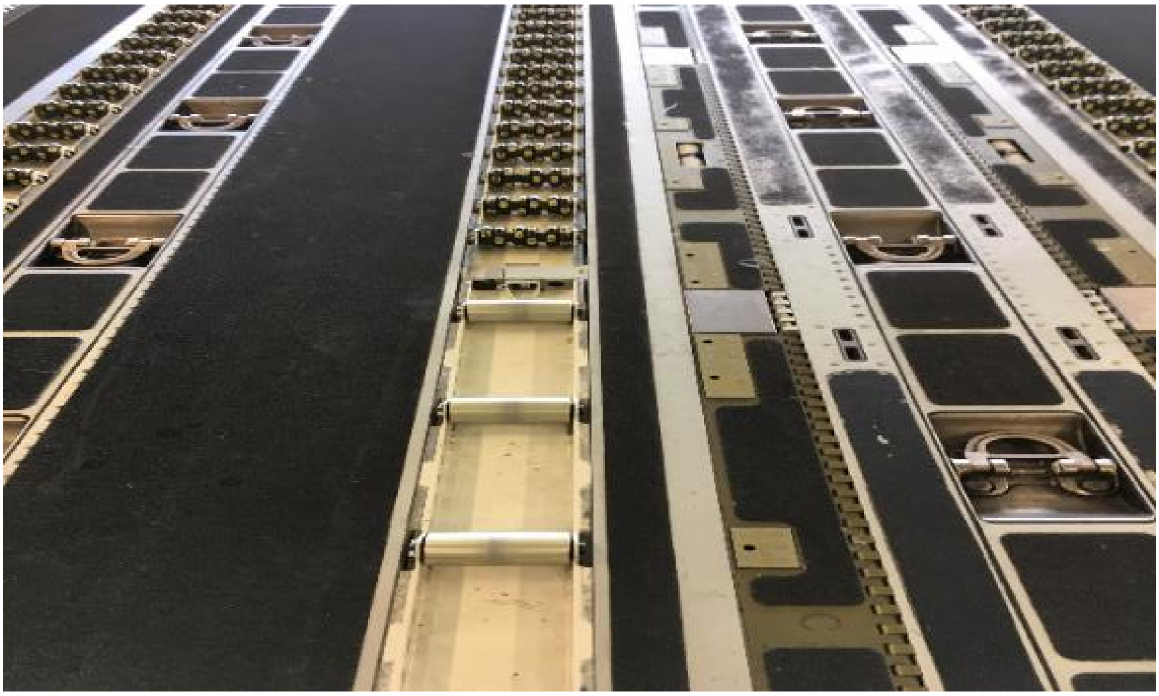
- In addition to the nine stairs into the aircraft, there were nine stairs leading from the lower deck, where the loadmaster is situated, up to the pilots (see Figure 7.17). During the observation phase, which involved a preflight check and pallet loading, the trainee loadmaster traversed these stairs a total of five times (10 ascents/ descents = 90 stairs). Noting this, the loadmaster escorting the observation team and the instructing loadmaster supervising the trainee stated that during a short flight (less than 3 hours) the loadmaster would typically make around six trips up to see the pilot (totalling 12 ascends/descends or 108 stairs). On longer flights, this would often expand to around 12 trips (216 stairs).

Figure 7.17: Stairs inside the C17 Globemaster leading from the loadmaster seat to the pilot cockpit.

- While undergoing training, the loadmaster trainee would seldom prepare pallets for flight because this task was completed by air logistics personnel. However, the loadmaster was required to prepare the deck for the pallets, and that would entail collecting, carrying, and affixing a series of rollers ranging from approximately 4–5 kg up to 7 kg (See Figure 7.18). For the flights observed and discussed, the individual trainee loadmaster would typically prepare for and load only three pallets (as observed) equating to 32 of these rollers. However, when serving in an operational unit, up to five pallets could be loaded per flight, equating to 68 rollers. Although these loads were less than 20 kg individually and would not alter our estimates (Section 7.1) of exposures to factors recognised by the RMA as risk factors for OLL, they add to the estimated cumulative annual loads lifted and carried by trainees and qualified personnel.

- Talking about his experience during loadmaster training, a staff member informed us that in 1995 when he completed training, loadmasters had to carry all of the relevant flight and training manuals with them daily in an echelon bag. He estimated the load at around 30 kg and noted that the trainees completing training now had to carry only a single tablet with all the data uploaded onto it. This means that estimates of load carriage exposure derived from this project are likely to be conservative for those who completed equivalent training in prior decades.

Figure 7.18: Rollers that were often lifted and rotated by the loadmaster in a kneeling position.



7.2.1.5. Tri-Service Medical Assistant IET course

A notable observation that may have impacted estimates of stair climbing for medical assistant trainees is that the training observed during the days on which observation occurred for the medical assistant trainees was all conducted in one building and on one level (approx. 28 stairs up from the ground floor), with TAFE, paramedic, and Army instructional staff all contributing to the program in theory lessons and limited practical applications in classroom and lab environments. The position of this teaching area led to an increased number of stairs during the observation phase than had been estimated in the desktop.

7.2.2 Comparison of observed exposures to estimates from the desktop analysis

Data on key exposures observed during the observations of selected training days from each selected Air Force initial training program (Table 5.1) were compared as planned with estimates of these key exposures, from the same training days, obtained through the desktop analysis. The purpose of this comparison was to confirm the extent to which the estimates derived from the desktop analysis reflected the reality of training in the training context and to explore where differences arose if differences occurred.

7.2.2.1 Kneeling/squatting

Across all of the selected Air Force initial training programs, and across the 2 days of training that were observed for each, estimates derived from the desktop analysis of time personnel spent kneeling or squatting were within –6 minutes to +1.5 minutes (both kneeling and squatting together) on each observed day of the number of minutes observed, with the mean difference being –3 minutes. This means that the estimates of time spent kneeling or squatting derived from the desktop analysis accurately matched the times recorded during the observations of training, supporting the cumulative numbers of days estimated from the desktop analysis on which kneeling and squatting exceeded 1 hour in these selected Air Force initial training programs.

7.2.2.2 Climbing stairs / ladder rungs

Across all of the selected Air Force initial training programs, and across the days of training that were observed for each program, estimates derived from the desktop analysis of the numbers of steps/rungs climbed were within the bounds of –260 to 0 steps/rungs when compared with the numbers of steps/rungs observed, with the average difference for each day observed being –51 steps/rungs. This means that the estimates of numbers of steps/rungs climbed each day derived from the desktop analysis were conservative. Closer inspection to examine how the additional steps/rungs observed were distributed over the training programs and days of observation indicated that the difference was primarily due to loadmaster trainees ascending/descending 260 additional steps/rungs on the day they were observed, with 130 of these stairs and rungs being directly observed pre-flight. The trainees' instructors informed us that the same checklist was completed postflight in reverse order and therefore would double the number of steps and rungs traversed.

No, or minimal, differences were evident in the other training programs between estimates from the desktop analysis and observed numbers of steps/rungs ascended/ descended during the observed training days. In addition, the research team's observers were informed that during the flight the loadmaster (and hence trainee) would make several trips up to and down from the cockpit. For the loadmaster trainees, it is evident from reviewing their training program, paired with this new knowledge gleaned from the observations (and confirmed with qualified loadmaster personnel at that time), that the trainees routinely ascend/descend more than 150 stairs each day during which they train on aircraft. However, during training they do this on only 20 occasions across 34 weeks (including recruit training and loadmaster training). This means that during their time in training they would not meet the RMA-set threshold for number of days on which 150 or more stairs or ladder rungs have been ascended or descended. However, they will reach this threshold rapidly after completion of training, once operating as qualified personnel on aircraft, as confirmed by the loadmaster instructors.

It could therefore be expected on the basis of the revised estimates (supported by the observations and associated advice from subject matter experts) that loadmaster trainees will reach the RMA threshold for exposure to this climbing stairs/rungs risk factor for OLL within 2 years of commencing duties as qualified loadmaster personnel after completion of training, under the RMA's Reasonable Hypothesis scenario – thus, within 2 years and 34 weeks from date of enlistment under the Reasonable Hypothesis Scenario. The time frame to reach this threshold under the RMA's Balance of Probabilities scenario would be within 5 years and 34 weeks. These time frames assume that, after qualifying, these trainees will undertake work in their loadmaster role on aircraft on more days than not during the 2 or 5 year period, respectively.

7.2.2.3 Lifting

Total kilograms lifted where loads were greater than 20 kg differed between the estimates from the desktop analysis and the observed lifts only in Air Force recruit training. In the other selected Air Force initial training programs (Table 5.1), no differences were evident between estimates of cumulative lifted loads of greater than 20 kg derived from the desktop analysis and the cumulative loads of greater than 20 kg observed to be lifted during the days of training that were observed. In the Air Force recruit training program, the difference in cumulative loads lifted amounted to –3,008 kg across the 2 days of observations, indicating that the desktop analysis underestimated the total weight lifted by recruits on the training days that were observed by 3,008 kg. Further investigation revealed that all of these additional 3,008 kgs of loads greater than 2 kg that were observed to be lifted within the 2 training days observed were accumulated within a single strength-and-conditioning session completed by the recruits on one of the two training days observed. In that single session, recruits performed 64 lifts, each of loads of 22 kg (4 sets of 8 repetitions of a front squat and a shoulder press), and 32 lifts, each of loads of 50 kg (4 sets of 8 repetitions of a deadlift). Other exercises (i.e., sit ups and band-assist chin ups) were observed but these did not directly load the lower limbs.

These findings for Air Force recruit training indicates that the estimates of heavy loads lifted derived from the desktop analysis are conservative. It also further supports the existing conclusions for all of the selected Air Force Other Ranks occupations considered earlier in this section, which indicated that heavy lifting was an exposure of importance in all of these Air Force occupational groups as a risk factor for development of OLL. Although the findings from the observations indicate that Air Force recruits might lift more load during recruit training than estimated in the desktop analysis, because recruit training is relatively short (11 weeks) it is unlikely the additional loads they lift in this phase of their initial training would make a substantial difference to the timeframes within which the threshold exposures for heavy lifting specified by the RMA in the SoPs for OLL are projected to be met in each of the Other Ranks occupations (Section 7.1).

7.2.2.4 Carrying loads

No differences were observed in hours spent carrying loads greater than 20 kg when the observed hours were compared with the hours estimated from the desktop analysis, for the selected Air Force initial training programs. There were small differences between observed and estimated hours spent carrying lighter loads (5–19 kg) across the selected Air Force initial training courses, and this difference amounted to a mean of 11 minutes per day of additional lighter loads observed during the observations, again indicating that estimates derived in the desktop analysis for time spent carrying loads were slightly conservative.

8. FINDINGS: NAVY

8.1 Desktop Analysis

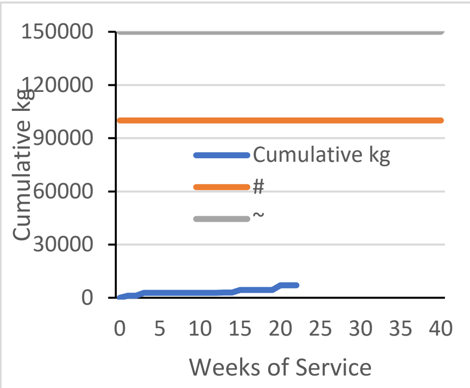
8.1.1 Exposures occurring during initial training for Navy officers

Figure 8.1 shows (blue line) the estimated cumulative kilograms of loads greater than 20 kg that are lifted by trainee Navy officers during the 22-week New Entry Officers' Course (NEOC). The first row of Table 8.1 identifies the thresholds of exposure set by the Repatriation Medical Authority (RMA) in its Statements of Principles (SoP)s for osteoarthritis of the lower limb (OLL), for repeated heavy lifting of this nature to have been a likely contributor to development of diagnosed OLL under its 'Reasonable Hypothesis and Balance-of-Probabilities scenarios. The exposure thresholds for the two scenarios are also represented in Figure 8.1 by the orange and grey lines, respectively.

The final column of Table 8.1 indicates the projected timepoint after enlistment at which the RMA-set threshold for each scenario would be met if the rate of exposure of Navy officers to such heavy lifting continued as it was during the 22 weeks of the NEOC. Table 8.1 indicates that, for this group, it is estimated the RMA-set threshold under its Reasonable Hypothesis scenario would be reached by officers 6 years and 1 week after enlistment. It is also estimated the RMA-set threshold under its Balance-of-Probabilities scenario would be reached 9 years and 1 week after enlistment.

Figure 8.2 and the second row of Table 8.1 take the same approach for estimated cumulative hours of carrying loads greater than 20 kg in this Navy officer population. In this instance, it is apparent that if exposure to carrying such heavy loads continued at the same rate as occurred during the NEOC, Navy officers would never meet the RMA's threshold specified in the SoPs for OLL within the timeframe set by the RMA.

Figure 8.1: Cumulative kilograms of lifted loads ≥ 20kg



\# Reasonable Hypothesis (RMA SoP for OLL)
~ Balance-of-Probabilities (RMA SoP for OLL)

Figure 8.2: Cumulative hours of carrying loads ≥ 20kg

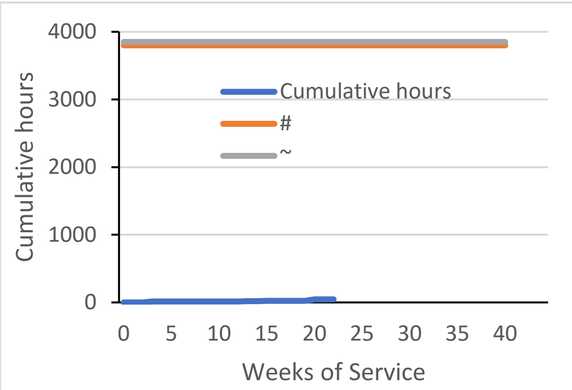


Figure 8.3: Cumulative days ≥ 150 stairs or ladder rungs

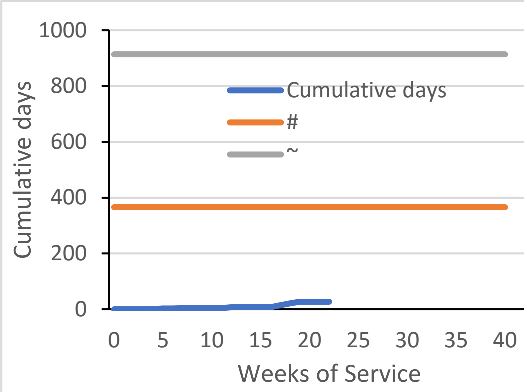
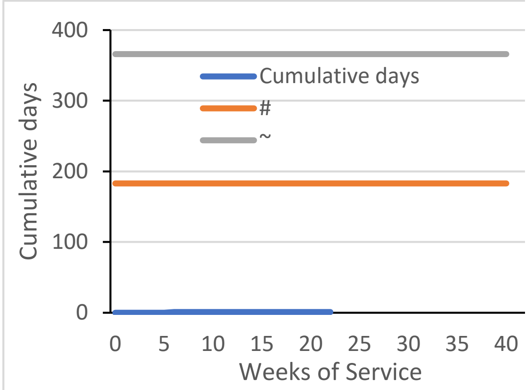


Figure 8.4: Cumulative days kneel/ squat ≥ 1 hr total



Reasonable Hypothesis (RMA SoP for OLL)
~ Balance-of-Probabilities (RMA SoP for OLL)

Table 8.1: Projected timeframes for Navy officers to reach RMA-recognised exposure thresholds.[a]

Exposure type	RMA thresholds	Estimated timepoint at which RMA threshold will be met
Cumulative kilograms of lifted loads ≥ 20kg* while weight bearing through the legs (excl. lifts due to strides) (Figure 8.1)	# 100,000 kg in any 10-yr period of service preceding clinical onset of OLL ~ 150,000 kg in any 10-yr period of service that falls within 35 years prior to date of clinical onset of OLL	6 years + 1 week 9 years + 1 week
Cumulative hours of carrying loads ≥ 20kg while weight bearing through the legs (Figure 8.2)	# 3,800 hrs in any 10-yr period of service preceding clinical onset of OLL ~ 3,800 hrs in any 10-yr period of service that falls within 35 years prior to date of clinical onset of OLL	Never Never
Cumulative days on which ≥ 150 stairs or ladder rungs ascended or descended (Figure 8.3)	# 366 days in any 2-yr period of service preceding clinical onset of OLL ~ 914 days in any 5-yr period of service that falls within 30 years prior to date of clinical onset of OLL	366 days after commencing first posting to sea or to vessels situated 'alongside' >1-yr (see text below) 914 days after commencing postings to sea or to vessels situated 'alongside' >2.5 yrs
Cumulative days on which kneeling and/or squatting was performed for ≥ a cumulative total of 1 hour (Figure 8.4)	# 183 days in any 1-yr period of service preceding clinical onset of hip or knee OA (only) ~ 366 days in any 2-yr period of service that falls within 27 years prior to date of clinical onset of hip or knee OA (only)	Never Never

[a] Based on exposure trajectories established during the New Entry Officer Course

[b] Lifting loads means manually raising an object; it excludes lifting of centre of mass and load that occurs with each stride when marching with load

[c] # Reasonable Hypothesis (RMA SoP for OLL) ~ Balance-of-Probabilities (RMA SoP for OLL)

The same conclusion can be drawn for cumulative number of days on which at least 150 stairs or ladder rungs are ascended or descended by Navy officers (see Figure 8.3 and third row of Table 8.1), and for cumulative number of days on which Navy officers' total time spent kneeling or squatting is 1 hour or more (see Figure 8.4 and fourth row of Table 8.1). However, although exposure of Navy officers to climbing of stairs and ladder rungs during the NEOC was not high overall, during the few days they spent at sea they climbed more than 150 stairs or ladder rungs each day. On this basis, Navy officers who are posted to sea or to vessels situated 'alongside' at some stage following completion of the NEOC for more than 1 year would likely meet the RMA-set threshold for climbing stairs and ladder rungs approximately 366 days after commencing their first posting to sea, with the exact timepoint at which this occurs following enlistment depending on the time following completion of the NEOC at which they commence such a posting to sea.

Two further projections were made for Navy officers, based on exposures estimated in the NEOC:

- Projected annual cumulative hours of carrying loads ≥ 5 kg while weight bearing through the legs = 408 hours.
- Projected annual cumulative kilograms of all lifted loads while weight bearing through the legs (excl. lifts in strides) = 87,195 kg.

8.1.2 Exposures occurring during initial training for Navy boatswain's mates

The Navy Boatswain's Mate Course is representative of Navy trade training courses characterised by high physical demands. In this section, the exposures of boatswain's mate trainees during the recruit course, Boatswain's Mate Course, and Basic Seamanship Course are documented.

Figure 8.5 shows (blue line) the estimated cumulative kilograms of loads greater than 20 kg that are lifted by Navy boatswain's mates' trainees during their recruit course, Boatswain's Mate Course, and Basic Seamanship Course. Using a similar approach to that used in Table 8.1, Table 8.2 indicates that, for this group, it is estimated the RMA-set threshold under its reasonable-hypothesis scenario would never be reached by trainees. It is also estimated the RMA-set threshold under its Balance-of-Probabilities scenario would never be reached by trainees.

Figure 8.6 and the second row of Table 8.2 take the same approach for estimated cumulative hours of carrying loads greater than 20 kg in the boatswain's mate trainee population. In this instance, it is apparent that if exposure to carrying such heavy loads continued at the same rate as occurred during the recruit course, Boatswain's Mate Course and Basic Seamanship Course trainees would never meet the RMA's threshold specified in the SoPs for OLL within the timeframe set by the RMA.

Figure 8.5: Cumulative kilograms of lifted loads ≥ 20 kg

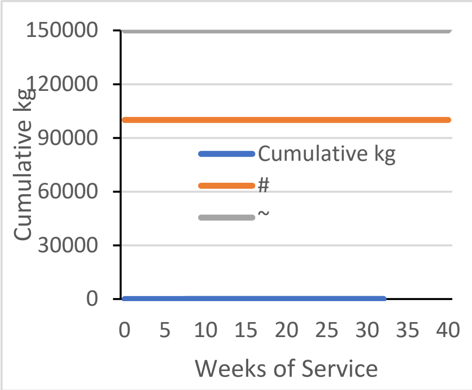
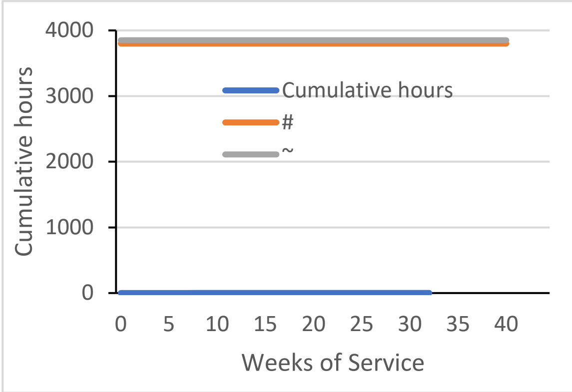


Figure 8.6: Cumulative hours of carrying loads ≥ 20 kg



Reasonable Hypothesis (RMA SoP for OLL)
~ Balance of Probabilities (RMA SoP for OLL)

Table 8.2: Projected timeframes for boatswain's mate personnel to reach RMA-recognised exposure thresholds.[a]

Exposure type	RMA thresholds	Estimated timepoint at which RMA threshold will be met
Cumulative kilograms of lifted loads ≥ 20kg* while weight bearing through the legs (excl. lifts due to strides) (Figure 8.5)	# 100,000 kg in any 10-yr period of service preceding clinical onset of OLL	Never
	~ 150,000 kg in any 10-yr period of service that falls within 35 years prior to date of clinical onset of OLL	Never
Cumulative hours of carrying loads ≥ 20kg while weight bearing through the legs (Figure 8.6)	# 3,800 hrs in any 10-yr period of service preceding clinical onset of OLL	Never
	~ 3,800 hrs in any 10-yr period of service that falls within 35 years prior to date of clinical onset of OLL	Never
Cumulative days on which ≥ 150 stairs or ladder rungs ascended or descended (Figure 8.7)	# 366 days in any 2-yr period of service preceding clinical onset of OLL	366 days after commencing first posting to sea (see text)
	~ 914 days in any 5-yr period of service that falls within 30 years prior to date of clinical onset of OLL	914 days after commencing first posting to sea (see text)
Cumulative days on which kneeling and/or squatting was performed for ≥ a cumulative total of 1 hour (Figure 8.8)	# 183 days in any 1-yr period of service preceding clinical onset of hip or knee OA (only)	Never
	~ 366 days in any 2-yr period of service that falls within 27 years prior to date of clinical onset of hip or knee OA (only)	Never

[a] Based on exposure trajectories established during the recruit course, Boatswain's Mate Course and Basic Seamanship Course

[b] Lifting loads means manually raising an object; it excludes lifting of centre of mass and load that occurs with each stride when marching with load

[c] # Reasonable Hypothesis (RMA SoP for OLL) ~ Balance-of-Probabilities (RMA SoP for OLL)

The same conclusion can be drawn for the cumulative number of days on which at least 150 stairs or ladder rungs are ascended or descended by boatswain's mate trainees (Figure 8.7 and third row of Table 8.2), and for cumulative number of days on which boatswain's mate trainees' total time spent kneeling or squatting is 1 hour or more (Figure 8.8 and fourth row of Table 8.2). However, while exposure of boatswain's mate trainees to climbing stairs and ladder rungs during the Boatswain's Mate Course and Basic Seamanship Course was not high overall, a Navy subject matter expert advised the research team that following these courses, boatswain's mates are all posted to sea, normally for 2 years, within 18 months and mostly (90% of the time) within 12 months of completing the courses.

Figure 8.7: Cumulative days ≥ 150 stairs or ladder rungs

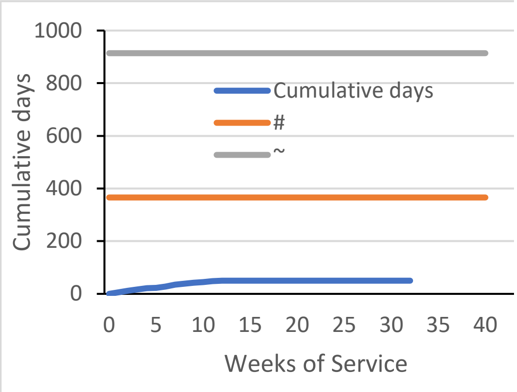
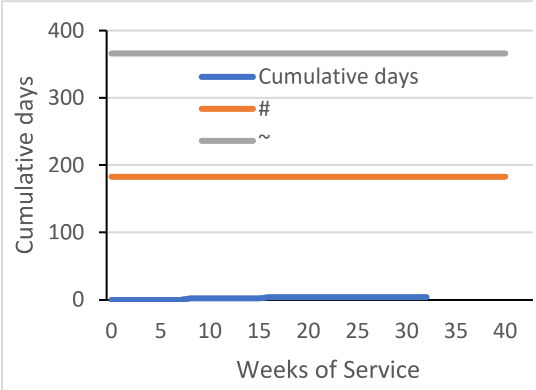


Figure 8.8: Cumulative days kneel/ squat ≥ 1 hr total



Reasonable Hypothesis (RMA SoP for OLL)
~ Balance-of-Probabilities (RMA SoP for OLL)

While at sea, all Navy personnel climb more than 150 stairs or ladder rungs on a daily basis as they move around the vessel they are aboard, consistent with the findings for Navy Officers when at sea for three days during the NEOC course (Section 8.1.1). On this basis, all boatswain's mate personnel would meet the RMA-set threshold for climbing stairs and ladder rungs within 2-3 years of enlistment, with the exact timepoint occurring approximately 1 year after they commence their first posting to sea or to vessels situated alongside and thus depending on the time at which they commence their posting to sea or to vessels situated alongside following completion of the Boatswain's Mate Course and Basic Seamanship Course.

Two further projections were made for boatswain's mate trainees, based on exposures estimated in the recruit course, Boatswain's Mate Course, and Basic Seamanship Course:

- Projected annual cumulative hours of carrying loads ≥ 5kg while weight bearing through the legs: 374 hours.
- Projected annual cumulative kilograms of *all* lifted loads while weight bearing through the legs (excl. lifts in strides) = 59,956 kg.

8.1.3 Exposures occurring during initial training for Navy marine technicians

The Navy Marine Technician Initial Technical Training and Certificate III courses are representative of Navy trade training courses characterised by high levels of exposure to occupational vibration.

Figure 8.9 shows (blue line) the estimated cumulative kilograms of loads greater than 20 kg that are lifted by marine technician trainees during the recruit course and Marine Technician Initial Technical Training and Certificate III courses. Using a similar approach to that used in Table 8.1, Table 8.3 indicates that, for this group, it is estimated the RMA-set threshold under its Reasonable Hypothesis scenario would never be reached by trainees. It is similarly estimated the RMA-set threshold under its Balance-of-Probabilities scenario would never be reached by trainees.

Figure 8.10 and the second row of Table 8.3 take the same approach for estimated cumulative hours of carrying loads greater than 20 kg in this marine technician trainee population. In this instance, it is apparent that, if exposure to carrying such heavy loads continued at the same rate as occurred during the recruit course and Marine Technician Initial Technical Training and Certificate III courses, trainees would *never* meet the RMA's threshold specified in the SoPs for OLL within the timeframe set by the RMA.

Figure 8.9: Cumulative kilograms of lifted loads ≥ 20 kg

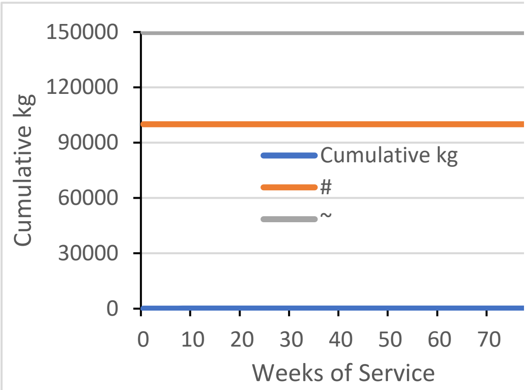
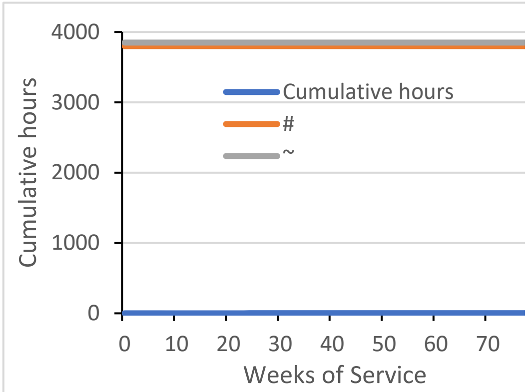


Figure 8.10: Cumulative hours of carrying loads ≥ 20 kg



Reasonable Hypothesis (RMA SoP for OLL)
~ Balance- of-Probabilities (RMA SoP for OLL)

Figure 8.11: Cumulative days ≥ 150 stairs or ladder rungs

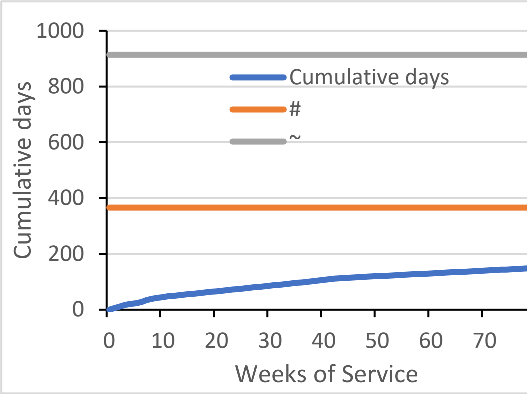
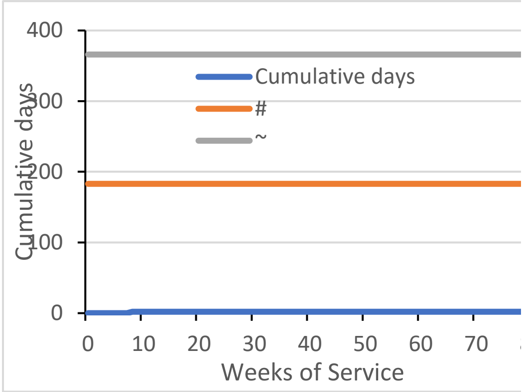


Figure 8.12: Cumulative days kneel/ squat ≥ 1 hr total



\# Reasonable Hypothesis (RMA SoP for OLL)
~ Balance of Probabilities (RMA SoP for OLL)

Table 8.3: Projected timeframes for marine technician personnel to reach RMA-recognised exposure thresholds.[a]

Exposure type	RMA thresholds	Estimated timepoint at which RMA threshold will be met
Cumulative kilograms of lifted loads ≥ 20kg* while weight bearing through the legs (excl. lifts due to strides) (Figure 8.9)	# 100,000 kg in any 10-yr period of service preceding clinical onset of OLL	Never
	~ 150,000 kg in any 10-yr period of service that falls within 35 years prior to date of clinical onset of OLL	Never
Cumulative hours of carrying loads ≥ 20kg while weight bearing through the legs (Figure 8.10)	# 3,800 hrs in any 10-yr period of service preceding clinical onset of OLL	Never
	~ 3,800 hrs in any 10-yr period of service that falls within 35 years prior to date of clinical onset of OLL	Never
Cumulative days on which ≥ 150 stairs or ladder rungs ascended or descended (Figure 8.11)	# 366 days in any 2-yr period of service preceding clinical onset of OLL	366 days after commencing first posting to sea or to vessels situated 'alongside' (see text)
	~ 914 days in any 5-yr period of service that falls within 30 years prior to date of clinical onset of OLL	914 days after commencing first posting to sea or to vessels situated alongside (see text)
Cumulative days on which kneeling and/or squatting was performed for ≥ a cumulative total of 1 hour (Figure 8.12)	# 183 days in any 1-yr period of service preceding clinical onset of hip or knee OA (only)	Never
	~ 366 days in any 2-yr period of service that falls within 27 years prior to date of clinical onset of hip or knee OA (only)	Never

[a] Based on exposure trajectories established during the recruit course and Marine Technician Initial Technical Training and Certificate III courses

[b] Lifting loads means manually raising an object; it excludes lifting of centre of mass and load that occurs with each stride when marching with load

[c] # Reasonable Hypothesis (RMA SoP for OLL) ~ Balance-of-Probabilities (RMA SoP for OLL)

The same conclusion can be drawn for the cumulative number of days on which at least 150 stairs or ladder rungs are ascended or descended by marine technician trainees (Figure 8.11 and third row of Table 8.3), and for cumulative number of days on which marine technician trainees' total time spent kneeling or squatting is 1 hour or more (Figure 8.12 and fourth row of Table 8.3). However, although exposure of marine technician trainees to climbing of stairs and ladder rungs during the Marine Technician Initial Technical Training and Certificate III courses was not high overall, while at sea and as noted in the preceding sections, all Navy personnel climb more than 150 stairs or ladder rungs on a daily basis as they move across the vessel they are aboard. On this basis, and assuming similar movement around the vessel at sea, marine technicians would likely meet the RMA-set threshold for climbing stairs and ladder rungs approximately 1 year (365 days) after commencing their first posting to sea or to vessels situated alongside, with the exact timepoint at which this occurs following enlistment depending on the time following completion of the Marine Technician Initial Technical Training and Certificate III courses at which they commence their posting to sea.

Three further projections were made for marine technician trainees, based on exposures estimated in the recruit course and Marine Technician Initial Technical Training and Certificate III courses:

- Projected annual cumulative hours of carrying loads ≥ 5kg while weight bearing through the legs = 305 hours.
- Projected annual cumulative kilograms of *all* lifted loads while weight bearing through the legs (excl. lifts in strides) = 32,027 kg.
- Projected annual cumulative exposure to occupational vibration:
    - Occasional vibration = 376 hours
    - Constant vibration = 130 hours.

8.1.4 Exposures occurring during initial training for Navy Maritime Logistics – Personnel Operations

The Navy Maritime Logistics – Personnel Operations Course is representative of Navy trade training courses characterised by lower physical demands. Figure 8.13 shows (blue line) the estimated cumulative kilograms of loads greater than 20 kg that are lifted by Maritime Logistics – Personnel Operations trainees during the recruit course and Maritime Logistics – Personnel Operations Course. Using a similar approach to that used in Table 8.1, Table 8.4 indicates that, for this group, it is estimated the RMA-set threshold under its Reasonable Hypothesis scenario would never be reached by trainees. It is similarly estimated the RMA-set threshold under its Balance-of-Probabilities scenario would never be reached by trainees.

Figure 8.14 and the second row of Table 8.4 take the same approach for estimated cumulative hours of carrying loads greater than 20 kg in this Maritime Logistics – Personnel Operations trainee population. In this instance, it is apparent that if exposure to carrying such heavy loads continued at the same rate as occurred during the recruit course and Maritime Logistics – Personnel Operations Course, trainees would *never* meet the RMA's threshold specified in the SoPs for OLL within the timeframe set by the RMA.

Figure 8.13: Cumulative kilograms of lifted loads ≥ 20 kg

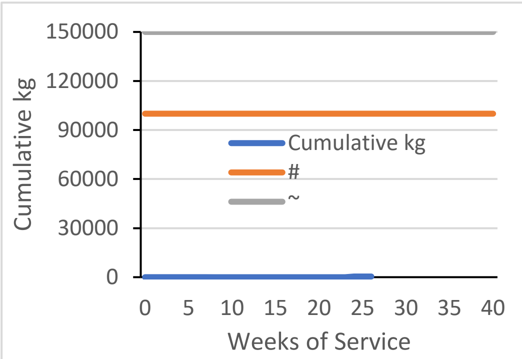


Figure 8.14: Cumulative hours of carrying loads ≥ 20 kg

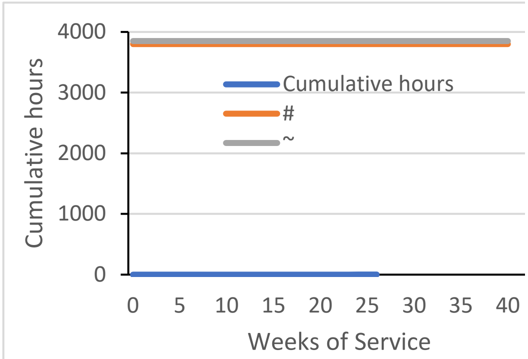


Figure 8.15: Cumulative days ≥ 150 stairs or ladder rungs

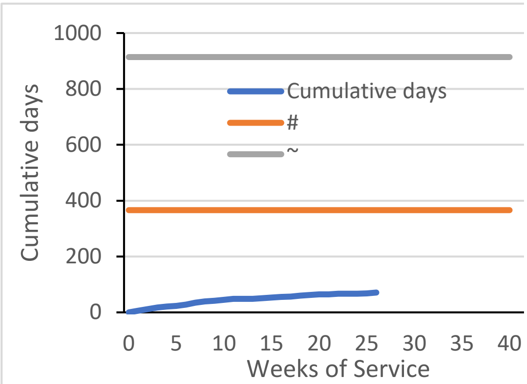
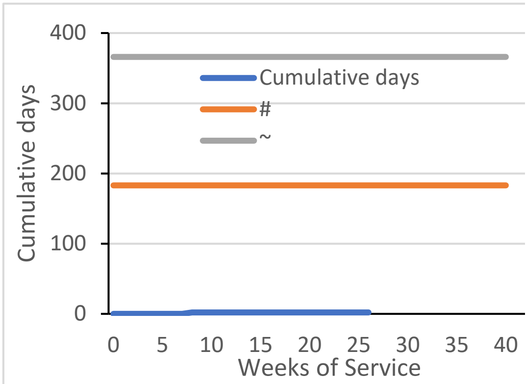


Figure 8.16: Cumulative days kneel/ squat ≥ 1 hr total



Reasonable Hypothesis (RMA SoP for OLL)
~ Balance-of-Probabilities (RMA SoP for OLL)

The same conclusion can be drawn for the cumulative number of days on which at least 150 stairs or ladder rungs are ascended or descended by Maritime Logistics – Personnel Operations trainees (Figure 8.15 and third row of Table 8.4), and for cumulative number of days on which Maritime Logistics – Personnel Operations trainees' total time spent kneeling or squatting is one hour or more (Figure 8.16 and fourth row of Table 8.4). However, while exposure of Maritime Logistics – Personnel Operations trainees to climbing of stairs and ladder rungs *during the Maritime Logistics – Personnel Operations Course* was not high overall, while at sea or to vessels situated alongside and as noted in preceding sections, all Navy personnel climb more than 150 stairs or ladder rungs on a daily basis as they traverse the vessel they are aboard.

Table 8.4: Projected timeframes for Maritime Logistics – Personnel Operations personnel to reach RMA-recognised exposure thresholds.[a]

Exposure type	RMA thresholds	Estimated timepoint at which RMA threshold will be met
Cumulative kilograms of lifted loads ≥ 20kg* while weight bearing through the legs (excl. lifts due to strides) (Figure 8.13)	# 100,000 kg in any 10-yr period of service preceding clinical onset of OLL	Never
	~ 150,000 kg in any 10-yr period of service that falls within 35 years prior to date of clinical onset of OLL	Never
Cumulative hours of carrying loads ≥ 20kg while weight bearing through the legs (Figure 8.14)	# 3,800 hrs in any 10-yr period of service preceding clinical onset of OLL	Never
	~ 3,800 hrs in any 10-yr period of service that falls within 35 years prior to date of clinical onset of OLL	Never
Cumulative days on which ≥ 150 stairs or ladder rungs ascended or descended (Figure 8.15)	# 366 days in any 2-yr period of service preceding clinical onset of OLL	366 days after commencing first posting to sea or to vessels situated 'alongside'>1 yr (see text below)
	~ 914 days in any 5-yr period of service that falls within 30 years prior to date of clinical onset of OLL	914 days after commencing postings to sea or to vessels situated alongside >2.5 yrs
Cumulative days on which kneeling and/or squatting was performed for ≥ a cumulative total of 1 hour (Figure 8.16)	# 183 days in any 1-yr period of service preceding clinical onset of hip or knee OA (only)	Never
	~ 366 days in any 2-yr period of service that falls within 27 years prior to date of clinical onset of hip or knee OA (only)	Never

[a] Based on exposure trajectories established during the recruit course and Maritime Logistics – Personnel Operations Course

[b] Lifting loads means manually raising an object; it excludes lifting of centre of mass and load that occurs with each stride when marching with load

[c] # Reasonable Hypothesis (RMA SoP for OLL)   ~ Balance of Probabilities (RMA SoP for OLL)

On this basis, and assuming similar movement around the vessel at sea, Maritime Logistics – Personnel Operations trainees who are posted to sea or to vessels situated alongside at some stage following completion of the Maritime Logistics – Personnel Operations Course for more than 1 year (365 days) would likely meet the RMA-set threshold for climbing stairs and ladder rungs approximately 366 days after commencing their first posting to sea, with the exact timepoint at which this occurs following enlistment depending on the time following completion of the Maritime Logistics – Personnel Operations Course at which they commence such a posting to sea.

Two further projections were made for Maritime Logistics – Personnel Operations trainees, based on exposures estimated in the recruit course and Maritime Logistics – Personnel Operations Course:

- Projected annual cumulative hours of carrying loads ≥ 5kg while weight bearing through the legs = 126 hours.
- Projected annual cumulative kilograms of ***all*** lifted loads while weight bearing through the legs (excl. lifts in strides) = 48,192 kg.

8.2 Observations

8.2.1 Commentary

The following commentary is based on the observation phase.

8.2.1.1 Navy New Entry Officers' Course

A notable observation regarding implications of observations for estimates derived from the desktop analysis findings is that the training college located at HMAS Creswell, Jervis Bay is a small compact base with minimal distances between accommodation, central training classrooms, gymnasium, and mess hall, and there are few steps and slight gradients. The trainees march between training sessions. Therefore, there were minimal differences between estimates of distances derived from the desktop analysis and what was observed for the trainees' marched distances. However, there were incidental stairs that were not accounted for in the desktop analysis, and therefore the estimates of stair climbing derived from the desktop analysis were conservative.

8.2.1.2 Navy Recruit Training Course

Notable observations impacting desktop analysis findings are:

- More stairs were observed to be traversed during the observation days than had been estimated in the desktop analysis. Given that it was only Week 2 of this course when observations occurred, recruits often formed up outside the accommodation blocks wearing incorrect uniform or forgetting vital equipment for the next lesson. Consequently, there were numerous occasions when individuals, or entire groups were made to return to their accommodation and obtain equipment or change, and this increased the numbers of stairs they climbed in a day.

- The 'shakedown' activity included a 'Tour of Cerberus', which was a run around Cerberus conducted by the physical training instructors. During this activity, recruits were halted outside each of the various schools in which Initial Employment Training (IET) was conducted and tasked with a series of questions regarding the training. If they were incorrect, recruits were given a number of exercises to perform (e.g., body weight squats, lunges, pushups) that were not captured as part of the desktop analysis, and therefore some of the related estimates derived from the desktop analysis will be conservative.

8.2.1.3 Boatswain's Mate Course

A notable observation impacting desktop analysis findings is that observations made during the boatswain's-mate course indicated the numbers of stairs traversed into and out of the Weapon Training Simulation System venue and around the military area led to a stair count that was higher than estimates derived from the desktop analysis. Therefore, the latter estimates were conservative.

8.2.1.4 Marine Technician IET Course

A notable observation impacting desktop analysis findings is that reports from Cerberus were that all Marine Technician Training was performed on ground level and, although this is true for training conducted in the workshop, the classroom that the recruits used was accessed via 41 stairs. Because the majority of the day was spent on the workshop floor finalising assessments, this classroom was not used for any lessons while the observation phase was in effect. Despite this, recruits stored their personal effects in the classrooms, and were observed to traverse them during each break and at the end of the day to retrieve their personal effects. This substantially added to the number of stairs observed for this occupation, leading to them being higher than the numbers estimated from the desktop analysis.

8.2.1.5 Maritime Logistics – Personnel Operations Course

Notable observations impacting desktop analysis findings are:

- During the days of observation, training was provided in a different classroom than usual due to several buildings undergoing renovations. Therefore, the distances observed to be travelled each day may be lower than is typical.

- There were notable numbers of intermittent and random stairs that the trainees were required to traverse, including multiple single or double steps that would be traversed into and out of the classroom several times per day and along foot paths.

- An unprogrammed march past was conducted, which required the trainees to march to a podium on the parade ground and then march back to the classroom. The activity lasted 20 minutes and required the trainees to march an unscheduled additional 1,200 m.

8.2.2 Comparison of observed exposures to estimates from the desktop analysis

Data on key exposures observed during the observations of selected training days from each selected Navy initial training program (Table 5.1) were compared as planned with estimates of these key exposures, from the same training days, obtained through the desktop analysis. The purpose of this comparison was to confirm the extent to which the estimates derived from the desktop analysis reflected the reality of training in the training context and to explore where differences arose, if these occurred.

8.2.2.1 Kneeling/squatting

Across all of the selected Navy initial training programs, and across the two days of training that were observed, estimates derived from the desktop analysis of time spent kneeling or squatting were within the bounds of –50 minutes to 0 minutes (both kneeling and squatting together) when compared with the number of minutes observed, with the mean difference being –21 minutes. This means that the estimates of time spent kneeling or squatting derived from the desktop analysis were slightly conservative, but it is unlikely that the difference (which occurred over a 48-hour period) would have affected the cumulative numbers of days estimated from the desktop analysis on which kneeling and squatting exceeded 1 hour in these selected Navy initial training programs.

8.2.2.2 Climbing stairs/ ladder rungs

Across all of the selected Navy initial training programs, and across the 2 days of training that were observed for each, estimates derived from the desktop analysis of the numbers of steps/rungs climbed were within the bounds of –554 to –68 steps/rungs when compared with the number of steps/rungs observed, with the mean difference being –267 steps/rungs.

This means that the estimates of numbers of stairs/rungs climbed each day derived from the desktop analysis were again conservative, and closer inspection to examine how these additional stairs/rungs were distributed over the 2 days of observations indicated that across all of the Navy initial training programs except for the Maritime Logistics – Personnel Operations initial training program (for which the threshold numbers of stairs/rungs was not reached on either of the days observed), the cumulative numbers of days estimated from the desktop analysis on which 150 or more stairs/rungs were climbed should be increased by an average of 2.5 days per week (one additional day for each 2-day period, assuming a 5-day working week).

This adjustment would mean that, assuming exposure to climbing stairs and ladders remains at similar levels as those encountered during initial training, personnel from all of the selected Navy occupations except for Maritime Logistics – Personnel Operations would meet the RMA-specified threshold for number of days on which 150 stairs/rungs were climbed within 1 year and 47 weeks of enlistment under the Reasonable Hypothesis scenario and within 4 years and 40 weeks of enlistment under the Balance-of-Probabilities scenario, whether they are posted to sea or not.

As noted in Section 8.1, personnel from all of the selected occupations would meet these thresholds earlier if they were posted to sea or to vessels situated ‘alongside’ for more than a year under the Reasonable Hypothesis scenario or more than 3 years within a 5-year period under the Balance-of-Probabilities scenario.

8.2.2.3 Lifting

Total kilograms lifted where loads were greater than 20 kg differed little between the estimates from the desktop analysis and observed lifts across the initial training programs of the selected Navy occupations. The only difference that occurred was on one of the two days of the Navy Recruit Training Course that were observed. On that day, an additional 638 kg comprising 29 x 22 kg loads were lifted during a gym-based lift-and-carry session. This was above the loads estimated in the desktop analysis. Although this finding from the observations means that the estimates derived from the desktop analysis were once again conservative, this additional load lifting, observed only during the recruit training program that preceded IET, would not have altered the conclusion from the desktop analysis for each selected Other Ranks Navy occupation. This indicates that the cumulative kilograms of lifted loads ≥ 20 kg, although weight bearing through the legs, would not have been sufficient to reach the thresholds set by the RMA for such lifting to have contributed to OLL within any timeframe. This is under the premise that the exposures to this factor observed during initial training continued unchanged into the future.

Total cumulative loads (of any weight) observed to be lifted within the 2 days of observations in each of the selected initial training programs were either not different from, or were greater than, the cumulative loads estimated from the desktop analysis for the same training days. The mean difference across the occupations was 132 kg on each day. This finding from the observations once again indicates that the estimates of total lifted loads derived from the desktop analysis were conservative, but it does not otherwise change the conclusions reached in relation to lifting as a risk factor for OLL in these Navy personnel, in Section 8.1.

8.2.2.4 Load carriage

No differences were observed in hours spent carrying loads of greater than 20 kg when the observed hours were compared with the hours estimated from the desktop analysis, for the selected Navy initial training programs. There were small differences between observed and estimated hours spent carrying lighter loads (5–19 kg) in the Navy Recruit Training Course, and this difference amounted to a mean of 40 minutes per day of additional carriage of lighter loads observed during the observations, again indicating that estimates derived in the desktop analysis for time spent carrying loads were conservative.

9. FINDINGS: ARMY

9.1 Desktop Analysis

9.1.1 Exposures occurring during Army initial officer training

Figure 9.1 shows (blue line) the estimated cumulative kilograms of loads greater than 20 kg that are lifted by trainee Army officers during the 18-month period of initial officer training. The first row of Table 9.1 identifies the thresholds of exposure set by the Repatriation Medical Authority (RMA) in its Statements of Principles (SoPs) for osteoarthritis of the lower limb (OLL) for repeated heavy lifting of this nature to have been a likely contributor to development of diagnosed OLL under its reasonable- hypothesis and Balance-of-Probabilities scenarios.

The exposure thresholds for the two scenarios are also represented in Figure 9.1 by the orange and grey lines, respectively. The final column of Table 9.1 indicates the projected timepoint after enlistment at which the RMA-set threshold for each scenario would be met if the rate of exposure of Army officers to such heavy lifting continued as it was during the 18-month period of initial officer training. Table 9.1 indicates that, for this group, it is estimated the RMA-set threshold under its Reasonable Hypothesis scenario would not be reached within the 10-year period mandated by the RMA, and the RMA-set threshold under its Balance-of-Probabilities scenario would similarly not be reached within the 15-year period mandated by the RMA.

Figure 9.2 and the second row of Table 9.1 take the same approach for estimated cumulative hours of carrying loads greater than 20 kg in this Army officer population. In this instance, it is apparent that if exposure to carrying such heavy loads continued at the same rate as occurred during Initial Officer Training, Army officers would meet the RMA's threshold specified under its Reasonable Hypothesis scenario and under its Balance-of-Probabilities scenario in the SoPs for OLL within 4 years and 37 weeks after commencement of service.

In similar fashion, it is clear from Table 9.1 and Figures 9.3 and 9.4 that neither the cumulative number of days on which at least 150 stairs or ladder rungs are ascended or descended by Army officers nor the cumulative number of days on which Army officers' total time spent kneeling or squatting is 1 hour or more would ever reach RMA-mandated thresholds of exposure under either scenario if exposures continued as they were observed to occur during initial officer training.

Two further projections were made for Army officers, based on exposures estimated from initial officer training:

- Projected annual cumulative hours of carrying loads ≥ 5 kg while weight bearing through the legs = 1,621 hours.

- Projected annual cumulative kilograms of all lifted loads while weight bearing through the legs (excluding lifts during strides) = 135,219 kg.

Figure 9.1: Cumulative kilograms of lifted loads ≥ 20kg

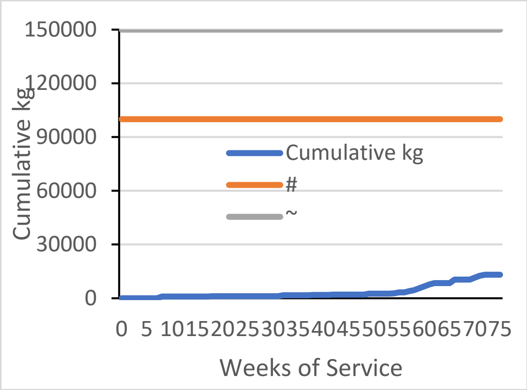


Figure 9.2: Cumulative hours of carrying loads ≥ 20kg

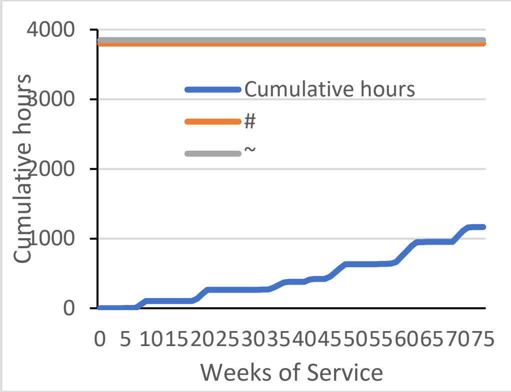


Figure 9.3: Cumulative days ≥ 150 stairs or ladder rungs

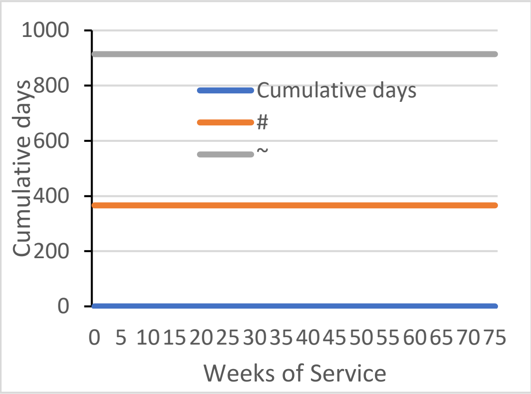
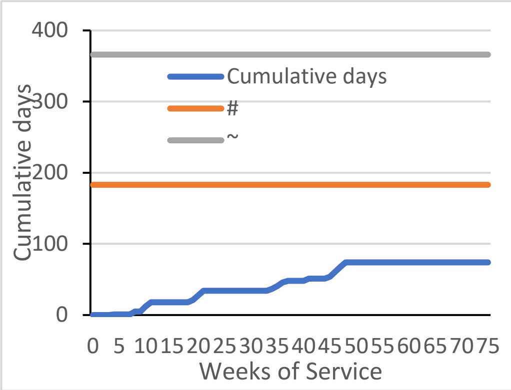


Figure 9.4: Cumulative days kneel/squat ≥ 1 hr total



Reasonable Hypothesis (RMA SoP for OLL)
~ Balance-of-Probabilities (RMA SoP for OLL)

Table 9.1: Projected timeframes for Army officers to reach RMA-recognised exposure thresholds.[a]

Exposure type	RMA thresholds	Estimated timepoint at which RMA threshold will be met
Cumulative kilograms of lifted loads ≥ 20kg* while weight bearing through the legs (excl. lifts due to strides) (Figure 9.1)	# 100,000 kg in any 10-yr period of service preceding clinical onset of OLL	Never
	~ 150,000 kg in any 10-yr period of service that falls within 35 years prior to date of clinical onset of OLL	Never
Cumulative hours of carrying loads ≥ 20kg while weight bearing through the legs (Figure 9.2)	# 3,800 hrs in any 10-yr period of service preceding clinical onset of OLL	4 years + 37 weeks following service commencement
	~ 3,800 hrs in any 10-yr period of service that falls within 35 years prior to date of clinical onset of OLL	4 years + 37 weeks following service commencement
Cumulative days on which ≥ 150 stairs or ladder rungs ascended or descended (Figure 9.3)	# 366 days in any 2-yr period of service preceding clinical onset of OLL	Never
	~ 914 days in any 5-yr period of service that falls within 30 years prior to date of clinical onset of OLL	Never
Cumulative days on which kneeling and/or squatting was performed for ≥ a cumulative total of 1 hour (Figure 9.4)	# 183 days in any 1-yr period of service preceding clinical onset of hip or knee OA (only)	Never
	~ 366 days in any 2-yr period of service that falls within 27 years prior to date of clinical onset of hip or knee OA (only)	Never

[a] Based on exposure trajectories established during initial officer training
[b] Lifting loads means manually raising an object; it excludes lifting of centre of mass and load that occurs with each stride when marching with load
[c] # Reasonable hypothesis (RMA SoP for OLL) ~ Balance-of-Probabilities hypothesis (RMA SoP for OLL)

9.1.2 Exposures occurring during Infantry Initial Employment Training

The Army's 16-week Infantry Initial Employment Training (IET) is representative of Army IET characterised by high physical demands. In this section, the exposures of Infantry trainees during recruit training and Infantry IET to factors that may increase the risk of developing OLL are documented.

Figure 9.5 shows (blue line) the estimated cumulative kilograms of loads greater than 20 kg that are lifted by infantry trainees during recruit training and Infantry IET. Using a similar approach to that used in Table 9.1, Table 9.2 indicates that, for this group, it is estimated the RMA-set threshold under its Reasonable Hypothesis scenario would be reached within 2 years and 26 weeks of commencement of service. It is similarly estimated the RMA-set threshold under its Balance-of-Probabilities scenario would be reached within 3 years and 39 weeks of commencement of service.

Figure 9.6 and the second row of Table 9.2 take the same approach for estimated cumulative hours of carrying loads greater than 20 kg in this Infantry trainee population. In this instance, it is apparent that if exposure to carrying such heavy loads continued at the same rate as occurred during recruit training and Infantry IET, trainees would meet the RMA's thresholds specified in the SoPs for OLL within 4 years and 45 weeks of commencing service.

In contrast, it is evident the RMA's threshold exposures will never be reached by Infantry personnel for risk of developing OLL associated with the projected cumulative number of days on which at least 150 stairs or ladder rungs are ascended or descended (Figure 9.7 and third row of Table 9.2), or the projected cumulative number of days on which total time spent kneeling or squatting is 1 hour or more (Figure 9.8 and fourth row of Table 9.2).

Figure 9.5: Cumulative kilograms of lifted loads ≥ 20kg

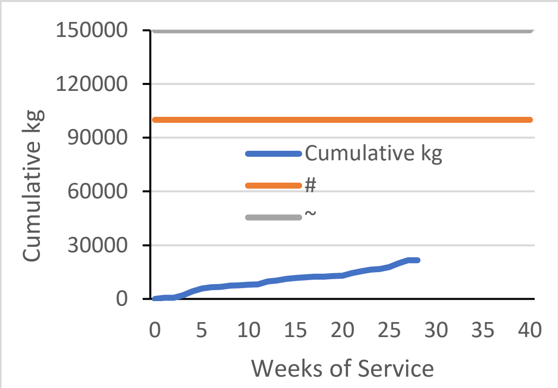


Figure 9.6: Cumulative hours of carrying loads ≥ 20kg

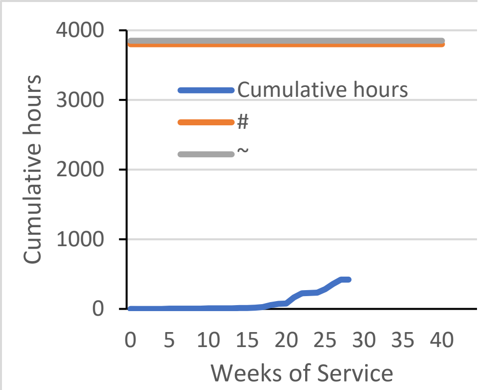


Figure 9.7: Cumulative days ≥ 150 stairs or ladder rungs

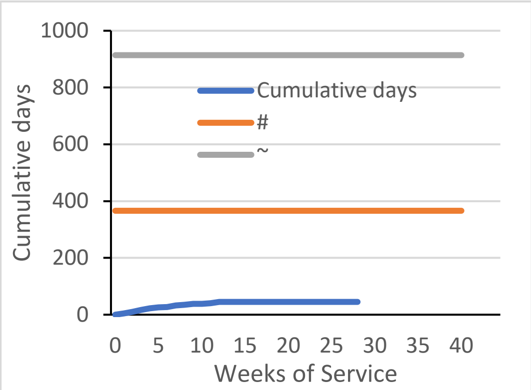
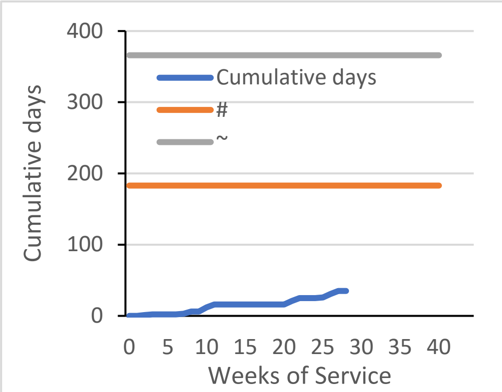


Figure 9.8: Cumulative days kneel/squat ≥ 1 hr total



Reasonable Hypothesis (RMA SoP for OLL)
~ Balance-of-Probabilities (RMA SoP for OLL)

Table 9.2: Projected timeframes for Infantry personnel to reach RMA-recognised exposure thresholds.[a]

Exposure type	RMA thresholds	Estimated timepoint at which RMA threshold will be met
Cumulative kilograms of lifted loads ≥ 20kg* while weight bearing through the legs (excl. lifts due to strides) (Figure 9.5)	# 100,000 kg in any 10-yr period of service preceding clinical onset of OLL	2 years + 26 weeks following service commencement
	~ 150,000 kg in any 10-yr period of service that falls within 35 years prior to date of clinical onset of OLL	3 years + 39 weeks following service commencement
Cumulative hours of carrying loads ≥ 20kg while weight bearing through the legs (Figure 9.6)	# 3,800 hrs in any 10-yr period of service preceding clinical onset of OLL	4 years + 45 weeks following service commencement
	~ 3,800 hrs in any 10-yr period of service that falls within 35 years prior to date of clinical onset of OLL	4 years + 45 weeks following service commencement
Cumulative days on which ≥ 150 stairs or ladder rungs ascended or descended (Figure 9.7)	# 366 days in any 2-yr period of service preceding clinical onset of OLL	Never
	~ 914 days in any 5-yr period of service that falls within 30 years prior to date of clinical onset of OLL	Never
Cumulative days on which kneeling and/or squatting was performed for ≥ a cumulative total of 1 hour (Figure 9.8)	# 183 days in any 1-yr period of service preceding clinical onset of hip or knee OA (only)	Never
	~ 366 days in any 2-yr period of service that falls within 27 years prior to date of clinical onset of hip or knee OA (only)	Never

[a] Based on exposure trajectories established during recruit training and Infantry IET

[b] Lifting loads means manually raising an object; it excludes lifting of centre of mass and load that occurs with each stride when marching with load

[c] # Reasonable Hypothesis (RMA SoP for OLL) ~ Balance-of-Probabilities (RMA SoP for OLL)

Two further projections were made for infantry trainees, based on exposures estimated in recruit training and Infantry IET:

- Projected annual cumulative hours of carrying loads ≥ 5 kg while weight bearing through the legs = 2,030 hours.
- Projected annual cumulative kilograms of all lifted loads while weight bearing through the legs (excluding lifts in strides) = 144,140 kg.

9.1.3 Exposures occurring during Army Driver Specialist IET

Army Driver Specialist IET is representative of Army IET characterised by high levels of exposure to vibration. It has a total duration of around 70 days (10 weeks). In this section only the 5-week Driver's Training Package component of the Driver Specialist IET is considered because we are currently awaiting program information from Army for the other two components of the IET.

Figure 9.9 shows (blue line) the estimated cumulative kilograms of loads greater than 20 kg that are lifted by driver specialist trainees during recruit training and the 5-week Driver's Training Package component of the Driver Specialist IET. Using a similar approach to that used in Table 9.1, Table 9.3 indicates that, for this group, it is estimated the RMA-set threshold under its reasonable-hypothesis scenario would be reached by trainees within 1 year and 4 weeks following commencement of service. It is similarly estimated the RMA-set threshold under its balance-of-probabilities scenario would be reached by trainees within 1 year and 32 weeks following commencement of service.

Figure 9.10 and the second row of Table 9.3 take the same approach for estimated cumulative hours of carrying loads greater than 20 kg in this driver specialist trainee population. In this instance, it is apparent that if exposure to carrying such heavy loads continued at the same rate as occurred during recruit training and the 5-week driver's training package component of the Driver Specialist IET, trainees would never meet the RMA's threshold specified in the SoPs for OLL within the timeframe set by the RMA.

The same conclusion can be drawn for the cumulative number of days on which at least 150 stairs or ladder rungs are ascended or descended by driver specialist trainees (Figure 9.11 and third row of Table 9.3), and for cumulative number of days on which Driver Specialist trainees' total time spent kneeling or squatting is 1 hour or more (Figure 9.12 and fourth row of Table 9.3).

Three further projections were made for driver specialist trainees, based on exposures estimated in recruit training and the 5-week Driver's Training Package component of the Driver Specialist IET:

- Projected annual cumulative hours of carrying loads ≥ 5 kg while weight bearing through the legs = 1,358 hours.

- Projected annual cumulative kilograms of all lifted loads while weight bearing through the legs (excluding lifts in strides) = 179,164 kg.

- Projected annual cumulative hours of exposure to constant vibration = 251 hours.

Figure 9.9: Cumulative kilograms of lifted loads ≥ 20kg

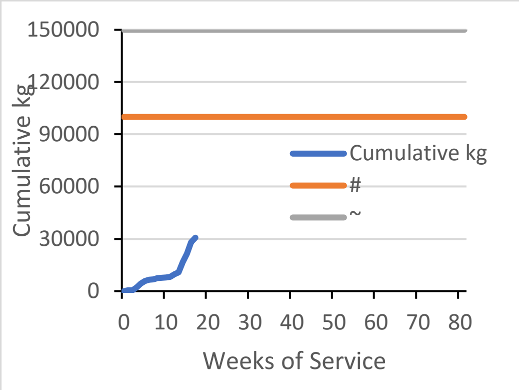
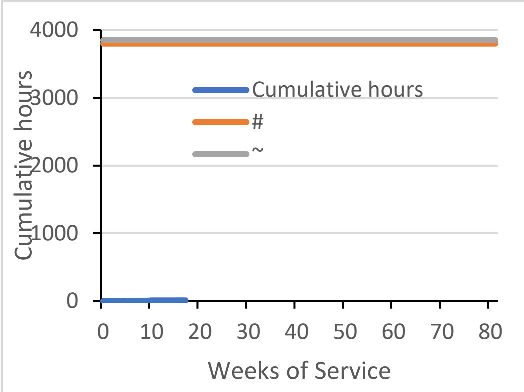


Figure 9.10: Cumulative hours of carrying loads ≥ 20kg



Reasonable Hypothesis (RMA SoP for OLL)
~ Balance-of-Probabilities (RMA SoP for OLL)

Table 9.3: Projected timeframes for Army Driver Specialists to reach RMA-recognised exposure thresholds.[a]

Exposure type	RMA thresholds	Estimated timepoint at which RMA threshold will be met
Cumulative kilograms of lifted loads ≥ 20kg* while weight bearing through the legs (excl. lifts due to strides) (Figure 9.9)	# 100,000 kg in any 10-yr period of service preceding clinical onset of OLL	1 year + 4 weeks following service commencement
	~ 150,000 kg in any 10-yr period of service that falls within 35 years prior to date of clinical onset of OLL	1 year + 32 weeks following service commencement
Cumulative hours of carrying loads ≥ 20kg while weight bearing through the legs (Figure 9.10)	# 3,800 hrs in any 10-yr period of service preceding clinical onset of OLL	Never
	~ 3,800 hrs in any 10-yr period of service that falls within 35 years prior to date of clinical onset of OLL	Never
Cumulative days on which ≥ 150 stairs or ladder rungs ascended or descended (Figure 9.11)	# 366 days in any 2-yr period of service preceding clinical onset of OLL	Never
	~ 914 days in any 5-yr period of service that falls within 30 years prior to date of clinical onset of OLL	Never
Cumulative days on which kneeling and/or squatting was performed for ≥ a cumulative total of 1 hour (Figure 9.12)	# 183 days in any 1-yr period of service preceding clinical onset of hip or knee OA (only)	Never
	~ 366 days in any 2-yr period of service that falls within 27 years prior to date of clinical onset of hip or knee OA (only)	Never

[a] Based on exposure trajectories established during recruit training and the 5-week Driver's Training Package component of the Driver Specialist IET

[b] Lifting loads means manually raising an object; it excludes lifting of centre of mass and load that occurs with each stride when marching with load

[c] # Reasonable hypothesis (RMA SoP for OLL) ~ Balance-of-Probabilities (RMA SoP for OLL)

Figure 9.11: Cumulative days ≥ 150 stairs or ladder rungs

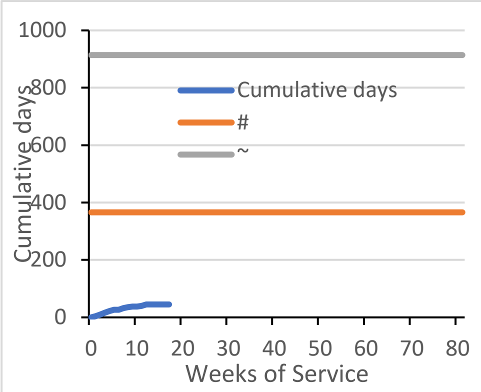
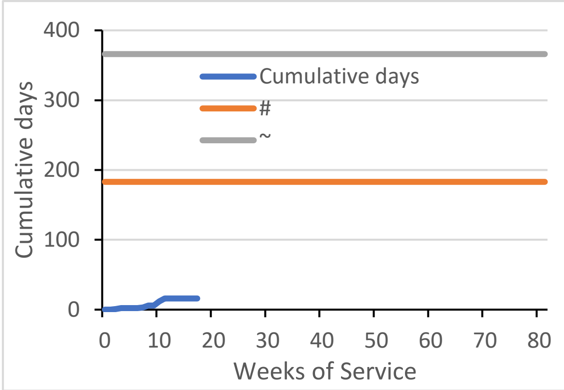


Figure 9.12: Cumulative days kneel/squat ≥ 1 hr total



\# Reasonable Hypothesis (RMA SoP for OLL)
~ Balance-of-Probabilities (RMA SoP for OLL)

9.1.4 Exposures occurring during the ADF Medic Training continuum

Army Medical Assistant IET is representative of Army IET characterised by lower levels of exposure to physical activity. It is conducted over a period of 69 weeks following recruit training, and incorporates a nursing module, military module, paramedic module, and several workplace learning placements.

Figure 9.13 shows (blue line) the estimated cumulative kilograms of loads greater than 20 kg that are lifted by army medical assistant trainees during recruit training and Medical Assistant IET. Using a similar approach to that used in Table 9.1, Table 9.4 indicates that, for this group, it is estimated the RMA-set threshold under its Reasonable Hypothesis scenario would be reached by trainees within 1 year and 48 weeks following commencement of service. It is similarly estimated the RMA-set threshold under its Balance-of-Probabilities scenario would be reached by trainees within 2 years and 46 weeks following commencement of service.

Figure 9.14 and the second row of Table 9.4 take the same approach for estimated cumulative hours of carrying loads greater than 20 kg in this medical assistant trainee population. In this instance, it is apparent that if exposure to carrying such heavy loads continued at the same rate as occurred during recruit training and Medical Assistant IET, trainees would never meet the RMA's threshold specified in the SoPs for OLL within the timeframe set by the RMA.

The same conclusion can be drawn for the cumulative number of days on which at least 150 stairs or ladder rungs are ascended or descended by medical assistant trainees (Figure 9.15 and third row of Table 9.4), and for cumulative number of days on which medical assistant trainees' total time spent kneeling or squatting is 1 hour or more (Figure 9.16 and fourth row of Table 9.4).

Two further projections were made for medical assistant trainees, based on exposures estimated in recruit training and Medical Assistant IET:

- Projected annual cumulative hours of carrying loads ≥ 5 kg while weight bearing through the legs = 328 hours.
- Projected annual cumulative kilograms of *all* lifted loads while weight bearing through the legs (excl. lifts in strides) = 93,019 kg.

Figure 9.13: Cumulative kilograms of lifted loads ≥ 20kg

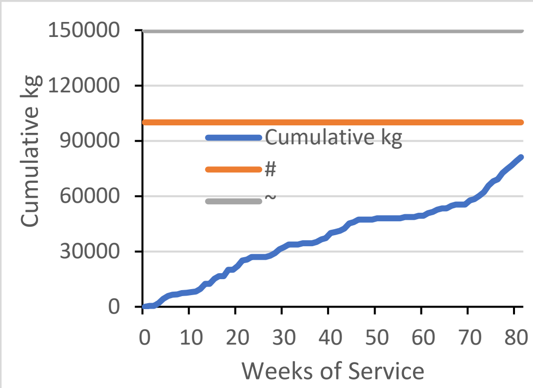


Figure 9.14: Cumulative hours of carrying loads ≥ 20kg

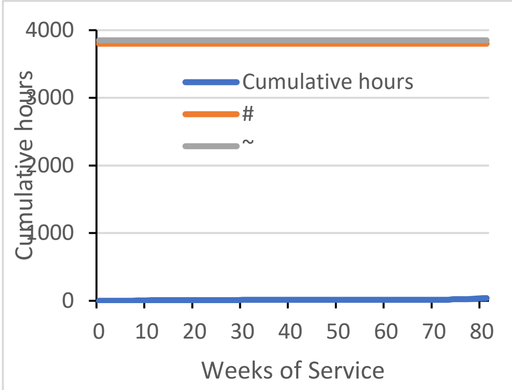


Figure 9.15: Cumulative days ≥ 150 stairs or ladder rungs

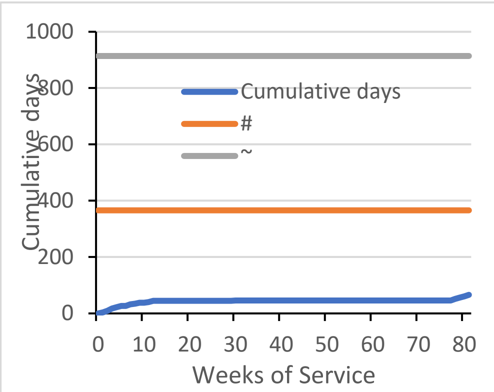
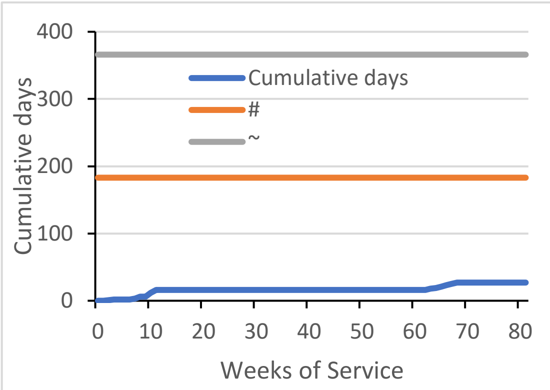


Figure 9.16: Cumulative days kneel/ squat ≥ 1 hr total



\# Reasonable Hypothesis (RMA SoP for OLL)
~ Balance-of-Probabilities (RMA SoP for OLL)

Table 9.4: Projected timeframes for Army medical assistant personnel to reach RMA-recognised exposure thresholds.[a]

Exposure type	RMA thresholds	Estimated timepoint at which RMA threshold will be met
Cumulative kilograms of lifted loads ≥ 20kg* while weight bearing through the legs (excl. lifts due to strides) (Figure 9.13)	# 100,000 kg in any 10-yr period of service preceding clinical onset of OLL	1 year and 48 weeks following service commencement
	~ 150,000 kg in any 10-yr period of service that falls within 35 years prior to date of clinical onset of OLL	2 years and 46 weeks following service commencement
Cumulative hours of carrying loads ≥ 20kg while weight bearing through the legs (Figure 9.14)	# 3,800 hrs in any 10-yr period of service preceding clinical onset of OLL	Never
	~ 3,800 hrs in any 10-yr period of service that falls within 35 years prior to date of clinical onset of OLL	Never
Cumulative days on which ≥ 150 stairs or ladder rungs ascended or descended (Figure 9.15)	# 366 days in any 2-yr period of service preceding clinical onset of OLL	Never
	~ 914 days in any 5-yr period of service that falls within 30 years prior to date of clinical onset of OLL	Never
Cumulative days on which kneeling and/or squatting was performed for ≥ a cumulative total of 1 hour (Figure 9.16)	# 183 days in any 1-yr period of service preceding clinical onset of hip or knee OA (only)	Never
	~ 366 days in any 2-yr period of service that falls within 27 years prior to date of clinical onset of hip or knee OA (only)	Never

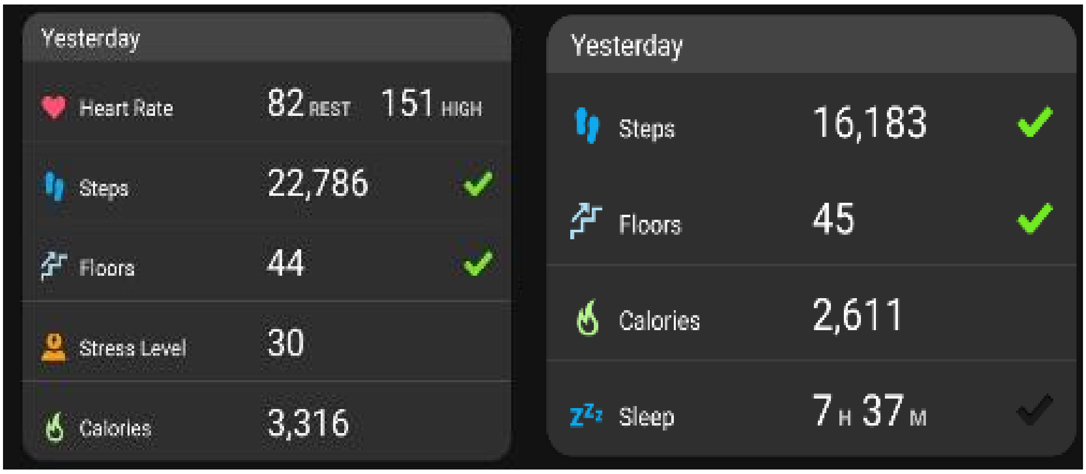
[a] Based on exposure trajectories established during recruit training and Medical Assistant IET
[b] Lifting loads means manually raising an object; it excludes lifting of centre of mass and load that occurs with each stride when marching with load
[c] # Reasonable Hypothesis (RMA SoP for OLL) ~ Balance-of-Probabilities (RMA SoP for OLL)

9.2 Observations

9.2.1 Feedback provided by staff

Discussions with staff at the Army Recruit Training Centre regarding the project resulted in staff volunteering information captured on their Garman watches in relation to stairs they climbed each day. As can been seen in Figure 9.17, the two staff members who were platoon staff for the recruit platoon being observed climbed a total of 44–45 floors of stairs in a day. With movement from one floor to another involving 18 stairs, the total number of stairs climbed by the staff (*N* = 792–810), is consistent with, though slightly greater than, the number observed being climbed by the recruits (*N* = 723 stairs) on the day of observation.

Figure 9.17: Daily step and stair count from two Army recruit instructors.



9.2.2 Commentary

The following commentary is based on the observation phase.

9.2.2.1 Royal Military College-Duntroon officer course

A notable observation impacting desktop analysis findings is that the desktop analysis did not account for any stairs during the days on which Staff Cadets attended the range. However, observations revealed that the cadets' accommodation blocks were 500 m from the range, with a total of 57 stairs that needed to be traversed at the beginning and end of each day. This discrepancy explained some of the differences reported below between the desktop analysis and the observation data.

9.2.2.2 Army Basic Recruit Training Course

Notable observations impacting desktop analysis findings are:

- Along several common footpaths travelled by the formed recruit platoon, there were collections of multiple stairs (see Figure 9.18). These stairs were not identified during the desktop analysis and therefore the number of stairs traversed per day, derived from the desktop analysis, is considered to be conservative.

- Although most exercises observed during the physical training (PT) sessions were as described in the desktop analysis, the weight of the loads lifted in the observed introductory session were notably higher, with deadlifts of around 50 kg, for example, being the average load lifted during this exercise. This means that the estimates of cumulative loads greater than 20 kg lifted that were derived from the desktop analysis are lower than those observed and therefore conservative.

- Similarly, one exercise completed in the PT session was step-ups. These step-ups were onto a box approximately 80 cm in height, with recruits holding weights in their hands.

Therefore, noting the estimates of numbers of steps derived from the desktop analysis were already conservative, it should also be noted that there may be occasions when the steps ascended/descended are higher than standard stairs and are completed at speed with the recruit carrying load.

Figure 9.18: Collection of stairs along the pathways of the Army Recruit Training Centre.

9.2.2.3 Infantry IET Course

Notable observations impacting desktop analysis findings are:

- The trainees were observed during the urban operations phase of their Rifleman qualification, directly after their basic training at ARTC. The program observations did not significantly depart from the formal program used in the desktop analysis. During the observation phase, however, the wet bulb temperature dictated tools down for a period of some hours, with temperatures exceeding 38 degrees Celsius. During this period of 'rest', many 'debrief' and 'soldier 5' sessions were conducted while trainees kneeled or squatted down in the shade. Such additional, incidental squatting was not considered in the desktop analysis and thus estimates from the desktop analysis of time spent kneeling and squatting are conservative.

- The physical training session observed was a strength circuit session. Numerous squats and lunges were performed in this session. In the desktop analysis, the session was listed as a 'PT Warm Up', so no squatting or lunging was considered to have occurred. This observation explains some of the differences between the estimates derived from the desktop analysis and what was observed in relation to exposure to squatting.

9.2.2.4 Driver Specialist IET Course

A notable observation impacting desktop analysis findings is that trainees were harboured in a central location in the safe driving area and were rotated in and out of supervised driving on a heavy rigid truck for approximately 45 minutes of driving. Between these sessions, various concurrent assessments were conducted, including changing a tyre and identifying all components of a complete equipment schedule from one of the vehicles. Heavier loads were observed to be lifted than was reported in the desktop analysis, primarily due to the tyre-changing event. The trucks that were being driven included the Mack Fleetliner MC2 Heavy Rigid variants and Mack 'R' Series MC3 variants of Heavy Rigid trucks, and, despite these providing an assisted hydraulic lift for use when moving the spare tyres, a high level of manual handling and manoeuvring was required. These wheels and tyres were reported to weigh approximately 100 kg.

9.2.2.5 Tri-Service Medical Assistant IET Course

A notable observation that may have impacted estimates of stair climbing for medical assistant trainees is that the training observed during the days on which observation occurred for the medical assistant trainees was all conducted in one building and on one level (approximately 28 stairs up from the ground floor), with TAFE, paramedic, and Army instructional staff all contributing to the program in theory lessons and limited practical applications in classroom and lab environments. The position of this teaching area led to an increased number of stairs during the observation phase than was estimated in the desktop analysis.

9.2.3 Comparison of observed exposures to estimates from the desktop analysis

Data on key exposures observed during the observations of selected training days from each selected Army initial training program (Table 5.1) were compared as planned with estimates of these key exposures, from the same training days, obtained through the desktop analysis. The purpose of this comparison was to assess the extent to which the estimates derived from the desktop analysis reflected the reality of training in the training context and to explore where differences arose if these occurred.

9.2.3.1 Kneeling/squatting

Across all of the selected Army initial training programs, and across the days of training that were observed, estimates derived from the desktop analysis of time personnel spent kneeling or squatting were within –80 minutes to 0 minutes (both kneeling and squatting together), on each observed day, of the number of minutes *observed*, with the mean difference being –20 minutes. This means that the estimates of time spent kneeling or squatting derived from the desktop analysis were conservative estimates of the actual time personnel spent kneeling or squatting, the latter recorded during the observations of training.

Closer inspection revealed that nearly all of this difference arose from the officer training and Infantry training courses, where officer cadets and Infantry trainees exceeded estimates of time derived from the desktop analysis spent kneeling, by 80 minutes and 65 minutes, respectively, on one of the two training days observed for each program. This finding, particularly when paired with existing estimates from the desktop analysis of the numbers of days on which officer cadets and Infantry trainees spend 1 hour or more squatting or kneeling, suggests that Staff Cadets and Infantry trainees probably spend 1 hour or more squatting or kneeling on more days than not in a typical month.

On this basis, and assuming this rate of exposure continues at similar levels beyond initial training for Infantry trainees particularly (since officer training is 18 months in duration), it is likely that Staff Cadets and Infantry trainees would reach the RMA threshold for exposure to this kneeling/squatting risk factor for OLL within 1 year of enlistment, under the RMA's Reasonable Hypothesis scenario. The time frame to reach this threshold under the RMA's Balance-of-Probabilities scenario would be within 2 years of enlistment.

The above would appear to be a reasonable expectation, based also on consideration of the length of Staff Cadet (officer) training (18 months), the types of training in the field routinely and frequently undertaken within initial training of both groups, and the roles that Army officers and particularly Infantry trainees (who have a shorter initial training program) fulfill in the longer term, once qualified.

9.2.3.2 Climbing stairs / ladder rungs

Across all of the selected Army initial training programs, and across the days of training that were observed for each program, estimates derived from the desktop analysis of the numbers of steps/rungs climbed were within the bounds of –603 to 0 steps/rungs when compared with the numbers of steps/rungs observed, with the mean difference for each day observed being –135 steps/rungs. This means that the estimates of numbers of stairs/rungs climbed each day derived from the desktop analysis were conservative, and closer inspection to examine how the additional stairs/rungs were distributed over the training programs and days of observation indicated that the difference was primarily due to Army recruit trainees ascending/descending 603 additional steps/rungs on one of the two days on which they were observed and officer cadets ascending/descending an average of 193 additional steps/rungs on each of the 2 days they were observed. No, or minimal, differences were evident in the other training programs, between estimates from the desktop analysis and observed numbers of steps/rungs ascended/descended for the observed training days.

It is likely, on this basis, that Army recruits exceed 150 steps/rungs ascended/ descended on more days than were estimated during the desktop analysis. However, this difference is unlikely to impact in the longer term on the conclusions reached earlier in this section that Other Ranks trainees are unlikely to ever meet the threshold for stair climbing specified by the RMA as a risk factor for OLL. This is because our evidence indicates that although stair climbing is a routine requirement during recruit training, it is not routine when trainees move on to IET in any of the selected Army Other Ranks occupations examined in this project, and recruit training is of relatively short duration, so the RMA thresholds will not be exceeded within that timeframe and thereafter the rate of accumulation of days on which stair climbing exceeds 150 flattens out.

For officer cadets, a similar assessment can be made because the additional stairs they encountered during the observed days occurred only in relation to the range of activities they undertook on those days. These activities are not undertaken regularly across the full training program. On this basis, although the numbers of steps observed in this occupational group exceeded those estimated for the observed training days in the desktop analysis, indicating that the latter estimates are conservative, it remains unlikely that officer cadets will reach the stair/ladder climbing thresholds specified by the RMA.

9.2.3.3 Lifting

Total kilograms lifted where loads were greater than 20 kg differed between the estimates from the desktop analysis and the observed lifts in Army officer training, Army recruit training, and Infantry IET, but not in Driver Specialist IET or Medical Assistant IET. In Army officer training, Army recruit training, and Infantry IET, the difference in cumulative loads lifted amounted to an average of –2276 kg for each program across the 2 days of observations, with similar differences for each of these three programs. This indicates that the desktop analysis underestimated the total kilograms lifted by trainees on the training days that were observed in each of these three programs by a mean 2,276 kg. Further investigation revealed that all of these additional kilograms of loads greater than 20 kg that were observed to be lifted within the two training days observed for each program were in each case accumulated within a single strength-and-conditioning or PT session completed by the recruits on one of the two training days observed in the respective program. In that single session, trainees lifted loads additional to those originally estimated from the desktop analysis, which accumulated to the mean additional loads cited.

This finding for Army officer, recruit, and Infantry training indicates that the estimates of heavy loads lifted derived from the desktop analysis for each of these occupations are conservative. It also further supports the existing conclusions for all of the selected Army Other Ranks occupations considered earlier in this chapter, which indicated that heavy lifting was a risk factor for development of OLL in all of these Army occupational groups. Although the findings from the observations indicate that Army recruits may lift more load during recruit training than estimated in the desktop analysis, because recruit training is relatively short (12 weeks), it is likely the additional loads they lift in this timeframe would make only a small difference to the timeframes within which the threshold exposures for heavy lifting specified by the RMA in the SoPs for OLL are projected to be met in each of the Other Ranks occupation, which are listed earlier in this chapter—perhaps shortening these timeframes by around 23%, assuming additional loads like these are lifted once per week.

However, assuming additional loads weighing 20kg or more and amounting to over 2000 kg are lifted at least once per week, on average, by Staff Cadets, it is now likely that Staff Cadets will reach the RMA threshold for exposure to this heavy lifting risk factor for OLL within 1 year of enlistment, under the RMA's Reasonable Hypothesis scenario. The time frame to reach this threshold under the RMA's Balance-of-Probabilities scenario would be within 18 months of enlistment. Both of these time frames fall within the duration of Officer Training.

For Infantry trainees, again assuming they lift additional loads weighing 20 kg or more and amounting to over 2,000 kg at least once per week, on average, it is likely the additional lifting of heavy loads observed would result in them reaching the RMA threshold for exposure to this heavy lifting risk factor for OLL within 1 year of enlistment, under the RMA's Reasonable Hypothesis scenario. The time frame to reach this threshold under the RMA's Balance-of-Probabilities scenario would likely be within 18 months of enlistment. Both of these estimates of time points are shorter than those originally estimated from the desktop analysis and take into account the additional lifting observed during observations, the original estimates from the desktop analysis, and the likelihood that Infantry personnel will continue these levels of heavy lifting as qualified personnel, given the arduous nature of their occupational role.

9.2.3.4 Carrying loads

Differences in estimates of hours spent carrying loads greater than 20 kg when the observed hours were compared with the hours estimated from the desktop analysis were minimal for the selected Army initial training programs and ranged from –1.5 hours to 0 hours per day across the selected initial training programs of the Army. Nearly all of this difference was attributable to Infantry training. These small differences are unlikely to appreciably affect the estimates provided earlier in this chapter for the projected times at which personnel from any of the selected Army initial training programs are likely to meet RMA thresholds associated with this risk factor for OLL.

There were small differences between observed and estimated hours spent carrying lighter loads (5–19 kg) across all of the selected Army initial training courses excluding officer cadets, and this difference amounted to a mean of +5 minutes per day of additional carriage of lighter loads observed during the observations of these selected initial training programs. In officer cadets, the difference was larger. The observations revealed that cadets carried lighter loads (5–19 kg) for an average of 6.5 hours per day above the hours estimated in the desktop analysis, but mostly (83% of the time) the loads carried for additional time were in the 5–9 kg range, so relatively light. These loads typically comprised light webbing and a day pack / camel back hydration system.

10. JOB EXPOSURE MATRIX

Accompanying this report are the job exposure matrices for osteoarthritis of the lower limb (JEM-OLL) for each of the three Australian Defence Force (ADF) services, listing all of the full-time ADF occupations. For each listed occupation, the JEM OLL provides a hyperlink to an appended job information sheet downloaded from the Defence Jobs Australia website (www.defencejobs.gov.au) in 2018. Each sheet provides a job overview and information about pathways for entry, salary and benefits, locations, entry requirements, and training requirements.

The JEM-OLL also provides the formal occupation title, sub-functions, and codes for each listed occupation, extracted from PMKeyS—the ADF's personnel management system. Details of the initial training courses that personnel from each occupation must complete are also provided, including course names, locations, and durations. Also hyperlinked from selected occupation listings (Table 5.1) and appended to the JEM-OLL are:

- program-specific weekly exposure workbooks for the initial training courses associated with those occupations,
- occupation-specific cumulative exposure spreadsheets, and
- occupation-specific cumulative exposure summaries for OLL.

The selected occupations are those for which initial training programs were analysed in the desktop analysis (Table 5.1) and for which the results of that analysis are reported in Chapters 7, 8, and 9. These occupations include:

- ADF officer occupations

- three Other Ranks occupations from each service for which initial training is known to involve:

    a. a relatively low level of physical activity loading,
    b. a relatively high level of physical activity loading, and
    c. a high level of specific exposure concern (e.g., exposure to heavy lifting).

It should be noted that each JEM-OLL contains information about many more types of occupational exposures than those for which findings are detailed in Chapters 7, 8, and 9 where the focus was on types of occupational exposures recognised by the RMA as risk factors for subsequent development of OLL. On that basis, the JEM-OLL provides useful information about a range of occupational exposures that may be relevant to other types of conditions or to OLL as research evidence regarding relevant exposures evolves in the future.

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11. HISTORICAL REVIEW

11.1 Introduction

The main question to be answered by the historical review documented in this chapter is whether the physical demands of initial training in the Australian Defence Force (ADF) have changed significantly over the preceding 60 years, affecting the exposure of personnel to factors that are known to increase their risk of developing osteoarthritis in the lower limbs (OLL). This is important because the Department of Veterans' Affairs (DVA) needs to know whether it is valid, when assessing a claim for service-related OLL, to assume that exposures at the levels identified through this project as occurring in initial training programs of the ADF in 2018 are representative of the exposures that personnel would have experienced when completing initial training for the same or similar occupations in the preceding 60 years. In particular, the DVA needs to be assured that exposures experienced by ADF personnel in previous decades were not less than the current estimates of exposure in order to be satisfied that where current analyses indicate Repatriation Medical Authority (RMA)-specified threshold exposures would be met within a certain timeframe, this would also be the case for personnel who undertook initial training and service in previous decades.

To address this question, the historical review reported in this section was informed by a range of information that was gathered regarding initial training undertaken in preceding decades, including:

- available documentation of initial training programs,
- images of personnel undertaking initial training,
- first-hand narrative accounts of initial training undertaken or observed,
- published reports detailing training undertaken and/or exposures of trainees to factors of relevance to subsequent development of OLL (e.g., rates of training-related injuries or exposures to different types of physical training), and
- other ADF training documentation (e.g., training manuals).

Data were sourced from participating training establishments, ADF subject-matter experts, previously published reports, and research undertaken by the research team at the Australian War Memorial Research Centre, with support of centre staff, for which we are grateful. These sources were reviewed and synthesized using a narrative approach, which was also informed by quantitative analyses where appropriate.

11.2 Physical training

In providing an historical account of physical training (PT) in the ADF, it is important to note that, unlike civilians engaging in recreational PT, military personnel are required to undertake PT as a core part of their employment and are required to pass regular fitness assessments [1, 2] that inform assessments of their deployability and potential promotion [3]. Often the type of PT being undertaken, and the intensity and volume of the PT, are dictated by military programming and other external factors over which the individual member has limited control.

This enforced and rigid PT approach is strongly evident in both historic and present-day initial training programs of the ADF. As an example, pelvic stress fractures were observed in the Australian Army in the early 1990s to result from requirements for recruits to march a given distance at a given speed in a uniform manner that was not conducive to their normal biomechanics, often while carrying a mandated backpack [4].

Due to its often arduous nature, PT has therefore comprised a source of occupational exposure to factors that increase the risk of ADF personnel developing OLL. In this chapter, we reveal how PT has remained a constant but has also evolved in the ADF over time.

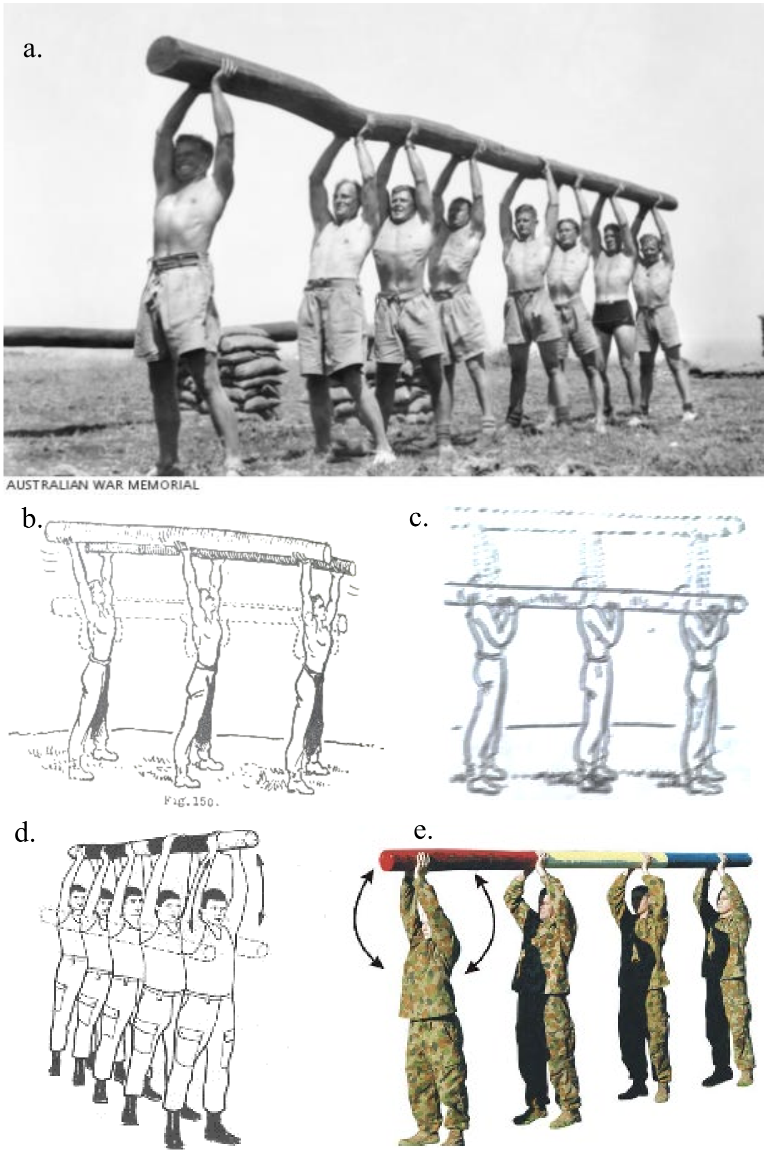
11.2.1 Doctrine and images documenting ADF PT through time

The requirement and use of PT as a major component of ADF initial training programs can be found as a consistent theme across the years in both accounts from previous military establishments and formal doctrine (e.g., military manuals and routine orders). For example, in Air Force, 6 Recruit Depot (1942–1945) made particular mention that their training consisted of physical training and swimming as well as rifle and bayonet training, in their brief synopsis of the unit [5]. Unarmed defence training and obstacle courses were also mentioned [5]. Similarly, in an Infantry Centre (Ingleburn) course program dated 1958 and obtained from the Australian War Memorial, PT requirements (e.g., runs and battle PT) were noted throughout its pages [6]. These requirements are noted in similar present-day documents, suggesting little change over at least the preceding 60 years.

Military training manuals, in particular, serve to highlight the employment of physical training as a core and mandatory component of training in Australian military personnel as consistent through time. For example, the manual *Physical Training 1937* [7] stated that 'Recruits of all arms and services will undergo a comprehensive course of physical training exercises'. The same requirement was noted in a similar military manual in 1946 [8]. More recent doctrine, in 1987, highlighted that 'Physical training (PT) is a key element in achieving and maintaining a high standard of military performance', with a directive noting that, 'Physical training (PT) is a function of leadership and, therefore, all commanders should actively enforce its conduct' [9].

Many types of training undertaken in PT, including Game Form Exercises, Logs, Relay Races, Carriage, and Battle PT, can be found in manuals from 1946 [8], 1955 [10], 1958 [6, 11], and 1987 [9], through to the latest *Land Warfare Publication* (Amendment 1 of 2009) [12]. As one example of this persistence of training approaches over time, the conduct of log exercises is shown in archival photographs (Figure 11.1a.) and doctrine (Figures 11.1 b-e). These training sessions have remained virtually unchanged for more than 65 years.

Figure 11.1: Log exercises over a span of 67 years.



Log exercises: (a) being conducted in 1942 and subsequently depicted in military training documents of (b) 1946 [11], (c) 1958 [14], (d) 1987 [12], and (e) 2009 [15].

Obstacle course training and competition comprise another timeless requirement (Figures 11.2 and 11.3). A further broadly termed form of PT, yet again consistent in its conduct across time and noted across multiple historical documents, is battle PT [6, 12].

This form of PT is found in both doctrine [12] and in individual unit programs for recruits and infantry trainees [6], and is evidenced by images from multiple timepoints across the last century (Figures 11.2 –11.6).

Figure 11.2: Trainees showing an unchanged requirement to complete traverse rope training and compete in competitions across a span of 97 years.

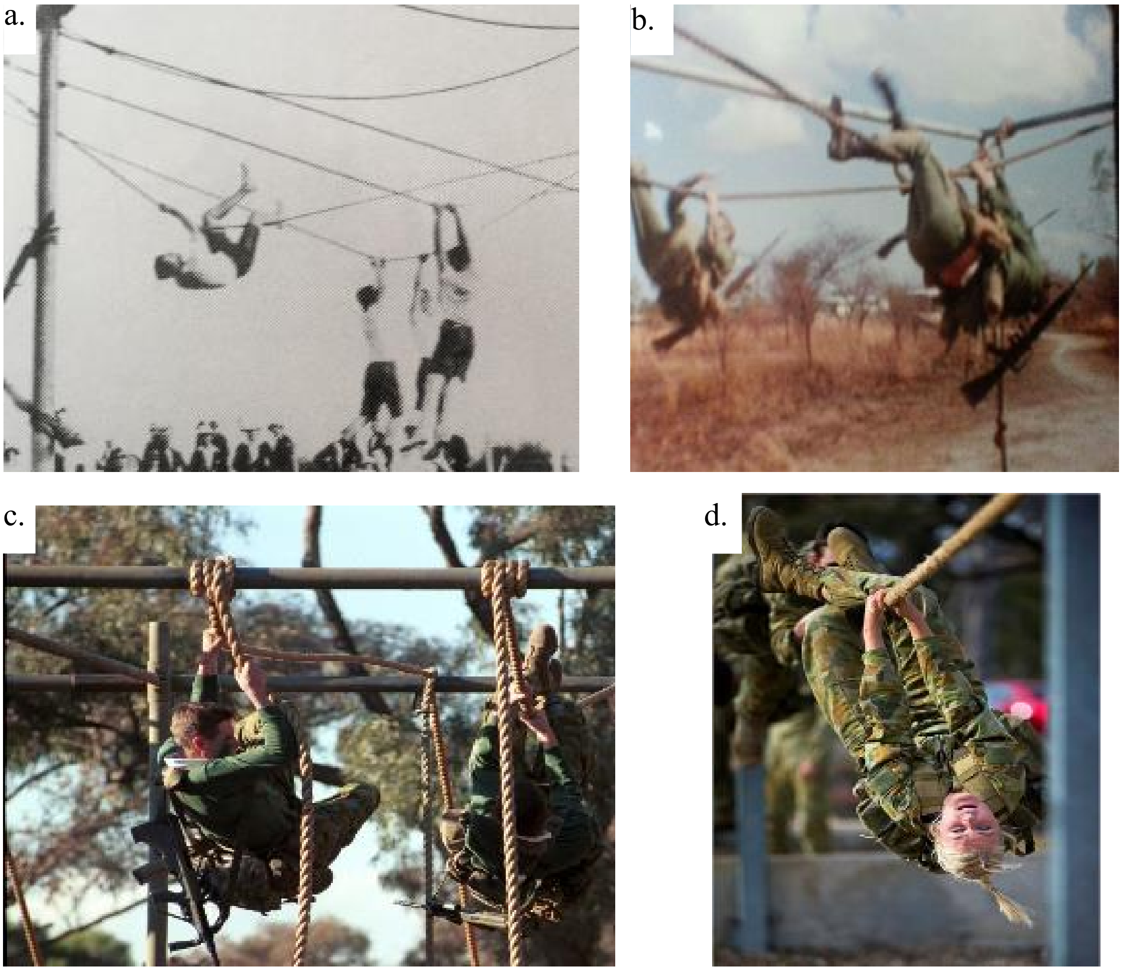


Figure 11.2: a) Circa 1918: RMC cadets compete on the obstacle course (RMC Achieves), b) 1983: Obstacle course training at Lavarack Barracks (Photograph provided by owner) c) 2001: RMC Staff Cadets compete on the obstacle course (Photograph provided by 1 JPAU), d) 2015: An ADFA officer cadet competes on the obstacle course (Photographer Petty Officer Paul Berry, Defence Images Online).

Figure 11.3: Trainees showing an unchanged requirement to complete general obstacle course training across a span of 45 years.

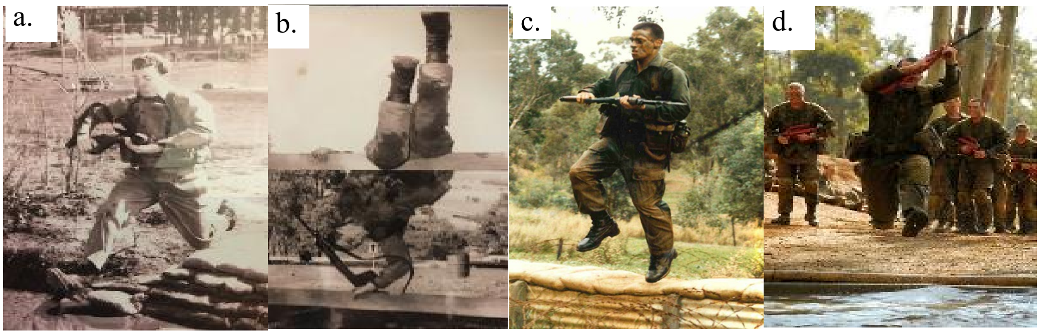


Figure 11.3 a) 1970: A recruit negotiating the obstacle course at Kapooka (Photo via B Steward, Kapooka Memorial), b) 1977: A recruit negotiating the obstacle course at Kapooka (KHC 10227B, Kapooka) Memorial), c) 1989: A recruit negotiating the obstacle course at Kapooka (Photo from member), and d) 2015: A recruit negotiating the obstacle course at Kapooka (Photographer CPL Rachel Ingram, Defence Images Online).

Figure 11.4: Photographs of military trainees showing an unchanged requirement to complete load carriage training across a span of 42 years.

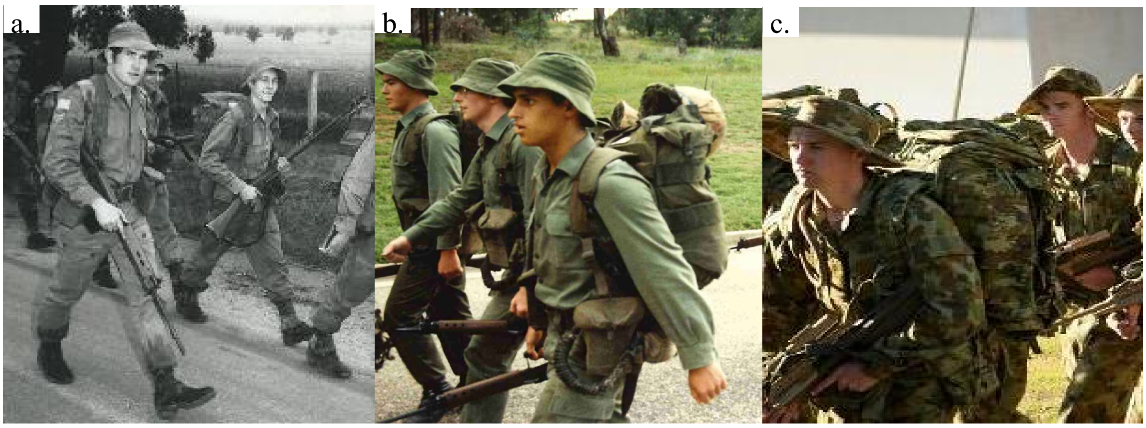
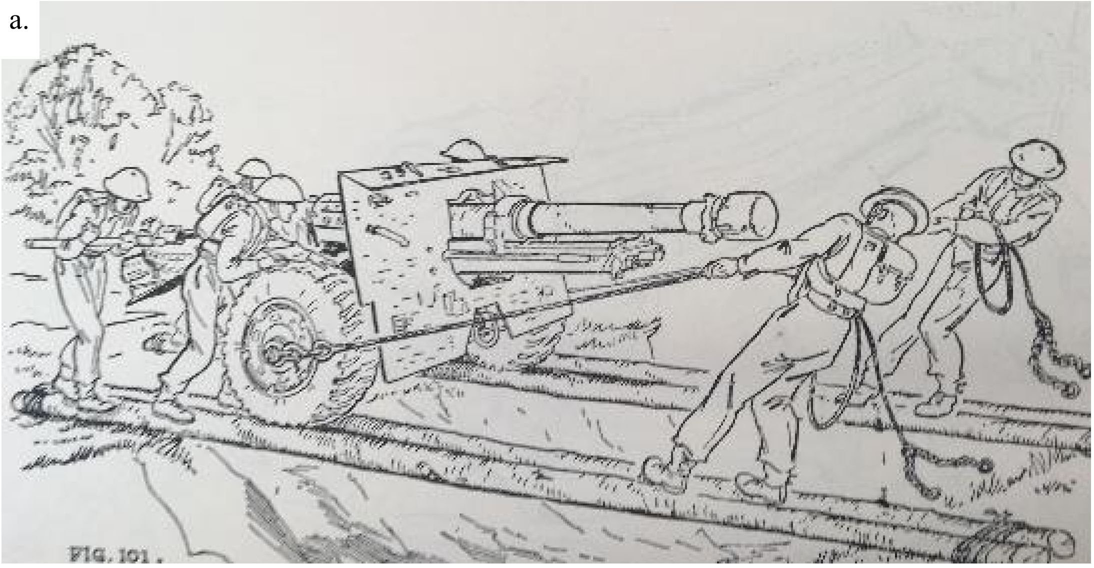


Figure 11.4: a) 1975: Recruits completing a 20 mile march at Kapooka (Photo from member, b) 1989: Recruits completing a 8 km pack march at Kapooka (Photo from member), and c) 2017: Year One officer cadets and Midshipmen (across three services) at the Australian Defence Force Academy undertake a weighted pack march (Photographer Michael Jackson-Rand, Defence Images Online).

Figure 11.5: Military personnel conducting load hauling (battle PT) training across a span of 48 years.

a.



b.

Figure 11.5: a) Physical training in the Army. 1958. Pamphlet No 4. Battle Physical Training, and b) RMC Staff Cadets complete a Battle PT session as part of Exercise Shaggy Ridge circa 2006 (Photograph provided by 1 JPAU).

Figure 11.6: Military trainees conducting bayonet assault training across a span of 42 years.

Figure 11.6: a) 1940 (AWM: 002021) b) 1970 (AWM: 002021), c) 1989 (Photo from member) and d) 2015 (Photographer CPL Rachel Ingram, Defence Images Online).

11.2.2 Perspectives of physical training instructors

Several current and former ADF Physical Training Instructors (PTIs), as well as instructional staff, provided their perspectives about the more subtle changes in physical requirements of initial training that have occurred over preceding decades in each of the services.

Army

A former PTI from the army[1] volunteered his perspective about how army recruit training has changed over the preceding three decades. A summation of his perspective is as follows:

- PT programs were considerably different from the PT programs of today in that PT programs of 3 decades ago (1988) incorporated a lot more running and more pack marching. The runs and marches at that time comprised mostly long slow distance training, with only one or two interval running sessions incorporated in the program.

- Overall, the number of PT classes within the recruit training program has remained relatively unchanged. The main change is that higher intensity training approaches have now been adopted to replace much of the previous distance running and pack marching. Recruits therefore now train at higher intensities but in a more graduated and controlled fashion involving shorter bursts of work with recovery time interspersed between bouts of intense work (through use of interval training, high intensity intermittent training, and heavier strength training). With this change, the overall volume of training has noticeably decreased due to reductions in distance runs and pack marches, so chronic loading of the musculoskeletal system has conceivably also reduced. Further adding to this reduced run requirement was the reduction in fitness assessment distances, from a 5 km run until the mid-1990s to the current 2.4 km run.

- Compared with previous years, there is now a better focus on coaching and increased use of quality training equipment during PT.

Air Force

A senior PTI from Air Force[2] volunteered his perspective on how Air Force Recruit Training has changed over the preceding two decades. A summation of his perspective is as follows:

- The Air Force has gone through a number of reviews with respect to the application of PT and how best to prepare recruits for progression into their IET and chosen vocations. Similar to the Navy and Army, Air Force historically focused on cardiovascular conditioning through running and strength development via bodyweight circuit training. This style of training failed to take into account age and incidental exercise experienced by recruits. As a physically active 17-year-old when I undertook recruit training, I was able to adapt fairly quickly without too many

[1] MAJ Gavin Wickham – formerly Army PTI. He completed Army Recruit Training at Army Recruit Training School, 1 Recruit Training Battalion, in 1988, and served as the Warrant Officer PTI in 2000.

[2] SGT Luke Hamilton – completed Air Force Recruit Training at No. 1 Recruit Training Unit (1 RTU), RAAF Base Edinburgh in 2000, and has served as a PTI in the Air Force since 2008. He is currently (2018) posted to the Australian Defence Force Physical Training School.

issues. However, I was the exception to the rule and often maligned by my peers for my ease of performance at PT due to my youth.

- The current 1 Recruit Training Unit PT program is again under review to align the recruit training continuum with the physiological demands of an evolving Air Force. Greater emphasis is being placed on education and the quality of movement, based on standardised assessment (Functional Movement Screen^{TM}), so that performance can be observed, assessed, and developed throughout the life cycle of service. To achieve this goal, the Air Force has consolidated its approach to physical performance through the development of the PT continuum (PTC). Initial entry establishments will address corrective movement, body weight, and soft-loaded exercise in preparation for barbell work (mainly compound lifts) in order to build the members' capacity to bear load more effectively. There is also a large focus on incorporating a variety of modalities for cardiovascular fitness, including nonimpact activities such as rowing, cycling, and air dyne.

- One of the areas that has been traditionally quite poor in the PTC is data tracking. This has been identified as a critical point of success/failure with respect to the PTC and is something that PTIs are working to improve.

Navy

Two PTIs from the Navy volunteered their perspectives about how Navy recruit training has changed over the preceding two decades.[3] A summation of their perspectives is as follows:

- The Navy recruit course *as a whole* has experienced only marginal changes. However, the recruit training course is currently considered physically easier, overall, than in prior years.

- The frequency and intensity aspects of PT conducted within the recruit course has reduced, with PT becoming more specific to requirements for military service. Long runs, which previously featured strongly, are now less dominant, and PT is more structured and targeted. The PT program is gradual and balanced, and the intensity increases appropriately as the recruits' fitness builds.

- Although the recruit training course, as a whole, is considered physically easier now when compared with past years, and the frequency and intensity aspects of the PT element within it have decreased, the PT element is perceived to be harder now

[3] PO Matthew Wildin - Completed Navy Recruit Training at the Recruit School, HMAS Cerberus in 1995, and served as a PTI at HMAS Cerberus in 2018; and CPO Chris Vale - Completed Navy Recruit Training at the Recruit School, HMAS Cerberus in 2001, and served as a PTI at HMAS Cerberus in 2018

> because it incorporates more strength work than was previously the case. This strength work has replaced much of the running that was previously conducted over long distances so that the PT program is more gradual and relevant.

Synopsis of PTI perspectives

The quantities of longer distance run training, body-weight circuit training, and pack marching (high volume / low intensity training) incorporated in recruit training courses of Army, Air Force, and Navy have been reduced in more recent training programs when compared with training programs employed in previous decades.

These types of training have been replaced by more specific, often higher intensity but lower volume, training, which is better graduated, balanced, and designed to meet requirements for military service. Although the short work bouts in current training sessions are often intense, recovery periods are interspersed between these bouts, reducing the overall volume of training and therefore conceivably reducing chronic loading of the musculoskeletal system.

Data-guided coaching and use of quality training equipment have become more a focus in PT programs, and a greater emphasis has been placed on strength and speed work (low volume / high intensity) taught progressively in a structured training format and often tailored to individuals or to small groups comprising individuals with similar fitness levels.

11.2.3 Records of historical physical training programs

Three published research reports have so far been identified that have quantified the PT programs that existed within army recruit training in specific prior years. In the current project we have similarly quantified the PT programs from Army recruit training in 2010 and 2018. A comparison of these programs, by year, is provided in Table 11.1.

This comparison suggests that, over the last three decades, overall numbers of PT sessions in the Army recruit training program have decreased, with other changes being a sharp drop in numbers of PT sessions focused on running and a recent return to greater numbers of sessions focused on assessing the physical abilities of recruits. More recent changes have included a reduction in route marching, battle PT, and circuit training sessions, and an increase in gym-based strength training sessions, thus partially replacing those military-specific training types that were previously employed to develop strength, endurance, and military toughness with more controlled, gym-based strength-training regimes.

Table 11.1: Numbers of PT sessions of specific types noted in published research reports and the current project to have comprised the PT programs within Army recruit training from 1987 to 2018.

PT Session	1987 [a]	1993 [a]	1994 [b]	1998 [a]	2001 [a]	2006 [c]	2007 [d]	2010 [e]	2018 [f]
Assessment	11	11	0	8	8	4.67	5.33	3	7
Route marching	15	15	10	3.5	5	8.67	11.33	9	6
Running	9	6	10.5	2	0.5	2	2.67	6	1
Strength based	0	0	0	3	0	0	0	0	12
Obstacle courses/RDJ	15	18.5	12.5	15.5	16	9	8	6	8
Circuit	5	4.5	7.5	5	7	6	4	7	0
Swim / swim circuit	4	4.5	4	3.5	4	6	4.67	7	3
Battle PT		3.5	5.5	0	0	8.67	6	0	0
Team games	2	1	0	1.5	0.5	0.67	0	0	0
Recovery	0	0	0	0	1	0	0	0	2
Lectures	2	2	0	4	4	1.3	1	3	1
TOTAL	63	66	50	46	46	47	43	41	40

[a] Data extracted from previous Army recruit training PT programs provided by ex/current Army physical training instructors serving at ARTC

[b] Pope RP, Herbert RD, Kirwan JD, Graham BJ. A randomized trial of pre-exercise stretching for injury prevention. *Medicine and Science in Sport and Exercise*. 2000;32(2): 271–277

[c] Orr R, Moorby G (2006). *The Physical Conditioning Optimisation Project - a Physical Conditioning Continuum Review of the Army Recruit Training Course*. Department of Defence, Canberra

[d] Goodall R, Pope R, Coyle J, Neumayer, R. Balance and agility training does not always decrease lower-limb injury risks: a cluster-randomised controlled trial. *International Journal of Injury Control and Safety Promotion*. 2013;20:271–281.

[e,f] Data compiled in the current project from analysis of 2010 and 2018 Army recruit training PT programs

These recorded changes are consistent with the perceptions of PTIs, discussed above, that in ADF recruit training the amount of distance running has reduced substantially over the preceding 3 decades and that data-guided coaching and graduated progression appropriate to the level of fitness of recruits has been increasingly re-emphasised, with a recent focus on gym-based strength development—all requiring more frequent assessment of physical capabilities to guide individual progression.

Similar reductions in the number of PT sessions were reported for the Royal Military College - Duntroon in 2007 [13]. In a report by Orr [13], a total of 267 periods of PT were reported to have been allocated across 2000–2001 as opposed to 154 sessions in 2006–2007.

These reductions in volume of PT are pronounced when examining policy changes over the decades. Where doctrine in 1937 stated that PT should be at the frequency of one attendance of 1 hour daily for 6 days a week and should not be reduced below 60 minutes, the *Australian Defence Force Policy on Physical Fitness* in 1997 [14] recommended each fitness component be performed at least three times per week. *HD No 252 ADF Health Promotion Program* (2007) states: 'All members should be advised to participate in 30 minutes of moderate activity on most, preferably all, of the days of the week' [15].

These findings, together with the findings reported in Sections 11.2.1 and 11.2.2, suggest that while *types* of occupational exposures encountered in PT components of initial training have remained broadly unchanged over the last 97 years, the volumes of those exposures have decreased over time and training has become more controlled such that the exposures to physically arduous tasks (including those that constitute occupational risk factors for OLL) measured today, while still notably arduous, will typically be conservative estimates of the exposures that existed in prior decades.

11.3 ADF Sports

Akin to PT, sport and sporting requirements have been constant expectations of employment in the ADF throughout ADF history, both during initial training (nowadays not in recruit training, but still in officer training and initial employment training programs) and while individuals serve as qualified personnel (Figures 11.7 & 11.8). Notwithstanding a suggestion that Australia needed units similar to the sportsmen's battalions of Britain during the Great War [16], and illustrated in a quote touting that a cricket 'Victory Test' played between Australia and Britain typified the sporting spirit that led these countries to defeat Germany and Japan in World War II [16], the importance of sport is found in ADF unit histories ([5, 17], policy [18], and enduring ADF media coverage [19]. For example, a synopsis describing RAAF: 3 National Service Training Unit (1953 – 1957) made specific mention that 'sport played a very important role at the Unit – rugby union, boxing and cricket particularly' [5]. Similar comments were found with regard to RAAF 4 NSTU and 7 NSTU, with the latter noting their strong swimming team [5]. An historical review of RMC [17] noted that sport 'has always been an essential component of cadet training*'* (Figure 11.8a). The enduring role of sport in the ADF can be seen in its dedicated inclusion in the service newspapers across all three services [19].

The *Australian Defence Force Health Status Report* of 2000 [20] indicated that sport (47%) and physical training (24%) accounted for approximately 70% of all working days lost due to injuries in the ADF from July 1997 to June 1998. This makes ADF sport another important historical source of occupational exposure of ADF personnel to factors that increase their risk of developing OLL—a source that has been relatively constant over time. Following the release of the ADF health status report [20], a report by Sherrard et al. in 2002 [21] made specific recommendations to reduce injuries in the ADF.

Figure 11.7: World War II - Australian soldiers playing soccer.

Source: Australian War Memorial (AWM061577).

Figure 11.8: RAAF, ADFA and RMC personnel playing rugby.

Figure 11.8 a) 1952: RAAF playing rugby against NZ (AWM JK0469), b) 2017: ADFA1 play ADFA 2 (Photographer SGT Dave Morley, Defence Images Online), c) 2018: The RMC Rugby Club 1st XV (Source: RMC Facebook page).

These recommendations focussed on soccer, rugby, and touch football (the three sports with the highest number of associated sporting injuries) as well as the ankle, knee, and shoulder (the three body sites with the highest numbers of associated sporting injuries). Concerns over injuries caused by PT and sport were again raised in a Senate Hansard Committee Meeting in 2004 [22]. Despite these concerns raised over a decade ago, a recent study specifically investigating injuries associated with Australian Army sports in 2015[23] found that sports remained the third most common activity to cause injury and accounted for 11% of all injuries in the Army—results similar to findings from the previous ADF Health Status Report [20] in which 13.9% of ADF injuries (and 47% of working days lost due to injuries) could be attributed to sport.

These figures also clearly indicate that sport-related injuries are not minor in nature because they contribute a disproportionate number of working days lost—an important point to note when considering whether ADF sports injuries are typically serious enough to cause symptoms and disability for 7 days or more, as required for recognition by the DVA of joint injuries as a potential contributor to OLL under criteria established by the RMA (discussed further in Chapter 12 within this report).

11.4 Historical Records of Lower-Limb Injury Rates during ADF Initial Training

11.4.1 Introduction

As will be further discussed in Chapter 12 within this report, significant injuries (or trauma) to joints of the lower limbs are recognised by the RMA as increasing the risk of OLL. Figure 4.6(f) in Chapter 4 of this report indicates that the pooled odds ratio for development of lower-limb OA in those exposed to prior injury when compared with those not exposed may be as high as 6 or 7, making a history of prior injury an important risk factor for OLL. Chapter 12, building on the information presented within this section, contains an overview of the exposures of ADF personnel to lower-limb joint injuries in initial training, permitting the conclusion that they constitute an important type of occupational exposure, with potential to affect the risk of all ADF personnel developing OLL within just a few years of commencing service. It is therefore important to consider the historical rates of lower-limb injuries in each service during initial training. In the remainder of this section, we do that before further discussion of this type of exposure, including in trained personnel, in Chapter 12.

11.4.2 The military injury pyramid and phenomena of underreporting and delayed reporting

Before exploring service-specific injury rates in ADF trainees, it is essential to understand the injury pyramid that exists within the ADF and other military forces, internationally. Understanding the military injury pyramid enables more informed and accurate estimates of true injury rates based on available data. Major considerations within the injury pyramid are the phenomena of underreporting and delayed reporting, and differences in the sensitivity of work health and safety (WHS) and point-of-care injury reporting systems. Each of these issues will now be discussed.

The concept of an injury pyramid has been described by the World Health Organisation[4] and in relation to military forces ([24], Figure 4.3). Briefly, an injury pyramid depicts the understanding that for every injury-related fatality that occurs in a population there will always be many more serious injuries, that for every serious injury there will always be many more moderately serious injuries, and that for every moderately serious injury there

[4] See https://www.who.int/violence_injury_prevention/key_facts/VIP_key_fact_5.pdf

will always be many more minor injuries—thus forming a pyramid in which each layer reflects a level of severity of the injuries represented within it and in which lower layers of the pyramid (reflecting lower levels of severity) include many more injuries than do higher layers (which often reflect more serious injuries or injury-related fatalities).

This understanding is important because it leads to a realisation that recorded injury rates will always be dependent on the level of injury severity that constitutes the threshold beyond which injuries are reported by military personnel. If the threshold level of injury severity is low for reporting (so that even minor injuries are reported), recorded injury rates will be much higher than if the threshold level of injury severity is high.

Delayed reporting and underreporting of injuries influence the injury pyramid that exists in military forces such as the ADF. Reporting of injuries can often be postponed (delayed reporting) or avoided altogether (underreporting), leading to a high injury-severity threshold for reporting and so to lower rates of recorded injuries than the true injury rates for the particular military population. Underreporting of injuries and delayed reporting of injuries are interrelated phenomena. If personnel delay reporting their injuries, any injuries that recover sufficiently within the period of delay are unlikely to ever be reported, resulting in further underreporting. We know from experience and from research (for example, [25]) that delays in reporting injuries of several weeks or more are not unusual in military personnel due to factors such as operational tempo, desire to complete a training program before reporting an injury, thinking that the injury might resolve without health care, and perceived lack of access to the required type or level of health care in a particular context or at a given point in time. This can mean that the threshold of injury severity before reporting occurs is high because only those injuries that have not resolved within the period of delayed reporting will ultimately be reported.

Underreporting can occur for a range of other reasons. Of particular relevance to underreporting, the Productivity Commission ([26], p. 310) recently noted that more than 90% of claims submitted to the DVA for injuries in the ADF were not accompanied by a supporting WHS injury report or medical injury record. Specifically, the Productivity Commission ([26], p. 310) stated:

> There are a number of ways to establish clinical onset or worsening of a condition. If the condition was caused by a particular incident during service (such as an accident), then ideally the claimant's service records would include a medical record or incident report that indicates a date of onset or worsening.

In practice, the use of incident reports in claims does not appear to be common. Available data suggest that under the Military Rehabilitation and Compensation Act (MRCA):

- only around 2,700 claimed conditions (2.4 per cent of the claimed conditions over the period 1 July 2004 to 30 June 2017) were linked to an incident report;

- the links to incident reports were much lower for claimed conditions related to operational service (particularly for the nearly 15,000 conditions related to service in Afghanistan, at around 1.1 per cent); and,

- despite this, some periods of operational service had significantly higher rates of linkages to incident reports, particularly claimed conditions related to service in Fiji (nearly 16.9%), the Solomon Islands (4.8%), and general peacekeeping service (5.1%). These commission estimates are based on unpublished DVA data.

These findings of the Productivity Commission [26] suggest that injury reports were not available to these claimants in either their Defence WHS or Defence medical records, making it likely the injuries were never recorded. Supporting this conclusion for the WHS incident-recording system, we recently reviewed WHS incident reports from the Australian Army and compared the rates of injuries recorded on that WHS reporting system with rates of injury recorded in elements of the Australian Army when personnel reported for health care [27]. On that basis, we estimated that 80–90% (depending on context) of injuries that have occurred to Australian Army personnel and have been reported to Defence healthcare providers have not been reported on the Defence WHS incident reporting systems.

The Productivity Commission [26] documented a range of reasons that ADF personnel do not report injuries, citing reasons found by McKinnon et al. [25] and the Australian National Audit Office. These reasons included incident notification not being mandatory for ADF personnel in warlike deployments ([26], p. 179) as well as the following direct quotations from the Productivity Commission,([26], pp. 195–196):

> *Reticence of serving members to record their injury or illness*
> Three (interrelated) factors are particularly significant in the reticence of serving ADF members to report an injury and illness:
>
> - a pervading culture in the military of perseverance and toughness
> - concern that reporting an injury or illness could have an adverse effect on a member's prospects of deployment or, in extreme cases, result in their discharge from the ADF
> - stigma associated with admitting to suffering from a mental illness.
>
> The first of these is a well-known barrier to comprehensive injury and illness reporting. A culture of machoism, which results in sentiments like 'don't be a woose' and 'tough it out', is inimical to the early and comprehensive self-reporting of injury and illness. In their study of military injury surveillance systems in the ADF, McKinnon, Ozanne-Smith and Pope [25] observed:
>
> > One important global factor [affecting data collection in injury surveillance systems] identified was military culture. Military

> environments such as the ADF, which inculcate an expectation of enduring physical hardship, can be perceived as running counter to the aim of injury prevention. The reporting of injuries that is critical to gaining comprehensive and representative data in military [injury surveillance systems] can be hampered in military contexts by a pervading ethos of perseverance and toughness … ([25], p. 475).

> The second factor — the concern that reporting an injury or illness could have adverse career effects — is particularly strong in the military context. The ANAO (when examining the usefulness of the Sentinel system in assisting Defence to manage WHS risks in the ADF) identified deficiencies in Defence's injury/illness reporting system for just this reason:
>
>> … the ANAO was informed during numerous audit interviews with a range of ADF staff of reluctance within some parts of the ADF to report incidents due to perceived potential negative career impacts. (ANAO [28], p. 9)
>
> This reluctance to report potentially career limiting injury or illness stems from the inherent requirement that ADF personnel must maintain a sufficiently high standard of fitness to be 'fit for service'. The ADF Medical Employment Classification (MEC) System defines a serving member's employment prospects based on their medical fitness. It ranges from MEC1 (Fully employable and deployable), MEC2 (Employable and deployable with restrictions), MEC3 (Rehabilitation), MEC4 (Employment transition) to MEC5 (Separation).
>
> Each Service has the right to retire members on the grounds of invalidity, that is, a physical or mental incapacity to do their duties ([29], p. 45). Thus, a fundamental problem is that where an injury or illness is likely to trigger an assessment of a reduced fitness for duty (and deployment) — or, in extreme cases, a discharge from service — if it is reported, there are very real incentives for serving members to not report it.

Supporting these findings from an international perspective and adding a further valuable perspective, Smith et al. [30] and Sauers et al. [31] reported on different aspects of the findings of a large survey of US Army personnel from a brigade, noting that many US army personnel indicated they have often not reported their injuries, and they identified a range of reasons for this. Findings of relevance are as follows:

- Respondents indicated half (49%) of all injuries they experienced in the preceding 12-month period were never reported [30].

- "More than half of participants agreed that aches and pains are a natural consequence of hard work (68.3%), that it is better to just work through pain (57.6%), that their unit believes in the 'suck it up' mentality when it comes to injuries (54.7%) and seeking medical attention is an inconvenience (50.7%)" [31].

- The main reasons respondents gave for not reporting injuries included fear of future impact on one's career (25%), avoidance of a duty-limiting 'profile' (23%), seeking treatment being inconvenient (18%), wanting to avoid negative perceptions (18%), and having had negative experiences with medical providers in the past (14%) [30].

- Respondents indicated that they generally self-managed the injuries they did not report, most often using over-the-counter pain medication (81%), ice packs (55%), heat packs (52%), hot tub (40%), pain avoidance (37%), splints or braces (25%), and a range of less common approaches, including (in descending order of frequency) yoga, narcotics, meditation, topical/muscle rubs, illicit drugs, additional sleep, massage, and alcohol [31]

These findings from the US Army are consistent with findings from the ADF in the areas in which they overlap, and they provide additional insights about the impact of military culture, values, and career concerns, as well as perceived capacity to self-manage injuries, on rates of reporting of injuries.

Returning to the point that injury rates calculated from ADF point-of-care reporting systems have been consistently much higher (our best estimate based on Australian Army data is 11.6 times higher) than those derived from ADF WHS incident-reporting systems [27], point-of-care reporting systems are much more sensitive than the WHS systems for detecting injuries that have occurred in ADF personnel. WHS incident-reporting systems underestimate the rates of injuries occurring in ADF personnel and being reported to Defence healthcare providers [27] and therefore should not be used as a gauge of the exposure of ADF personnel to lower-limb injury as a risk factor for development of OLL.

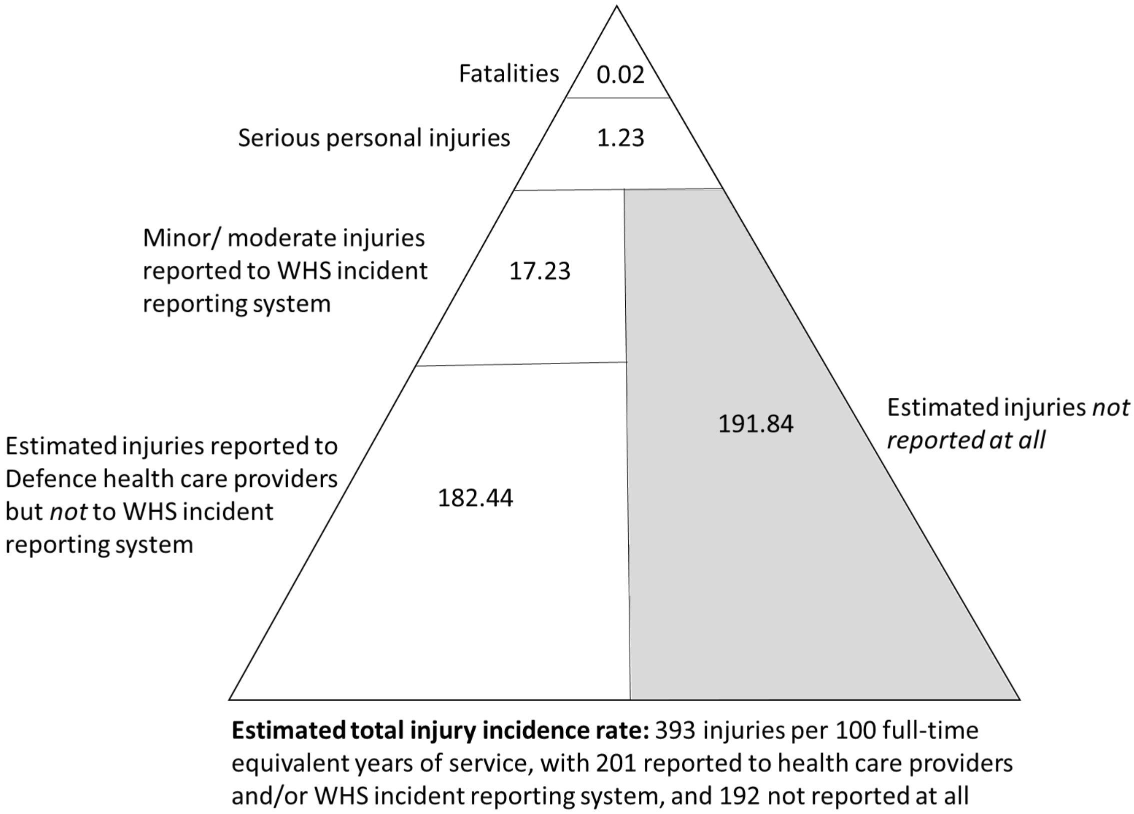
Only injury data derived from injury records systematically compiled at point-of-care should be used for this purpose, and this can be difficult to gather. Even where such data are available, the concept of an injury pyramid and related phenomena of underreporting and delayed reporting of injuries to healthcare providers should be considered because these factors will still lead to underestimates of true ADF injury rates if not properly considered. The findings of the US Army survey mentioned above regarding levels of underreporting of injuries to healthcare providers (49% of all injuries not reported [30]), indicate that military rates of injury calculated from point-of-care data should probably be doubled when estimating true underlying injury rates.

This finding would appear to hold true in the ADF context given the findings of the Productivity Commission [26] discussed above, that over 90% of claims to DVA are not supported by an incident record, suggesting such records are not available for most of these claims.

11.4.3 The ADF injury pyramid

The data presented above has been used by the research team to construct an estimate of the ADF injury pyramid shown in Figure 11.9. All injury incidence rates listed at each level of this pyramid represent our current best estimates of injuries per 100 full-time equivalent years of service and therefore provide a direct indication of the injury incidence rates that have been observed or estimated to exist at each pyramid level.

Figure 11.9: Estimated Australian Defence Force injury pyramid.



Note: Injury incidence rates listed at each level of the injury pyramid are injuries per 100 full-time equivalent years of service.

The ADF-wide incidence rates for fatalities and serious personal injuries, listed at the top of the ADF injury pyramid have been calculated from the data compiled by the Productivity Commission [26, p. 190, Table 5.3)], based on incident records drawn directly from the Defence WHS incident-reporting system for the eight financial-year periods 2010–2018. In both cases, the injury incidence rates were calculated as:

> number of recorded injuries / number of years across which they were reported / average size of the ADF population engaged in full-time service in those years x 100.

Thus, each listed incidence rate reflects injuries per 100 full-time equivalent years of service.

It is assumed that nearly all fatalities and serious personal injuries would have been recorded on the WHS system. This assumption reflects the mandatory reporting requirements for incidents at those levels of severity and the fact that incidents at these levels of severity would generally have demanded both command and medical attention, making their recording likely. However, it is possible that a small number of fatalities or serious injuries were not recorded in the WHS incident reporting system because incident notification is not mandatory for ADF personnel in warlike deployments (Productivity Commission [26], p. 179), so the figures for these serious incidents may be conservative.

The ADF-wide incidence rates for minor and moderate injuries reported to the WHS incident reporting system were calculated in the same manner from data compiled by the Productivity Commission [26, p. 190, Table 5.3], in this case based on incident records drawn from the Defence WHS incident reporting system for the four financial-year periods 2014–2018 (data on minor injuries were unavailable for earlier years).

In addition to the minor and moderate injuries reported to the WHS incident reporting system, there are many more minor and moderate injuries that are reported to Defence healthcare providers but not to the Defence WHS incident reporting system. The rate of such injuries was estimated for Figure 11.9 by using research data compiled by Pope and Orr [27] for the Australian Army. In their paper, Pope and Orr noted that although 17 injuries per 100 full-time equivalent years of service had been recorded on the Defence WHS incident-reporting system, 316 injuries and 78 injuries per 100 full-time equivalent years of service had been recorded for an Army training unit and Army brigade, respectively, in point-of-care injury reporting systems, giving an average injury incidence rate across training unit and brigade (reflective of the Army as a whole) of 197 injuries per 100 full-time equivalent years of service. This is 11.59 times the incidence rate of minor and moderate injuries recorded on the Defence WHS incident reporting system. The incidence rate listed in Figure 11.9 for minor and moderate injuries that are reported to Defence healthcare providers but not to the Defence WHS incident-reporting system was therefore estimated as:

> 11.59 x [ADF-wide incidence rate for minor and moderate injuries reported to the WHS incident reporting system (i.e., 17.23 injuries per 100 full-time equivalent years of service; Figure 11.9)] – [17.23 injuries per 100 full-time equivalent years of service (reported to the WHS incident reporting system)].

Finally, the incidence rate listed in Figure 11.9 for injuries not reported at all was estimated based on the finding by Smith et al. [30] in a survey conducted within a US Army brigade that 49% of all injuries experienced by personnel in a 12-month period were never reported. Supporting the relevance of this for the ADF are the findings of the Productivity Commission ([26], p. 310), discussed above, that more than 90% of claims for injuries and other conditions submitted to DVA are not accompanied by a WHS or medical record of the incident having occurred. This suggests that the US Army estimate of underreporting may be conservative if applied to the ADF. We have nevertheless taken a conservative approach in estimating the incidence rate listed in Figure 11.9 for injuries not reported at all, as follows:

> Incidence rate = {[incidence of minor (and moderate) personal injuries reported to the Defence WHS incident reporting system] + [incidence of minor and moderate injuries that are reported to Defence healthcare providers but not to the Defence WHS incident reporting system]} x {the ratio of unreported to reported injuries observed in a U.S. Army brigade by Smith et al. [30], i.e. 49%/51%}.

We excluded serious personal injuries and fatalities from this calculation based on the assumption, discussed above, that nearly all injuries of these levels of severity would have been reported due to their severity and the mandatory reporting rules that apply in most circumstances for such injuries. Nevertheless, it is worth noting that inclusion of the relatively few injuries of these types would have made little difference to the resulting estimate of underreporting listed in Figure 11.9.

It is worth noting that the estimated injury incidence rate (201 injuries per 100 full-time equivalent years of service) listed at the bottom of Figure 11.9 for injuries in the ADF that are reported to Defence healthcare providers and/or Defence WHS incident reporting systems is very similar to the rates of injuries reported as presenting for healthcare across the US military ([24], Figure 2) and to rates of injury that have been reported to Defence healthcare providers in various ADF training establishments, discussed in the sections that follow. In the US military, the rates of reported injuries have been found to vary by service ([24], Figure 2). This variation between services will be discussed in Chapter 12, with reference to the ADF.

In summary, when estimating injury rates in the ADF the context-specific injury pyramid requires consideration and account should be taken of the threshold levels of injury severity beyond which injuries are reported, contextual and other reasons to believe under-reporting or delayed reporting may have influenced recorded injury rates, and the magnitudes of known or estimated (based on previous experience and knowledge of the context and population) delays and non-reporting in the reporting of injuries. These concepts have been considered in the estimated ADF injury pyramid depicted in Figure 11.9, and will be considered in the remainder of this chapter and again in Chapter 12.

11.4.4 Army: Historical rates of lower-limb injuries during initial training

Two published research reports quantified the incidence rates for lower-limb injuries occurring in Army recruits undertaking recruit training in 1994 and 2007, both of which are cited in Section 11.2.2 [32,33]. The incidence rates documented in each report were based on injury data obtained through a stringent point-of-care injury recording process that was similar for both cohorts, although some delayed reporting and underreporting of injuries was still likely for reasons discussed in the preceding section. Although 13 years apart in time, each of the recruit training programs observed in these studies was 80 days (12 weeks) in duration. A comparison of the PT sessions involved in each program has been provided in Section 11.2.2, but it should be noted that PT comprised only a small proportion (40–50 hours) of the physical activity undertaken within the total recruit training course (80 days).

In 1994, 333 lower-limb injuries were reported in 1,538 Army recruits undertaking the recruit training program, equating to approximately 100 lower-limb injuries for every 100 years of full-time equivalent training. Of these injuries, 41% affected lower-limb joints [33]. In 2007, 357 lower-limb injuries were reported in 779 Army recruits undertaking recruit training, equating to approximately 210 lower-limb injuries for every 100 years of full-time-equivalent training, and a similar 44% of these injuries affected lower-limb joints [32].

A major difference between these studies, explaining at least some of the difference in observed injury rates based on the concept of the injury pyramid discussed in the preceding section, was the definition of injury in each study. In the first study [33], injuries were included if they were deemed severe enough to affect the recruit for 3 or more days and thus required referral to a medical officer for assessment and management. In the second study, injuries were included if they were severe enough to limit the recruit's participation in physical activity for at least 1 day. This definitional difference and the resulting difference in observed injury rates is a clear example of the impact of the ADF injury pyramid (Figure 11.9) in determining observed injury rates. It is also possible that some of the observed increase in reported lower-limb injury rates for Army recruits between these timepoints can be attributed to the fact that the injury surveillance system was new in 1994 but routine by 2007, with the latter perhaps leading to more comprehensive reporting of injuries.

Most importantly, these figures support the notion that lower-limb injuries as a risk factor for development of OLL [34, 35] have consistently occurred at high rates in Army recruits and have persisted as a feature of Army recruit training. Considering the injury rates observed in each study under its particular injury definition, in light of the discussion of the ADF injury pyramid and phenomena of underreporting and delayed reporting of injuries, it is likely that the true rate of lower-limb injuries in Army recruit training has historically been consistently well above the 210 lower-limb injuries for every 100 years of full-time-equivalent training recorded in the study of Goodall et al. [32] and reported to healthcare providers. We therefore estimate the injury rates to be nearly twice as high, at around 412 lower-limb injuries for every 100 years of full-time equivalent training.

11.4.5 Navy: Historical rates of lower-limb injuries during initial training

In the Navy Recruit School context, reports of injury rates have been more difficult to source. However, a study conducted at HMAS Cerberus and published in 2015 [36] observed, as a secondary outcome measure, that 148 of 306 recruit participants (48.4%) suffered a lower-limb injury over the 11-week training course. This equates to a lower-limb injury incidence rate of at least 230 lower-limb injuries per 100 full-time equivalent years of service (some recruits may have experienced more than one injury). In this study, "injury was defined by the presence of pain that scored at least 30 mm on a 100 mm Visual Analogue Scale (VAS) when at its worst".

This Navy lower-limb injury incidence rate is similar to, though a little higher than, the lower-limb injury incidence rate reported by Goodall et al. [32] in a cohort of Army recruits in 2007 (see above). Although the definitions of injury used in these studies differed in their focus (pain level and activity limitation, respectively), each represented a significant impact on the injured recruits. This finding suggests that injury incidence rates in Navy recruits have been similar to those in Army recruits and also relatively high. Additional historical injury data do not appear to be available for the Navy recruit population, though, given that the current injury rates for Navy recruit training mirror those recorded in published research for Army recruit training, it is likely historical injury rates in this Navy context have mirrored historical rates in Army recruits and have also been relatively high and persistent over time.

As with the Army recruit studies discussed above, the ADF injury pyramid and phenomena of underreporting and delayed reporting should be considered in relation to the estimate of the lower-limb injury rate in Navy recruits reported by Bonanno et al. [36]. In this light, it is likely that the true rate of lower-limb injuries in Navy recruit training has historically been consistently well above the 230 lower-limb injuries for every 100 years of full-time equivalent training estimated from the findings of Bonanno et al. [36] and potentially at least twice as high at an estimated 460 lower-limb injuries for every 100 years of full-time equivalent training. This is particularly so given the injury rate estimated here from the report of Bonanno et al. [36] assumes each trainee suffered only one injury and therefore is a conservative estimate. If some recruits suffered more than one injury, as is most likely, the incidence rates of lower-limb injuries would be higher.

11.4.6 Air Force: Historical rates of lower-limb injuries during initial training

For Air Force recruit training, injury rate data drawn from point-of-care injury recording systems have been reported for the 6-year period 1985–1990 [37] and for the period from September 2000 to March 2001 [38]. The definitions of injury differed between these two studies and also differed in these studies from the definitions of injury employed in the Army and Navy recruit training studies reported earlier in this section.

The main difference was that only more serious injuries—those resulting in significant time loss from training—were included in the injury rates reported in these two Air Force studies, and the injuries reported in the study by Ross and Woodward [37] had to meet a higher severity threshold than those reported in the study by Esterman and Pilotto [38] to be considered in the study.

These differences in injury definitions have contributed to differences in the reported incidence rates from the two Air Force studies discussed below and to differences between incidence rates reported in these two Air Force studies and those reported in the Army and Navy studies discussed above. All of these differences can be explained by the ADF injury pyramid.

In the first Air Force recruit training study, conducted by Ross and Woodward [37], 238 of 8,644 (2.7%) recruits undertaking the 9-week recruit training program in the period 1985 to 1990 were reported to have suffered a musculoskeletal injury that was sufficiently severe to require them to be backcoursed (i.e., to be delayed in progressing in their training to the extent that they could not complete training with their original cohort and instead had to join a later course) or medically discharged from the military. These injuries usually required the loss of at least 5 days of training [37]. The proportion of recruits who suffered injuries at this level of severity steadily increased from 1985 to 1990, when it reached more than 13.5% of recruits. An estimated 83% of these were lower-limb injuries, as is typical of military basic training (see, for example, [32]), approximately 20% were overuse injuries (rather than acute injuries), and one third (34%) were injuries to the knee or ankle joints. This equates to an estimated lower-limb injury rate across the period 1985–1990 of approximately 13 lower-limb injuries serious enough to lead to backcoursing or medical discharge per 100 full-time equivalent years of service.

However, consistent with the ADF injury pyramid, injuries that are severe enough to require backcoursing or medical discharge and loss of at least 5 days of training are the tip of the iceberg in ADF recruit training programs, and many more injuries occur that do not require backcoursing, medical discharge, or so many days missed from training. Supporting this assertion, Ross and Woodward [37] noted that, although only 2.9% of female recruits in their study were recorded to have sustained an overuse injury that met their injury definition, in terms of level of severity, more than 50% of all female recruits who undertook recruit training at 1 Recruit Training Unit in 1992 received physiotherapy care for an overuse injury.

This means that for every overuse injury recorded by Ross and Woodward, using their high-severity definition of injury, another 16 overuse injuries of lesser severity had occurred that were of sufficient severity to warrant physiotherapy care. Extrapolating this basis for estimation of total injury rates to acute injuries and also to the total male and female recruit population, it is most likely that the overall rates of lower-limb injuries in Air Force recruit training in the period 1985–1990 that resulted in recruits seeking health care were similar to the rates observed in Army and Navy recruits, discussed above, at approximately 221 reported lower-limb injuries for every 100 years of full-time equivalent Air Force recruit training.

In the period September 2000 to March 2001, Esterman and Pilotto [38] noted that 20% of Air Force recruits undertaking the 10-week Air Force recruit training course suffered an injury that prevented them from training for more than 3 days. If we again assume that 83% of these injuries affected the lower limb, this would equate to an estimated lower-limb injury rate of approximately 86 injuries serious enough to prevent the recruits from training for more than 3 days for every 100 years of full-time equivalent training.

Once again, based on evidence from two different studies with different definitions of injury, injuries at this level of severity are accompanied by many more injuries that do not lead to as many days of training having to be missed. It is therefore likely that the overall rates of reported lower-limb injuries in Air Force recruit training in the years 2000 and 2001 were at least as high as the rates estimated above for Air Force recruit training in the period 1985–1990, for Navy recruit training in 2015, and for Army recruit training in 1994 and 2007, each of which has been reported earlier in this section and ranged from at least 210 to 230 reported lower-limb injuries for every 100 years of full-time equivalent training.

Furthermore, in light of the ADF injury pyramid and associated phenomena of underreporting and delayed reporting of injuries, it is most likely that the true rate of lower-limb injuries in Air Force recruit training has historically been consistently well above the estimated 210 to 230 lower-limb injuries for every 100 years of full-time equivalent training estimated here as for Army and Navy, and again potentially at least twice as high at around 420 to 460 lower-limb injuries for every 100 years of full-time equivalent training.

11.4.7 Australian Defence Force Academy: Historical rates of lower-limb injuries during initial training

In officer cadets, including those from Army, Navy, and Air Force, undertaking training at the Australian Defence Force Academy (ADFA) in 2010 and 2011, an injury incidence rate equivalent to approximately 135 reported injuries (inclusive of upper- and lower-limb and trunk injuries) for every 100 full-time equivalent years of service was observed [39]). If we again assume that 83% of these reported injuries affected the lower limb, this would equate to an estimated lower-limb injury incidence rate of approximately 112 reported lower-limb injuries for every 100 full-time equivalent years of service in these officer cadets. However, considering the injury rate observed in this study of officer cadets, under its particular injury definition, in light of the ADF injury pyramid and associated phenomena of underreporting and delayed reporting of injuries it is most likely that the true rate of lower-limb injuries in officer cadets training at ADFA has historically been consistently well above the 112 reported lower-limb injuries for every 100 years of full-time equivalent training estimated here and potentially approaches recruit injury rates in recruits of each service.

Of importance in making this assessment is consideration of the estimated overall ADF injury incidence rate (Figure 11.9) and the fact that reporting of injuries may be further reduced and delayed in this officer cadet population relative to recruit populations due to the greater capacity of officer cadets for self-management. This greater capacity of officer cadets for self-management exists for three reasons. First, much of their work week is typically spent in a classroom setting, so they have opportunity for recovery and self-management of injuries in this context. Second, they receive specific education and training from the PTI staff in injury self-management, and trained officer cadets provide support to sports teams as sports first aid trainers during ADFA sports and thus have experience in managing injuries, which they can then apply to any injuries they themselves experience. Third, they can access initial injury management for sports injuries they experience from fellow officer cadets who are providing sports first aid trainer services at a sporting event, so that in many instances they will not need to present for further health care unless the injury is severe. This assumption of greater capacity of officer cadets for injury self-management is supported by experience of our team, who have observed that typical reporting delays for injuries are greater in officer cadets than in recruits undertaking basic training—often three times as long.

11.4.8 Summation: Historical rates of lower-limb injuries during initial training in the ADF

Overall, these historical accounts of recorded injury rates observed in recruit training of Army, Navy, and Air Force and in officer cadets from all three services undertaking training at ADFA suggest that lower-limb injury rates in recruit training and officer cadet training have been similar across the three services and consistently high for several decades—most likely between 420 and 460 lower-limb injuries for every 100 years of full-time equivalent training once the ADF injury pyramid and associated phenomena of underreporting and delayed reporting of injuries are considered. Furthermore, it appears that between 34% and 44% of these injuries have been acute injuries that have affected joints of the lower limbs. Notably, exposure to lower-limb injuries is a key risk factor for development of OLL [34] and recognised by the RMA as such in its SoPs for OLL, and therefore these findings are highly relevant. They are further discussed in this light in Chapter 12.

11.5 Summation of Historical Review

It is evident from the information presented in this chapter that the types of physical demands associated with initial training and service in the ADF, including demands of PT and sport that have historically accounted for 70% of injury-related working days lost by ADF personnel [20], have remained relatively unchanged over the last 60 years. What has changed is the volume of PT, which has substantially decreased. This means that the occupational exposures of ADF personnel to factors that increase the risk of OLL will now be similar in type but reduced in volume when compared with prior decades.

11.6 References

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12. LOWER-LIMB INJURIES AS A RISK FACTOR FOR LOWER-LIMB OSTEOARTHRITIS IN THE AUSTRALIAN DEFENCE FORCE

12.1 Overview

As noted in Section 11.4, the Repatriation Medical Authority (RMA), in its Statements-of-Principles (SoPs) for osteoarthritis of the lower limb (OLL)[1], recognises the well-known fact that injuries to joints of the lower limb are a risk factor for development of OLL ([1] Section 4, Figure 7(f)). Specifically, the current versions of the RMA's SoPs for OLL recognise the following types of joint injuries or conditions as risk factors for development of OLL:

- inflammatory joint disease
- infection of the affected joint
- intra-articular fracture
- haemarthrosis
- trauma to the affected joint – defined as:

  > a discrete event involving the application of significant physical force to or through the affected joint, that causes damage to the joint and the development, within 24 hours of the event occurring, of symptoms and signs of pain and tenderness, and either altered mobility or range of movement of the joint. These symptoms and signs must last for a period of at least 7 days following their onset, save for where medical intervention for the trauma to that joint has occurred and that medical intervention involves one of the following: (a) immobilisation of the joint or limb by splinting or similar external agent, (b) injection of corticosteroids or local anaesthetics into that joint, or (c) surgery to that joint.

- acute articular cartilage tear
- acute meniscal tear
- frostbite involving the affected joint
- disordered joint mechanics of the affected joint (for at least 3 years before the clinical onset of osteoarthritis in that joint)

[1] These SoPs may be found at the following site: www.rma.gov.au/sops/condition/osteoarthritis.

- necrosis of the subchondral bone near the affected joint, including that from dysbaric osteonecrosis
- for osteoarthritis of a joint of the lower limb only: (a) an amputation involving either leg, or (b) an asymmetric gait (for at least 3 years before the clinical onset of osteoarthritis in the joint)
- for osteoarthritis of a knee joint only, internal derangement of the affected joint
- for osteoarthritis of the patello-femoral joint only, chondromalacia patella
- disorders associated with loss of pain sensation or proprioception involving the affected joint
- joint instability or dislocation of the affected joint (at least 1 year before the clinical onset of osteoarthritis in the joint)
- for osteoarthritis of a hip joint only, femoro-acetabular impingement syndrome of the affected joint.

There is some evidence that rates of injuries may be higher in ADF trainees undergoing initial training than in personnel who have completed initial training, and this difference is reflected in the higher injury rates cited in Section 11.4 for recruits and officer cadets when compared with the overall ADF injury incidence rate derived from the estimated ADF injury pyramid (Figure 11.9). However, it is clear from the ADF injury pyramid and supporting evidence (for example, [2]) that rates remain relatively high in serving personnel after initial training is complete. As noted in Section 11.4, incidence rates of lower-limb injuries in Army, Navy, and Air Force recruits, and in ADFA officer cadets undergoing initial training, have been observed in published studies to be similar and consistently high, and our best estimates are that they range between 420 and 460 lower-limb injuries for every 100 full-time equivalent years of service, with 34–44% of these (i.e., around 172 injuries for every 100 full-time equivalent years of service) being acute injuries affecting joints of the lower limb. Due to normal tissue healing times following injury, it is likely that the majority of these lower-limb joint injuries will meet the trauma definition provided by the RMA, affecting mobility or joint range of motion and causing symptoms for at least 7 days following the initial injury. This has been the experience of members of the research team who have provided health care to ADF trainees over extended periods of time.

In an operational Australian Army brigade in the years 2004 and 2005, reported injury incidence rates averaging 78 injuries for every 100 full-time equivalent years of service (inclusive of upper and lower-limb and trunk injuries) in trained Army personnel (Rudzki & Pope [3]; cited in Pope and Orr [2]). In a separate study conducted in the same location and population, but in the years 1987 to 1992, an incidence rate of 19 injuries requiring physiotherapy care (meaning the injuries were moderate or serious) for every 100 full-time equivalent years of service was recorded (inclusive of upper- and lower-limb and trunk injuries), and 57% of these injuries affected the knee or ankle joints [4]. Considering these figures in light of the estimated ADF injury pyramid and associated phenomena of underreporting and delayed reporting of injuries discussed in Section 11.4, it is most likely that the true underlying injury incidence rates in these Army operational units were much more like the overall injury incidence rate estimated for the ADF as a whole (Figure 11.9) at 393 injuries for every 100 full-time equivalent years of service (inclusive of upper- and lower-limb and trunk injuries), with at least 57% of these injuries affecting joints of the lower limbs [4]. This estimated injury rate for Army is consistent with the rate reported for the US Army by Jones et al. [5], which was 220 injuries for every 100 full-time equivalent years of service (inclusive of upper- and lower-limb and trunk injuries). Noting that half of all injuries in a US Army brigade have been found to go unreported by injured personnel [6], this gives a likely true underlying injury rate for the US Army of around 440 injuries for every 100 full-time equivalent years of service.

Beyond the factors discussed in Section 11.4, a further factor that can contribute to trained military personnel not reporting or delaying reporting of their injuries within Defence is their typically greater opportunity than trainees to self-manage their injuries, including by negotiating a modified workload (if needed) with their supervisor to facilitate recovery, or, in some instances, seeking medical care from healthcare providers external to Defence. Trainees often do not have these opportunities (though see the discussion regarding officer cadets at ADFA in Section 11.4) and in many instances must report an injury in order to gain assistance for recovery and time out of training to facilitate recovery. Trained personnel often have more control over their workload, schedule, and lives in general.

Based on US military data for injury rates by service in the period 2000–2006 [6], it is likely that injury rates for trained Air Force personnel (after initial training has been completed) are on average approximately 65% of those for Army personnel, and for Navy personnel approximately 45% of those for Army. This conservatively equates to around 255 and 177 injuries (inclusive of upper- and lower-limb and trunk injuries) for every 100 full-time equivalent years of service in the Australian Air Force and Navy if we conservatively assume Australian Army injury incidence rates are equivalent to the overall ADF injury incidence rate listed in the estimated ADF injury pyramid at 393 injuries per 100 full-time equivalent years of service. In addition, it is likely that around two-thirds of these injuries are injuries to joints of the lower limb because in the Army 57% have been observed to be injuries to the knee or ankle alone. On this basis, rates of lower-limb joint injuries in Army, Air Force, and Navy are estimated to be around 224, 145, and 100 lower-limb joint injuries, respectively, for every 100 full-time equivalent years of service.

Taken together, these findings suggest that injury rates and rates of lower-limb joint trauma remain relatively high across the service career of ADF personnel but are highest during the initial training period apart from the Army.

With regard to Other Ranks trainees undertaking initial employment training courses, although injury data for those courses are scant for the three services, it could be expected that the rates of lower-limb joint trauma in those groups would lie somewhere between the estimates derived above for recruits from each service and those derived for operational personnel for each service. Therefore, for the Army, between 172 and 224 lower-limb joint injuries would meet the RMA criteria for joint trauma for every 100 years of full-time equivalent service, for the Air Force, between 172 and 145 lower-limb joint injuries would meet the RMA criteria for joint trauma for every 100 years of full-time equivalent service, and for the Navy, between 172 and 100 lower-limb joint injuries would meet the RMA criteria for joint trauma for every 100 years of full-time equivalent service. More precise estimates for each service would need to be based on the occupation for which any particular group of trainees was being trained through initial employment training.

Of note, although sports participation is likely to be one source of injuries for trained personnel in operational units and for officer cadets at ADFA or in single-service officer training, this was not the case for the injuries observed in Army, Navy, or Air Force recruit training because none of these recruit training courses incorporates any sports. Therefore, lower-limb injury rates can be relatively high in military trainees undergoing initial training, even when sport is not played.

Importantly, given lower-limb injury is a known risk factor for the development of osteoarthritis, the relatively high estimated lower-limb joint injury rates in ADF recruits, officer cadets, and trained personnel indicate that lower-limb joint injuries represent an important risk factor for development of OLL in all ADF personnel. Moreover, it is clear that exposure to this risk factor begins very early in a person's military career. On this basis, it is likely that within 1–2 years from date of enlistment, nearly all ADF personnel will have experienced a significant injury to a lower-limb joint that will increase their risk of developing OLL and ensure they meet one of the injury thresholds specified by the RMA in its SoPs for OLL. This is so even when the fact that some personnel will account for more than one injury is considered. In all three services, many personnel (we would estimate at least 30% based on the figures discussed here) will have met one of these thresholds within the period of recruit training, initial officer training, or first 3 months of training at ADFA, and many more (we would estimate at least another 25–30%, depending on service) will have met one of the injury thresholds within 6 months of enlistment as they continue with subsequent initial training and increase their participation in ADF sport.

12.2 Relationship between OLL Development and the Early Onset and Patterns of Lower-Limb Joint Injuries in Military Personnel

Consistent with this assessment of early onset and rates of joint injuries that may increase the risk of ADF personnel developing OLL, the review by Knapik et al. [1; Appendix 2] indicates that in the US military, osteoarthritis is not limited to older personnel or those with many years of service. According to the authors of that review, 37 new cases of osteoarthritis are diagnosed for every 100,000 full-time equivalent years of service in military personnel aged less than 20 years, and this incidence rate for osteoarthritis increases exponentially to around 100 new cases in those aged 20–24 years, 400 cases in those aged 25–29 years, 600 cases in those aged 30–34 years, 1,500 cases in those aged 35–39 years, and 3,073 cases in those aged more than 40 years. These figures relate only to current service personnel and exclude veterans who may have developed osteoarthritis substantially arising from exposures during, and subsequent to leaving, service.

In addition, in the US military, incidence rates of OA between 2010 and 2015 were highest in the Army (985 per 100,000 full-time equivalent years of service), slightly less in the Air Force (704 per 100,000 full-time equivalent years of service), and less again in the Navy (456 per 100,000 full-time equivalent years of service) [7]. Thus, the differences between Army, Air Force, and Navy in relative incidence rates of osteoarthritis mirror the relative incidence rates of lower-limb joint injuries between Army, Air Force, and Navy, discussed above.

12.3 Does an Injury Have to Have Affected the Joint in Which OLL Develops to Have Been a Contributing Factor?

A major question arising from the exposure findings detailed above is whether injuries affecting one lower-limb joint or region can increase the risk of development of osteoarthritis in another joint in the same or contralateral leg. Recent prospective longitudinal research [8] indicates they can, specifically where the initial symptoms are sustained and affect the foot or ankle and the OLL is subsequently developed in either knee. This supports the aetiological relevance of trauma or chronic conditions affecting the ankle or foot (joints or other structures) for later development of osteoarthritis in the knee joint of the same or other leg. Specifically, Paterson et al. [8] noted in their report:

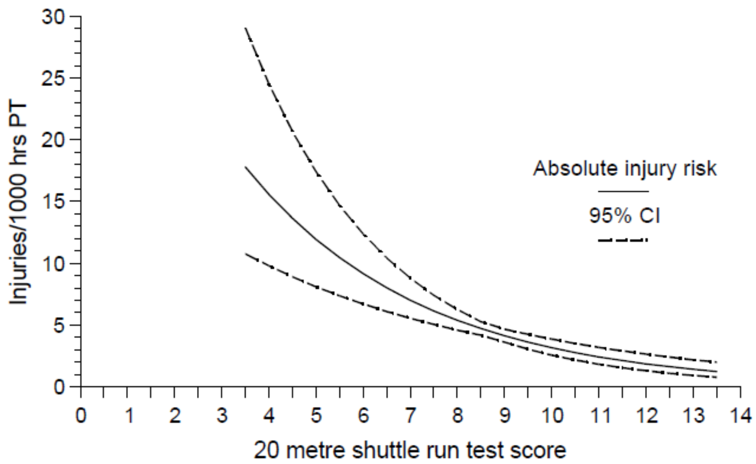
> Foot/ankle symptoms in either or both feet significantly increased the odds of developing knee symptoms (adjusted odds ratio (OR) 1.55, 95% confidence interval (CI) 1.10 to 2.19), and developing symptomatic radiographic knee OA (adjusted OR 3.28, 95% CI 1.69 to 6.37). Based on laterality, contralateral foot/ankle symptoms were associated with developing both knee symptoms (adjusted OR 1.68, 95% CI 1.05 to 2.68) and symptomatic radiographic knee OA (adjusted OR 3.08, 95% CI 1.06 to 8.98), whilst bilateral foot/ankle symptoms were associated with developing symptomatic radiographic knee OA (adjusted OR 4.02, 95% CI 1.76 to 9.17).

Thus, prior trauma to one ankle or foot joint or symptoms in other structures in the foot or ankle should be considered potential contributing factors to osteoarthritis observed in the knee of either leg. This finding clearly indicates that *any* chronic musculoskeletal condition causing ongoing symptoms in a foot or ankle may substantially increase the risk of OLL developing in a knee joint in either leg. In this instance, the injury and symptoms do not have to have been in the joint affected by OLL to have been a contributing factor to the OLL. Further research is warranted to explore whether this finding applies where initial symptoms are in parts of the lower limb other than the foot and ankle, but in the interim this finding strengthens the case for recognising prior lower-limb injury (and specifically foot or ankle injury) or symptoms as likely contributors to subsequent development of knee OLL.

12.4 The Relationship Between Aerobic Fitness Levels and Risk of ADF Personnel Experiencing Lower-limb Injuries

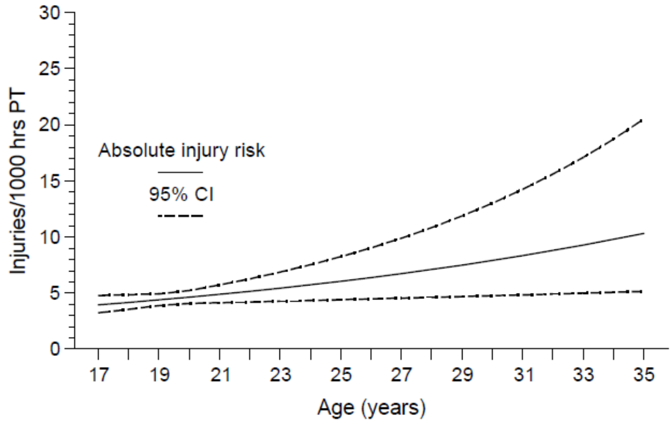
One aim of the current project was to examine factors that may increase the exposure of ADF personnel to increased risk of developing OLL. Noting the preceding discussion indicating that a history of prior injury to the lower limbs is a known risk factor for subsequent development of OLL, it should be recognised that the aerobic fitness levels and age of ADF personnel affect their exposure to lower-limb injuries during initial training. In a series of studies that underpinned the introduction of pre-enlistment fitness screening for ADF personnel, Pope and colleagues identified that, in a prospective cohort study involving 1,317 Australian Army recruits, lower levels of aerobic fitness were associated with increased lower-limb injury risks during initial training [9, 10]. The relationship between aerobic fitness levels (indicated by score on the 20 m multistage fitness test) and lower-limb injury risks is illustrated in Figure 12.1 (which is extracted directly from the thesis by Pope [9]). In the same study, age at time of enlistment was also identified as a further predictor of lower-limb injury risk (Figure 12.2).

Figure 12.1: Relationship between level of aerobic fitness and lower-limb injury risk in Army recruits undertaking basic training.



Reprinted, with permission, from Pope [9]

Figure 12.2: Relationship between age at time of enlistment and lower-limb injury risk in Army recruits undertaking basic training.



Reprinted, with permission, from Pope [9]

12.5 Improving the Monitoring of True Injury rates and Patterns in ADF Personnel

As noted in Section 11.4, lower-limb injury as a major risk factor for development of OLL has undoubtedly been historically underestimated in its prevalence and importance, with a strong contributor to this situation being that Australian Defence WHS incident reporting systems have underestimated the true rates of injury in the ADF [2]. Evidence of injuries experienced by individuals has therefore also often been lacking when claims are submitted to DVA.

These concerns have been previously highlighted by members of the current research team, who have proposed that one way to improve this situation would be for Defence to implement a hybrid incident reporting system for ADF personnel [2]. Such a system would use point-of-care reporting to reliably record injuries for which personnel seek Defence health care and feed these injury reports into the WHS incident database. It would also use WHS reporting systems to record exposures, near misses, and dangerous occurrences that would not generally be reported at a point of care because they had not resulted in an immediately evident injury [2].

Although this approach would not fully address the accompanying underreporting of injuries by ADF personnel to Defence healthcare providers (Figure 11.9), it is likely to increase injury reporting in the WHS incident reporting system 11-fold and further enhance reporting of injuries in health records of ADF personnel by more reliably recording injuries at point-of-care. This approach would ensure that all ADF personnel have enduring records of any injuries they have experienced during their period of service and reported to health care providers—listed in both the WHS incident reporting system and their health records. Such records would provide evidence of injuries, when needed, to support subsequent claims. They would also allow the overall burden of injuries in the ADF and the likelihoods with which ADF personnel will meet RMA-set thresholds for exposure to injuries as a risk factor for development of OLL to be estimated with greater accuracy, particularly within different ADF services, groups, and occupations. It is worth reiterating as we conclude this section that, to date, such records and evidence have been lacking in an estimated 80–90% or more of injury cases [2; 11, p. 310].

12.6 References

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13. SURVEYS

13.1 Response Rates

Of the trainees who were part of the trainee cohorts involved in the observations, 271 (34%) volunteered to complete the anonymous trainee questionnaires (Table 13.1). Trainee response rates were variable across programs and strongly affected by the intensity of the respective training schedule, group/peer influences, and the interest of trainees in the research. In the Air Force loadmaster program, there was only one trainee (typical of this course), so issues of anonymity meant this trainee did not participate in the survey.

Table 13.1: Survey response rates and distributions.

Course	Week of training	Trainees observed and invited to participate in survey	Trainee respondents N (response rate)	Staff respondents[a] N
NAVY Entry Officers' Course	2	130	8 (6%)	1
NAVY Recruit School	2	138	5 (4%)	0
NAVY Boatswain's Mate Course	3	25	25 (100%)	5
NAVY Marine Technician ITT	13	12	5 (42%)	0
NAVY Maritime Logistics-Personnel	3	16	14 (88%)	1
RAAF Initial Officer Course	4	35	35 (100%)	0
RAAF Recruit Training	2 & 4	55	55 (100%)	3
RAAF Loadmaster IET (C17)	4	1[b]	0 (0%)	0
RAAF Airfield Defence Guard IET	7	40	17 (43%)	0
RAAF Airfield Defence Guard IET	2	40	0 (0%)	0
ARMY Initial Officer Training	3	150	14 (9%)	0
ARMY Recruit Training	3	62	49 (79%)	6
ARMY Driver Specialist IET	2	15	15 (100%)	1
ARMY Infantry IET	11	45	11 (24%)	1
ADF Medic Training Continuum	78	30	18 (60%)	0
Overall		794	271 (34%)	18

[a] Numbers of staff respondents were dictated by the (generally very small) numbers involved in conducting and supervising the observed training sessions and their willingness and capacity to respond to the staff survey in what was typically a busy schedule.

[b] Only two trainees on the course, working on alternate days

Staff responses were limited to 18 personnel, with these individuals distributed variably across the programs and numerous programs having no staff respondents (Table 13.1). Availability and willingness of staff to participate was strongly influenced by the training context and most notably whether there were any staff who accompanied trainees throughout each whole day of observations or whether, instead, individual staff delivered individual training sessions and then handed training over to other staff to deliver other individual training sessions throughout the day. In these latter instances, there were few or no staff able to answer the survey, which pertained primarily to the percentages of the full days observed in which specific types of training and training loads were undertaken by trainees. The numbers of staff available and willing to complete the questionnaire was also affected by the intensity of the respective training schedule and the interest of staff in the research.

13.2 Trainee Participant Characteristics

From responses provided by the trainee respondents, 62% were male, 34% female, and 4% did not disclose their sex. The lengths of service of trainees varied widely, with a long tail in the distribution, consistent with the range of stages of training at which trainees completed the survey (Table 13.1) and also reflecting some trainee participants on altered programs (e.g., due to injury, illness, or failing a stage of training and having to repeat through back coursing). However, the median length of service of trainees was 4 weeks and, consistent with stages of training at which trainees were observed and numbers of trainees in each cohort (Table 13.1), 146 (54%) of trainee respondents had served for 4 weeks or less and 69% had served for less than 6 months at the time they completed the survey. Other trainee characteristics are summarised in Table 13.2.

Table 13.2: Trainee respondent characteristics.[a]

Age (years)	Height (cm)	Weight (kg)	BMI (kg/m^2)	Fitness: 2.4 km run time (min:sec) (N = 175)	Fitness: 20 m Multistage fitness test (shuttles) (N = 87)
23 (6) [90% ≤ 30 yrs]	175 (10)	74 (12)	24 (3)	11:17 (2:20)	70 (18) [70 shuttles = Level 8–9]

[a] Cell entries are means (*SD*s)

13.3 Trainee Experiences of Osteoarthritis and Lower-Limb Injuries

None of the trainee respondents reported having had a diagnosis of osteoarthritis. This is consistent with 90% of trainees being aged under 30 years and a relatively small cohort of respondents. This finding prohibited any analysis of associations between trainee characteristics and risk of osteoarthritis.

A total of 376 lower limb joint injuries (N = 269), fractures (N = 20), stress fractures (N = 14), and instances of shin pain (N = 73) were reported by the 271 trainee respondents as having been experienced at some time in their life, with nearly half (N = 156) of these injuries reported to have occurred since enlistment and thus during the period of initial training completed to date. This gives a post enlistment injury prevalence among the trainee respondents of 58 lower limb injuries of these types per 100 trainees.

Perhaps more informative given the varying durations of training completed by trainees and the fact that some who had been training for longer periods had been on atypical training pathways for various reasons, three lower limb fractures, 14 foot injuries, 20 ankle injuries, 8 knee injuries, and 2 hip/pelvis injuries were reported to have occurred within the first 4 weeks of training by the 146 trainees who had served for 4 weeks or less at the time they were surveyed. This equates to at least 419 injuries of these relevant types per 100 full-time equivalent years of service in this early phase (weeks 1–4) of training—supporting the estimates of injury rates discussed in Section 11.4 and Chapter 12 of this report for trainees, based on other data sources. Notably, these 146 trainees reported that 62% of the foot, ankle, knee, and hip/pelvis injuries they reported had stopped them from playing sport, exercising, or working for 7 days or more, indicating that these were substantial injuries.

13.4 Trainee and Staff Estimates Related to the Observed Training Sessions

Due to the low numbers of staff and, in some cases, trainees from specific initial training programs who responded to the survey, it was not possible to conduct a comprehensive analysis comparing trainee and staff estimates of proportions of observed training days spent undertaking specific activities with estimates derived from observations and desktop analyses. However, it is worth noting that staff respondents across the various initial training programs indicated that 90% of the observed training followed the planned programming for the respective sessions, with a minimum of 60% and maximum of 100% being estimated by staff for specific programmed days across courses. This finding suggests that ADF initial training programs are generally well regulated and standardised in their implementation, with staff being careful to closely follow planned activities where possible.

13.5 Strengths and Limitations

The surveys were valuable for highlighting and confirming the high rates of lower-limb joint injuries occurring in the early phase of initial training courses across the services and to confirm that ADF training appears to generally be conducted by staff in a regulated and standardised manner as per their respective training program.

However, it is doubtful whether specific participant groups were representative given the frequent low numbers of respondents and long tail in the distribution of durations of trainee service, suggesting that many trainees were on atypical training pathways, perhaps because of injuries, rehabilitation, or failure in training—all of which were factors noted during observations of some of the program-specific cohorts. This limitation was controlled when assessing injury rates by conducting an analysis based on only the 54%

of respondents who had served for 4 weeks or less and were therefore still within their first 4 weeks of initial training at the time they were surveyed and unlikely to be on modified or atypical training pathways. Future research in this area would benefit from larger, more representative, samples, although this is difficult to achieve in a busy military training context, as demonstrated in the current study.

14. OSTEOARTHRITIS CLAIMS ASSESSED BY THE DEPARTMENT OF VETERANS' AFFAIRS 1994–2018

14.1 Introduction

At the request of the Department of Veterans' Affairs (DVA) and with approval from the Defence and DVA Human Research Ethics Committee (Protocol number: 037-18), the research team undertook an analysis of claims for osteoarthritis (OA) arising from employment in the Navy, Army, and Air Force and assessed by DVA in the period 1994–2018. The aim of this analysis was to provide a profile of claims for OA arising from employment in the Navy, Army, and Air Force.

14.2 Approach

14.2.1 Research design

We employed an epidemiological approach in which rates of OA claims assessed by DVA in the period 1994–2018 and arising from each of the three services were estimated and compared with averaged 2007, 2011, and 2015 service population sizes. Additionally, the profiles of OA claims arising from the Australian Defence Forces (ADF) as a whole and from each service were determined and assessed under each relevant Act.

14.2.2 Participants and claims records

We analysed data provided by the DVA that related to claims for OA arising from ADF service that were assessed by DVA in the period 1994–2018. The claims records were made nonidentifiable by DVA prior to them being provided to the research team through removal of all information that might identify claimants, including individual identification numbers, names, and dates of birth.

Initially, 86,626 records of claims purportedly for OA for the specified time period and arising from employment in the Navy, Army or Air Force were received from DVA and imported into SPSS (version 25.0.0.1; IBM, 2017) for checking, cleaning, and analysis. The documented date on which the diagnosis was formally recognised for the purposes of submitting each claim was listed in the claims records as the effective date. All but seven of the effective dates in the data set fell in the period 1994–2018. Records for the seven claims on which the effective date preceded 1994 were removed from the dataset because these dates were wide-ranging outliers that would otherwise have distorted the calculations of lag times from effective dates to decision dates.

A further three claims records were removed from the data set because the age of the claimant was listed as 14 or 16 years, suggesting it was most likely their participation as a school-age cadet resulted in their claim rather than employment within the Navy, Army, or Air Force. The service in which a further 251 claimants served was not recorded at all, and the service in which another 552 claimants served was listed as 'Allied' (N = 5), 'Australian mariner' (N = 457), 'Commonwealth' (N = 1), 'Eligible civilian' (N=69), 'Philanthropic organisation' (N = 6) or 'Special mission' (N = 14), rather than Navy, Army, or Air Force. All of these 803 claims records were also removed from the data set, leaving only claims attributed to employment in the Navy, Army, or Air Force.

Narrative descriptions within each claim record of the health condition for which each of the remaining claims was submitted were then searched through a semi-automated process in SPSS to identify and document, as a separate data field, the joints of the body noted to be affected by OA. Subsequently, the data recorded in this new 'joints' field within each record were individually validated by manually comparing the data in the original narrative field to the data in the new joints field. During this process of manual validation, 48 records of claims for which OA was not the health condition for which the claim was submitted were identified and removed from the dataset so that only claims for OA remained.

At the conclusion of these cleaning processes, 85,765 records of claims submitted to the DVA for OA, which were assessed by DVA in the period 1994–2018 and arose from employment in the Navy, Army, or Air Force, remained.

14.2.3 Data analysis

A preliminary review of the cleaned dataset identified that 9,712 of the 85,765 eligible claims records did not have a decision date listed, though effective dates were listed for all records. A review of the remaining 76,053 claims records revealed that in nearly two thirds (61%) of records, the decision date fell in the same year as the effective date, and that in another one third of records (33%), the decision date fell in the year following the effective date, so was very close in time.

Given that the decision year was, in the majority of complete records, the same as the year in which the effective date fell and that in nearly all other records the decision year was only 1 year later, a new *Decision year* variable was added to the record set and the decision year was recorded as the same year as that in which the effective date fell, in all 9,712 records in which the decision date was originally missing. Where the decision date had been originally provided (N = 76,053), the decision year was recorded as the year in which that decision date fell. In addition, a new *Effective year* variable was added to the data set and populated with the year in which the effective date fell for each claim. In claims records where other data fields were missing data, these data were not replaced because there was no accurate way of estimating what the missing data would have been. The numbers of records considered in each of the subsequent analyses, after records with missing data for the respective analysis were excluded, are noted in the results.

The eligible claims records were analysed to generate profiles of claims overall by service, by gender, and by Act. These profiles indicated proportions of claims for OA that met selected criteria related to acceptance or rejection, sex and age of claimant, service from which they arose, the Act under which they were assessed, the joints affected by OA, length of service, decision year, and lag time from end date of service to effective date. Charts were used to depict key relationships where this aided understanding and comparisons, and 95% confidence intervals around population estimates of proportions derived from the sample were calculated where useful. Spearman's rank-order correlation coefficients were calculated to indicate the relationships between claims acceptance rates and date, age, and time variables because not all variables met the assumptions required for parametric analyses. Chi-square tests were conducted to compare frequencies between categorical variables such as gender. Means and standard deviations were calculated where appropriate for describing the data.

Estimates of rates of OA claims arising from each of the three services, relative to averaged recent ADF service population sizes, were calculated using averaged permanent ADF population data from the years 2007, 2011, and 2015 provided in the *Defence Census 2015 Public Report* [1] and *Defence Census 2007 Public Report* [2]. These averaged population data are provided in Table 14.1, and permanent forces populations were used in this analysis because it is likely that most claims for OA related to service would have arisen from full-time service over lengthy periods of time rather than from part-time service.

Table 14.1: Average ADF permanent forces annual population sizes (2007, 2011 and 2015).[a]

Gender	Navy	Army	Air Force	ADF (total)
Male	11,148	25,316	11,729	48,193 (85.7%)
Female	2,512	3,035	2,464	8,011 (14.3%)
Intersex / indeterminate / unspecified	(< 0.3%)	(< 0.3%)	(< 0.3%)	(< 0.3%)
Total	13,660	28,351	14,193	56,204

[a] Based on population data drawn from the Defence Census 2015 Public Report, Australian Government Department of Defence [1] and the Defence Census 2007 Public Report. [2]).

Of note, these census reports indicate that the gender breakdowns in each service of the permanent ADF were relatively stable across the period 1991 to 2015 (noting that gender breakdowns for the periods preceding 2007 were provided for purposes of comparison in Figure 1 of the Defence Census 2007 Public Report [2]), although there were small reductions in proportions of personnel who were male (6% in the Navy, 2% in the Army, and 4% in the Air Force) over this timeframe. In addition, a review of the *Defence Annual*

Reports 1997–2018[1] indicates the permanent forces strengths of each service have also been relatively stable across this time period. On this basis, the analyses reported in subsequent sections of this chapter assume that the population sizes and gender breakdowns in Navy, Army, and Air Force across the 25 year study period were relatively constant and are adequately represented by the averages of 2007, 2011, and 2015 census figures presented in Table 14.1. Nevertheless, it must be acknowledged that the often lengthy time lags between end of service and effective dates of claims (reported in the results section below) mean that the rates of OA claims estimated relative to the averaged recent service populations represent only crude estimates of actual rates of OA claims per unit of the ADF population. These estimates are nevertheless useful to highlight service differences in experiences of OA leading to claims assessed by DVA.

14.3 Main findings

14.3.1 Assessed claims for OA by decision year, service, Act, and gender

There were 85,765 claims for OA arising from service in the ADF and assessed by the DVA in the period 1994–2018, with 53,015 (62%) from Army personnel, 19,125 (22%) from Air Force personnel, and 13,625 (15%) from Navy personnel. This equates to approximately 75 claims for OA assessed each year of the 25-year study period for every 1,000 personnel estimated to be in the Army (based on Table 14.1 and subsequent notes in Section 14.2.3), 54 claims for OA assessed each year for every 1,000 personnel estimated to be in the Air Force, and 40 claims for OA assessed each year for every 1,000 personnel estimated to be in the Navy. On this basis, the ratios of numbers of OA claims assessed by the DVA per unit population of each service were Army 1.88 claims : Air Force 1.35 claims : Navy 1.00 claim.

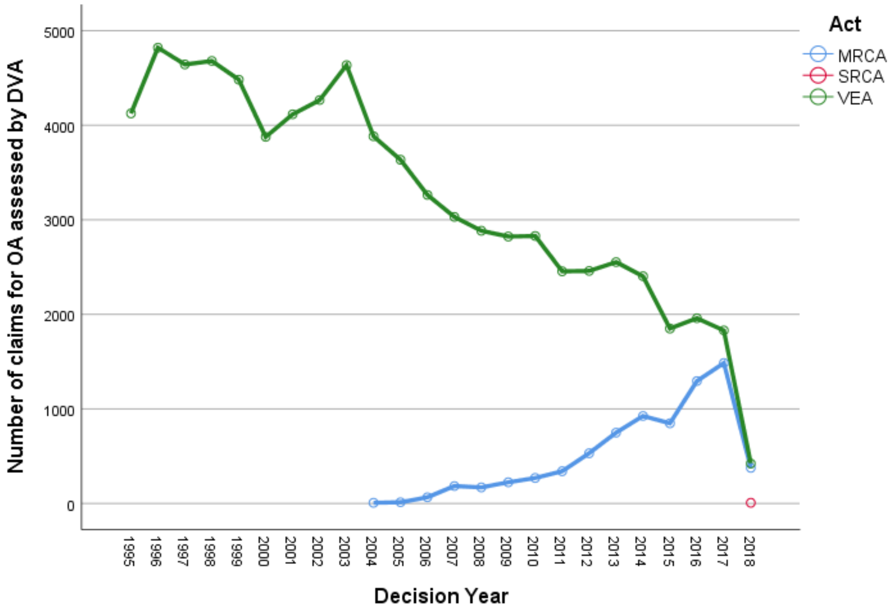
The annual numbers of claims for OA assessed by the DVA reduced steadily over the study period (see Figure 14.1) and were much greater under the Veterans' Entitlements Act 1986 (VEA; 78,273 claims) than under the Military Rehabilitation and Compensation Act 2004 (MRCA; 7,485 claims) and the Safety, Rehabilitation and Compensation Act 1988 (SRCA; only 7 claims, all in 2018).

The gender of claimants was recorded for only 54.7% of claims (46,912 claims) in the total data set provided by the DVA. Among the claims for OA assessed by DVA in the study period for which claimant gender could be ascertained, 95.1% were submitted by male claimants and 4.9% by female claimants. Comparison of these figures with the gender breakdown for the ADF population (Table 14.1) suggests that female claimants were underrepresented in claims for OA by a factor of nearly 3, whereas male claimants were slightly overrepresented. However, the fact that gender was not recorded for 45% of claimants makes it difficult to determine whether this underrepresentation of ADF women

[1] Information obtained from http://www.defence.gov.au/AnnualReports/

in the OA claims records reflects a lower risk of OA for women when compared with men or is simply an artefact of the deficit in gender data.

Figure 14.1: Numbers of claims for osteoarthritis assessed by the DVA, by Act and decision year.



With this in mind, analysis was made of claims data for the 2015 year alone to determine whether the gender breakdown of claims for OA in that year was reflective of the gender breakdown in the permanent ADF population indicated in Table 14.1 (because there is generally a lag between end of service and submission of a claim, we believe this is a reasonable comparison). In 2015, 96.1% of submitted claims records included gender details of the claimant. In that year, 93.6% of claims submitted to the DVA for OA were submitted by male claimants, while 6.4% were submitted by female claimants, giving a rate of submitted claims for OA of 50 per 1,000 male personnel estimated to have been in the ADF (Table 14.1) and 21 per 1,000 female personnel. This confirms an under-representation of female claimants in the OA claims data, suggesting that women submit claims for OA to the DVA approximately half to one third as often as do their male counterparts. Further research is needed to explore whether this difference is due to a lower risk of OA experienced by ADF women per unit time, to a lower propensity of women to submit claims, or to other differences that may exist, for example potentially shorter average lengths of service among women, which would in turn reduce exposure to risk factors for OA.

14.3.2 Accepted claims for OA, by decision year, Act, service, and gender

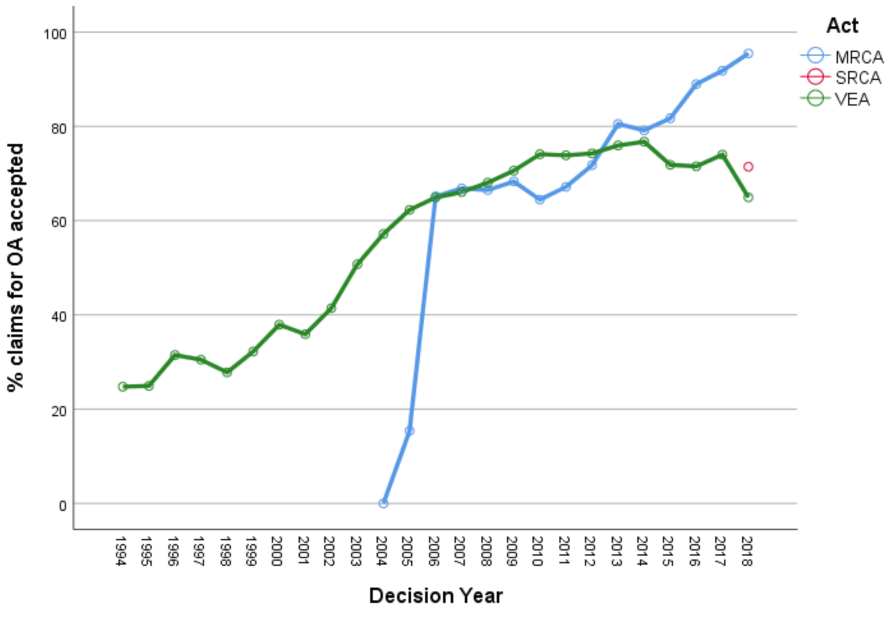
Of the 85,765 claims for OA arising from the ADF, 54% were accepted and 46% were rejected by the DVA under the relevant Act, with the proportion that was accepted increasing across the 25-year study timeframe and varying slightly across the Acts (Figure 14.2). This relationship between decision year and acceptance rate was statistically significant ($r_s = .37$, $p < .001$), and the overall percentages of OA claims accepted across the ADF were underpinned by the following figures from each of the three services:

- 55% of claims from Army personnel for OA were accepted by the DVA, amounting to an average of 41 accepted claims in each year of the 25-year study period for every 1,000 personnel estimated to be in Army;

- 51% of claims from Air Force personnel for OA were accepted by the DVA, amounting to an average of 27 accepted claims in each year of the 25-year study period for every 1,000 personnel estimated to be in Air Force; and

- 57% of claims from Navy personnel for OA were accepted by the DVA, amounting to an average of 23 accepted claims in each year of the 25-year study period for every 1,000 personnel estimated to be in Navy.

Figure 14.2: Proportions of claims for OA accepted by DVA, by Act and decision year.



The overall ADF average number of accepted OA claims in each year of the study was 33 accepted OA claims for every 1,000 personnel in the ADF (Table 14.1). This is very similar to the rates of new cases of OA reported by Knapik et al. [3] in US military personnel aged 40 years or more (31 new cases of OA each year per 1,000 personnel).

Among the 46,912 OA claims records that contained gender details of the claimant, 44,630 were submitted by male claimants and 2,282 by female claimants. A total of 67.1%

of these claims submitted by male claimants and 60.0% of claims submitted by female claimants were accepted by the DVA, with this difference between the genders in acceptance rates being statistically significant ($\chi^2[1] = 49.48$, $p < .001$). Using data from the year 2015 alone, where the reporting of claimant gender was almost complete (see preceding section) it was estimated that the gender-specific rates of accepted OA claims per 1,000 personnel (Table 14.1) in that year were:

- 38 for every 1,000 male ADF personnel, and
- 15 for every 1,000 female personnel.

This finding suggests that female ADF personnel may have historically had a substantially lower risk of OA arising from their service in the ADF than had their male counterparts, perhaps related to historical differences in roles and associated exposures to factors that increase risk of developing OA that may not persist today. It should be noted, for example, that OA claims considered in 2015 had an effective claim date that was on average 21 years later than the end date of the claimants' period of service in the ADF.

Therefore, the majority of claims accepted in 2015 (on which the figures above are based) would have arisen from service provided during time periods when women were not able to enter combat roles. Although it is possible that the gender-related bias in OA claims acceptance rates accounts for a proportion of this gender difference in apparent risk of developing OA, this proportion is likely to be small. From the current figures, the gender-related bias in acceptance rates can be estimated to account for only 8% of the estimated difference in rates of accepted OA claims when male and female claimants were compared.

14.3.3 Estimated relative risks of osteoarthritis by service and gender, based on claims

On the basis of the findings of the analysis of accepted claims presented in the preceding section, the estimated ratios of numbers of OA claims accepted by the DVA per unit population of each service, presumably indicating relative risks of OA in each service, were:

Army 1.78 : Air Force 1.17 : Navy 1.00.

These risk ratios are similar to those reported for US military personnel [3]: Army 2.16 : Air Force 1.54 : Navy 1.00.

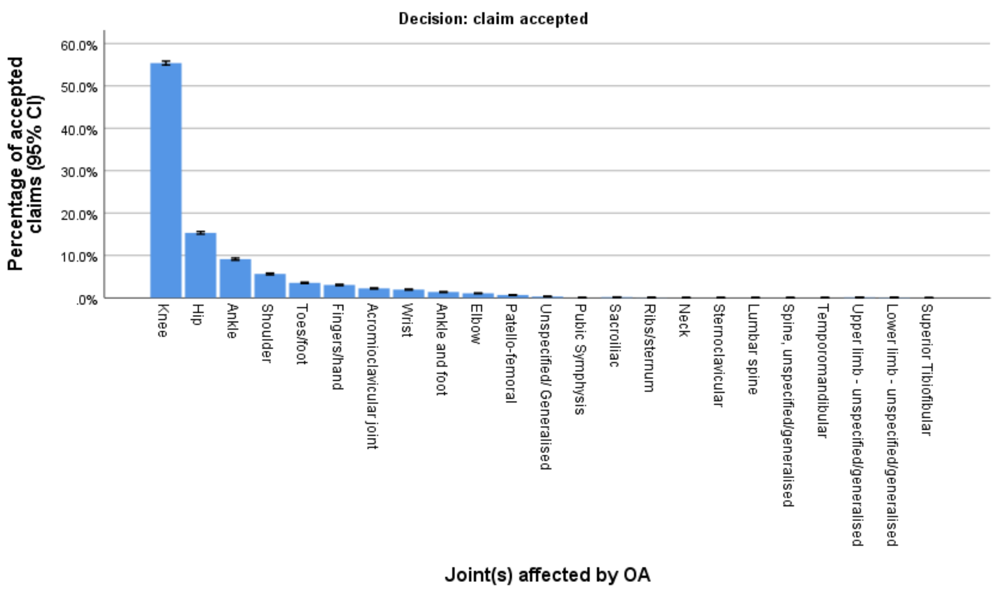
After adjustment for the lower acceptance rates for OA claims submitted by female claimants (which may reflect assessor biases), the estimated ratio of numbers of OA claims accepted by the DVA per unit population of each gender, presumably indicating historical relative risks of OA for each gender, would be: Males 2.4 : Females 1.0. This gender-related risk ratio for ADF personnel is considerably higher than that recently reported for

US military personnel [3]: males 1.06 : females 1.00. The difference between the Australian and US estimates may be due to the respective ratios relating to very different time periods. The US figures relate to the period 2010–2015, whereas the average 21-year time lag from end of service to effective claim date associated with OA claims from the ADF considered by the DVA in 2015 mean that the majority of those claims would relate to service undertaken by personnel prior to 1995. At that time, ADF women had little access to combat roles and were often trained separately from male personnel and therefore would have had different exposures to activities that increase risk of developing OA. However, this situation has now changed considerably, and it could be expected that the current ADF male: female ratio of risks of OA development would be steadily reducing, thus moving toward that reported for the US military.

14.3.4 Joints affected by osteoarthritis in accepted claims

There were 46,383 accepted OA claims decided in the study period for which the joints of the body affected by OA could be ascertained. The majority (55.4%) of accepted claims related to knee OA, which, together with the hip (15.3% of accepted claims) and ankle (9.1% of accepted claims), accounted for 80% of all accepted claims for OA (see Figure 14.3). The tight 95% confidence intervals around these estimates of percentages of claims associated with each specific joint complex indicate the estimates are precise.

Figure 14.3: Percentages of accepted claims for OA by specific affected joints (N = 46,383).

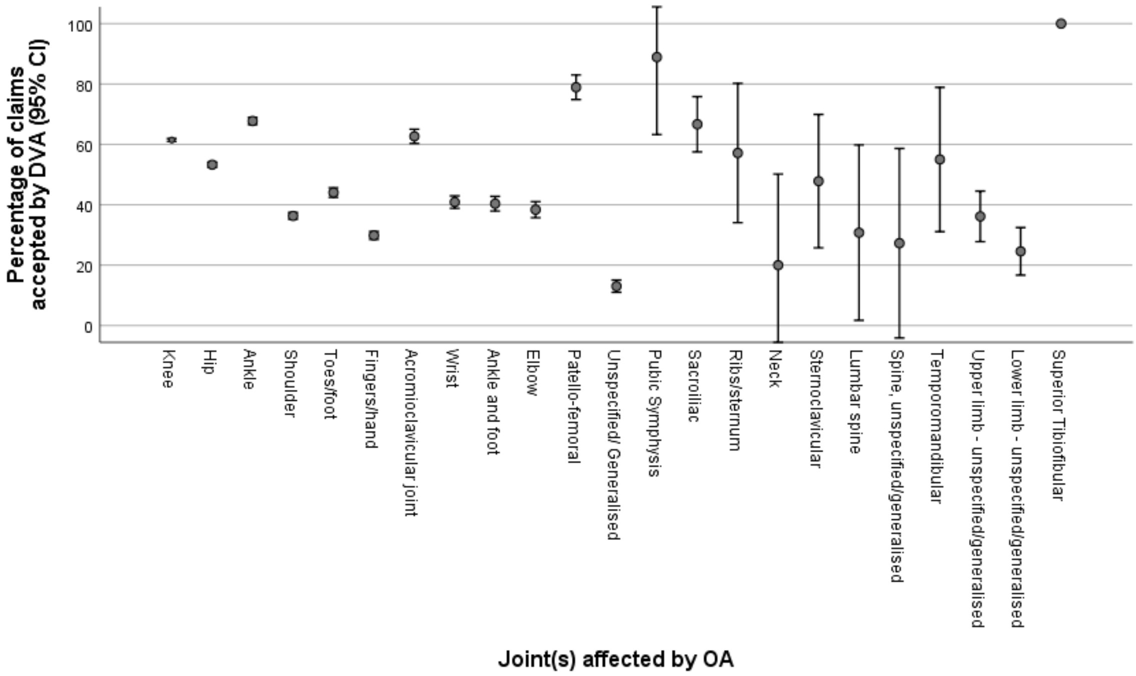


Within the accepted claims for OA, the distributions of OA by joint were very similar for males and females, with two exceptions. OA affecting the sacroiliac joints accounted for 3.5 times as high a proportion of claims from female claimants (accounting for 0.7% of all claims for OA) relative to claims from male claimants (accounting for 0.2% of all claims for OA). Additionally, OA affecting the patellofemoral joint accounted for three times as high a proportion of claims from female claimants (accounting for 2.8% of all claims for OA) relative to claims from male claimants (accounting for 0.9% of all claims for OA).

Within the accepted claims for OA, the distributions of OA by joint were also very similar for Navy, Army, and Air Force, with no exceptions.

The rates of acceptance of submitted claims for OA that affected specific joints are depicted in Figure 14.4.

Figure 14.4: Percentages of submitted OA claims accepted by the DVA, by affected joints (N = 85,617).[a]



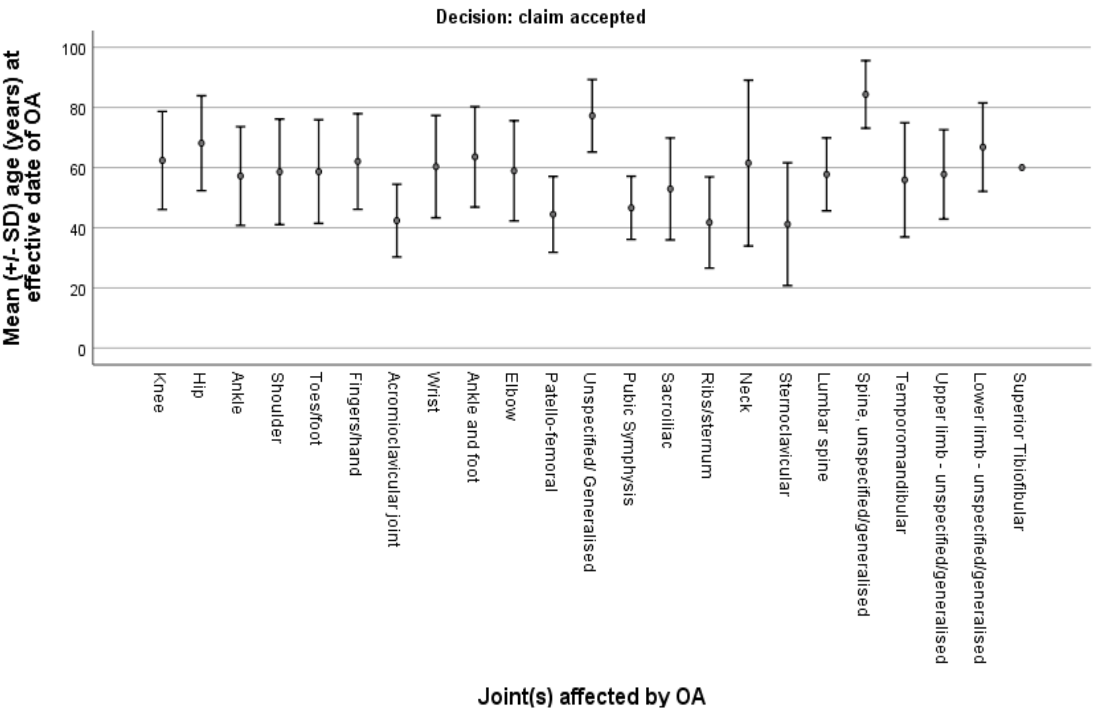
[a] The bars depicting 95% confidence intervals around each estimated percentage are wider for some joints because the sample size (number of cases) for those joints was relatively small, reducing the confidence with which we could estimate the true acceptance rates that occur in the underlying population, based on data from the sample (thus, the true estimate for any of these joints could lie anywhere within the 95% CI, although more extreme values within the CI are less likely than the central estimate depicted).

14.3.5 Claimant ages at effective date of osteoarthritis claim

There were 46,383 accepted OA claims decided in the study period for which claimant age at effective date of the OA claim could be ascertained. The average age of claimants at the effective date of accepted claims was 62 (+/- standard deviation of 17) years. 10% of claimants with accepted claims were aged 39 years or less (with the youngest being 17 years of age), 20% were aged ≤ 46 years, 30% ≤ 52 years, 40% ≤ 56 years, 50% ≤ 61 years, 60% ≤ 66 years, 70% ≤ 75 years, 80% ≤ 80 years, 90% ≤ 84 years, and no claimants with accepted claims were aged over 100 years. Therefore, although the vast majority of accepted claims relate to OA in claimants aged 50 years or more, smaller numbers of accepted claims are submitted by younger claimants—some as young as 17 years of age.

The average ages of claimants at the effective dates of accepted claims for OA that affected specific joints are depicted in Figure 14.5. It is clear from this figure that the average ages of claimants varied between 40 and 85 years for the different joints at the times the claims were submitted for OA.

Figure 14.5: Ages of claimants at effective date of accepted claims for OA affecting specific joints (N = 46,383).[a]



[a] The bars depicting +/- 1 standard deviation around each average generally encompass approximately 68% of all claimants for OA of the respective joint.

Interestingly, claims for OA submitted by claimants when they were younger were more frequently accepted than were claims from older claimants, and although this trend was statistically significant ($r_s = -.22$, $p < .001$), it plateaued and began to reverse from age 70. Those aged 18–30 years at the effective date of their claim had an 80% acceptance rate for the OA claims they submitted, but this reduced to a 40% likelihood of acceptance, or less, for claimants aged 70–80 years at the effective date of the claim, before climbing again for claimants aged 80–100 years.

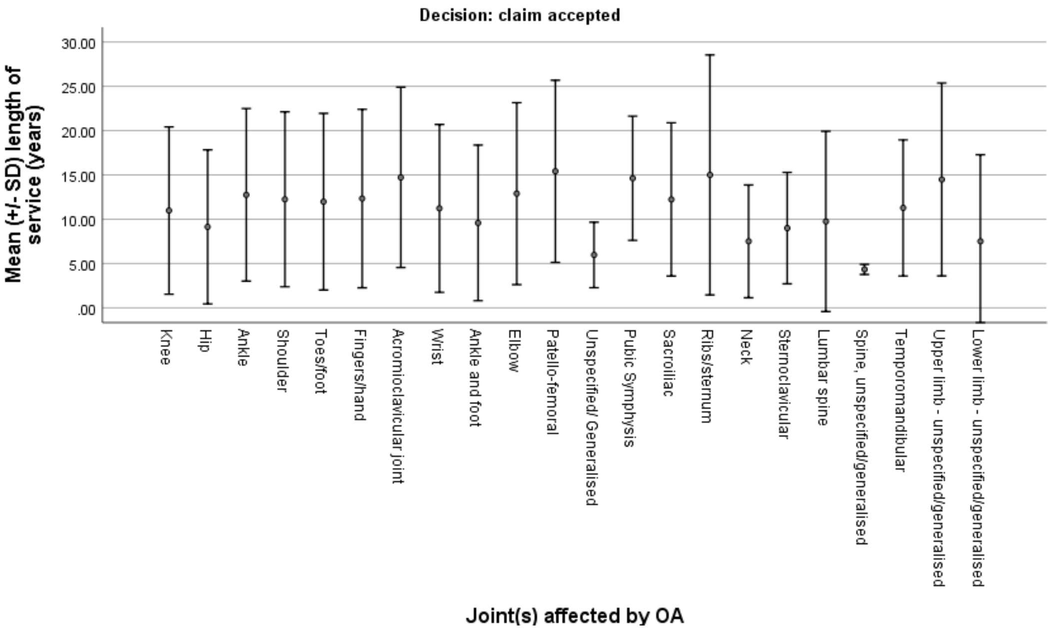
14.3.6 Lengths of service associated with osteoarthritis

There were 45,230 accepted OA claims decided in the study period for which length of service of the OA claimant could be calculated.

The average length of service of OA claimants with accepted claims was 11.1 years (+/- standard deviation of 9.5 years). Of claimants with accepted claims, 10% had served for ≤ 2 years, 20% for ≤ 3 years, 30% for ≤ 4 years, 40% for ≤ 5 years, 50% for ≤ 6 years, 60% for ≤ 11 years, 70% for ≤ 17 years, 80% for ≤ 20 years, 90% for ≤ 25 years, and no claimants with accepted claims had served for more than 49 years. Therefore, half of all accepted OA claims arose from military service of 6 years or less.

The average lengths of service associated with accepted claims for OA that affected specific joints are depicted in Figure 14.6. It is clear from this figure that the average lengths of service varied between 4 and 16 years for the different joints affected by OA.

Figure 14.6: Lengths of service associated with accepted claims for OA affecting specific joints (N = 45,230).



[a] The bars depict +/- 1 standard deviation around each average (mean) and will generally encompass around 68% of all claimants for OA of the respective joint.

Length of service was positively correlated with likelihood of acceptance of a claim (r_S = .24, p < .001), with claimants who had 1–4 years of service having only a 40% chance of having their claim accepted, compared with around 70% for those who had served for 20 years or more. This finding could be expected because longer service would increase the exposure of personnel to activities and injuries arising from service in the ADF that are known to increase the risk of developing OA. Interestingly, those with longer periods of service tended to submit their claim for OA at a younger age ($r_s = -.43$, $p < .001$) and to have less lag time between end of service and effective date of their claim for OA ($r_s = -.63$, $p < .001$).

Further analysis revealed that those with longer periods of service tended increasingly to have submitted their claim for OA before their period of service ended, as well as at a younger age. It is possible that this was a result of continued, unabated exposure in these personnel, who served for longer periods, to activities and injuries arising from ADF service which increased their risk of developing OA, so that the signs and symptoms (and thus diagnosis) of OA occurred earlier in their lives (and often within the span of their service life) than in those who served for shorter time periods.

14.3.7 Time lag between end of service and effective date of osteoarthritis claim

There were 45,230 accepted OA claims decided in the study period for which lag time from end date of service to effective date for the claim for OA could be calculated. The average lag time from end date of service to effective date for an accepted claim for OA was 30 years (+/- standard deviation of 23 years). The effective date for the claim of 10% of claimants with accepted OA claims fell within their period of military service.

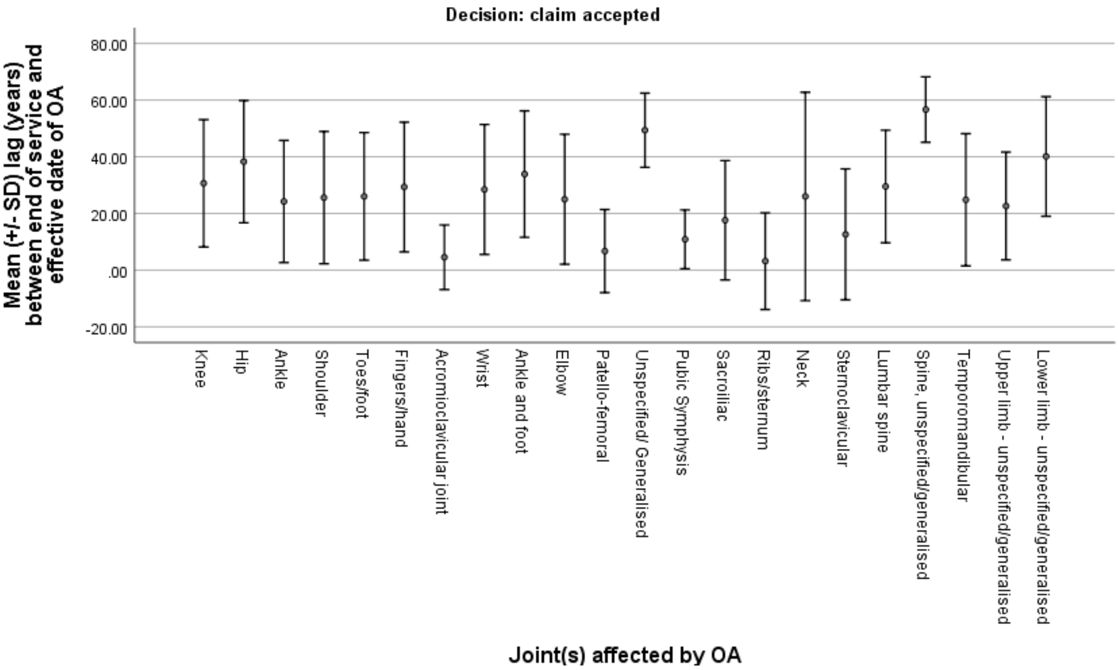
Of claimants with an accepted OA claim, 20% had a lag time from end of service to effective date of 5 years or less. There was a lag time of 13 years or less for 30% of claimants, and 40% had a lag time of 20 years or less while 50% had a lag time of 27 years or less and 60% had a lag time of 39 years or less. Furthermore, 70% had a lag time of 51 years or less, 80% had a lag time of 56 years or less, and 90% had a lag time of 59 years or less. No claimants with accepted claims had a lag time of more than 73 years. Therefore, half of all accepted OA claims had a lag time of more than 27 years from end date of military service to effective date of the claim for OA.

The average lag time from end of service to effective date of accepted claims for OA that affected specific joints are depicted in Figure 14.7. It is clear from this figure that the average lag time varied between 5 and 58 years for the different joints affected by OA. This may reflect the times in life at which signs and symptoms of OA become evident and lead to diagnosis, with OA in some joints becoming evident earlier than OA in other joints.

Lag time was also negatively correlated with likelihood of acceptance of a claim ($r_s = -.23$, $p < .001$), with claimants who had an effective date of their OA claim that preceded their exit from the ADF by 0–4 years having the highest acceptance rate of around 80%, and the acceptance rate dropping to around 50% for those whose effective OA claim date was 25 years or more after the date they left the ADF.

This finding may be due to difficulties that those with longer lag times had in convincing the DVA assessor or in gathering the necessary evidence to convince the assessor that their OA was related to their time in ADF service. It is likely that this negative correlation between lag time and acceptance likelihood largely explains the findings reported above that claims for OA submitted at a younger age (i.e., soon after leaving the ADF or even prior to leaving) were more likely to be accepted than were claims submitted at an older age, perhaps many years after leaving the ADF). Consistent with this hypothesis, lag time and age were very strongly correlated ($r_s = .92$, $p < .001$).

Figure 14.7: Time lags between end of service and effective date of accepted claims for OA affecting specific joints (N=45,230).[a]



[a] Negative time lags indicate that the claimants had not yet finished their period of service at the effective date for the claim. The bars depicting +/- 1 standard deviation around each average generally encompass around 68% of all claimants for OA of the respective joint.

14.4 Encapsulation

There were 85,765 claims for OA arising from ADF service submitted and assessed by the DVA in the years 1994–2018, with most assessed under the Veterans' Entitlements Act (VEA) 1986. Estimates indicate an average of 75 claims were submitted each year for every 1,000 Army personnel, 54 for every 1,000 Air Force personnel and 40 for every 1,000 Navy personnel, giving ratios of submitted claims of 1.88 Army : 1.35 Air Force : 1.00 Navy. OA claims rates steadily reduced over the study period and in later years were approximately half of what they were in early years of the study period. Women were underrepresented in the OA claims arising from ADF service and submitted to DVA, with estimates indicating an average of 50 claims submitted each year for every 1,000 male ADF personnel and 21 for every 1,000 female personnel, giving a male : female ratio for submitted OA claims of 2.4 : 1.0.

Overall, 54% of OA claims arising from ADF service were accepted by the DVA, with the proportion accepted increasing from around 25% of claims in early years of the study period to around 80% in later years, with more accepted in those later years under the Military Rehabilitation and Compensation Act (MRCA) 2004 than under the VEA or the Safety, Rehabilitation and Compensation Act (SRCA) 1988. Rates of OA claims acceptance by the DVA were similar across Navy, Air Force, and Army, but slightly lower for female claimants (60%) than for male claimants (67%). Estimates indicate that an average of 41 claims were accepted by the DVA each year for every 1,000 Army personnel, 27 for every 1,000 Air Force personnel, and 23 for every 1,000 Navy personnel, giving ratios of accepted OA claims of 1.78 Army : 1.17 Air Force : 1.00 Navy, presumably reflecting the relative risks of OA arising from employment in each of these services. Across the ADF as a whole, the estimated average rate of OA claims accepted by the DVA was 33 for every 1,000 personnel. This is very similar to the annual rate of new cases of OA diagnosed in US military personnel aged 40 years or more (31 cases for every 1,000 personnel [3]), which is not surprising given that the average age of claimants with OA claims accepted by the DVA was 62 years.

Women were also underrepresented in the OA claims arising from ADF service and accepted by DVA, with estimates indicating an average of 38 OA claims accepted by the DVA each year for every 1,000 male ADF personnel and 15 for every 1,000 female personnel, giving a male : female ratio for accepted OA claims of 2.5 : 1.0, or 2.4 : 1.0 after adjustment for the lower acceptance rate for claims submitted by females when compared with males.

Again, this ratio presumably reflects the relative risks of OA arising from ADF service for each gender. However, it should be noted that long lag times (21 years, commonly), between end of service and submission of an OA claim means that the claims in the study dataset would have mostly related to periods of service that preceded the opening up of ADF combat roles to women, and this may contribute to the estimated gender difference in historical risk of developing OA, with results perhaps being much closer to the US military male : female OA incidence ratio of 1.06 : 1.00 [3].

Among the 80% of accepted claims for OA arising from ADF service, percentages differed according to site, with OA of the knee (55.4%), hip (15.3%), or ankle (9.1%). The proportions of accepted claims relating to these joints were similar across Navy, Army, and Air Force, and between genders. However, a higher proportion of accepted claims from women than from men related to OA affecting the sacro-iliac joints (3.5 times higher proportion in women) and patella-femoral joints (3 times higher proportion in women).

The ages of claimants whose OA claims were accepted ranged from 17–100 years, but around three-quarters of these claimants were aged 50 years or more, and the average age of these claimants was 62. The average age of claimants with accepted OA claims varied widely with the joint affected, between around 40 and 80 years, but the average age for those with claims accepted for knee, hip, or ankle OA was in the vicinity of 60–70 years. Claims for OA submitted by younger claimants were more frequently accepted (80%) than were claims from older claimants (as low as 40%), and this trend was statistically significant ($r_s = -.22$, $p < .001$), though it plateaued and began to reverse from age 70.

The average length of service of OA claimants with accepted claims was 11 years, and around half of all accepted OA claims arose from ADF service of 6 years or less. Average lengths of service varied between 4 and 16 years for the different joints affected by OA, in accepted claims. Length of service was positively correlated with likelihood of acceptance of a claim ($r_s = .24$, $p < .001$), with claimants who had 1–4 years of service having only a 40% chance of their claim being accepted, compared with around 70% for those who had served for 20 years or more. Those with longer periods of service also tended to submit their claim for OA at a younger age ($r_s = -.43$, $p < .001$) and to have less lag time (often none) between end of service and effective date of their claim for OA ($r_s = -.63$, $p < .001$). These findings are consistent with the understanding that these personnel would have been exposed for long periods of service to heightened rates of exposure to factors that increase their risk of developing OA. Therefore, signs and symptoms (and therefore diagnosis) of OA may have occurred earlier in their lives (and often within the span of their service life) than for those who served for shorter periods.

The average lag time from end date of service to effective date for an accepted claim for OA was 30 years (+/- standard deviation of 23 years). However, the effective date for 10% of claimants with accepted OA claims fell within their period of military service. The average lag time varied, depending on the joint affected by OA, between 5 and 58 years. Lag time was also negatively correlated with likelihood of acceptance of a claim ($r_s = -.23$, $p < .001$), with claimants who had an effective date of their OA claim that preceded their exit from the ADF by 0–4 years having the highest acceptance rate of around 80%, and with the acceptance rate dropping to around 50% for those whose effective OA claim date was 25 years or more after the date they left the ADF. This finding may be due to difficulties that those with longer lag times had in convincing the DVA assessor or in gathering the necessary evidence to convince the assessor that their OA was related to their time in ADF service. It is likely that this negative correlation between lag time and acceptance likelihood largely explains the findings reported above, indicating that claims for OA submitted at a younger age (i.e., sooner after leaving the ADF or even prior to leaving) were more likely to be accepted than were claims submitted at an older age, perhaps many years after leaving the ADF). Consistent with this hypothesis, lag time and age were very strongly correlated ($r_s = .92$, $p < .001$).

14.5 References

1. Australian Survey Research Group. *Defence Census 2015 Public Report*. Canberra: Australian Government Department of Defence; 2016.

2. Roy Morgan Research. *Defence Census 2007 Public Report*. Canberra: Australian Government Department of Defence; 2009.

3. Knapik J, Pope R, Orr R, Schram B. Osteoarthritis: pathophysiology, prevalence, risk factors, and exercise for reducing pain and disability. *Journal of Special Operations Medicine*. 2018;18(3):67–73.

15. SUMMATION AND CONCLUSION

This report encapsulates the scope, methods, and findings of the DVA-sponsored research project *ARP1706 Measuring Occupational Exposures to Osteoarthritis in the Lower Limb (OLL) in ADF Job Categories*. The project scope was limited to examining exposures that occur during the initial training of full-time Australian Defence Force (ADF) personnel and comparing these findings with the exposure threshold levels set out in the Statements of Principles (SoPs) for osteoarthritis of the lower limb (OLL) established by the Repatriation Medical Authority (RMA*)*. Specifically, the project team was requested to identify projections of timeframes within which personnel in selected occupations would be likely to reach RMA-specified threshold exposures to risk factors for OLL, assuming exposures continued following completion of initial training at the levels that occurred during initial training.

The guiding research questions were:

- To what degree does initial training undertaken by ADF members meet the exposure thresholds for OLL set out by the RMA, including thresholds of exposure to joint trauma that may lead to OLL?
- To what extent do individual factors (e.g., body weight, sex, fitness, and age) affect the risk of military personnel developing OLL or their exposure to occupational risk factors for OLL, including joint trauma?
- How have exposures during initial training to factors that increase the risk of ADF personnel developing OLL changed over preceding decades?

To answer these questions, the project encompassed six main elements:

1. A desktop analysis of purposively selected ADF initial training courses
2. A job exposure matrix (JEM) for OLL
3. Direct observations of training and surveys of trainees and staff to confirm or examine the types and extents of any variations in observations from findings of the desktop analysis, in order to further inform the JEM-OLL
4. An historical review of ADF initial training
5. An analysis of osteoarthritis (OA) claims data 1994–2018
6. Literature reviews, comprising an umbrella review of previous reviews, a systematic review with meta-analysis, and additional reviews to examine the influences of specific factors on the risk of military personnel developing OLL or their exposure to occupational risk factors for OLL.

The umbrella review and the critical review with meta-analysis of recent studies, while noting limited research specifically in military populations (i.e., one study that met the criteria for selection) and diversity in approaches and definitions of work (e.g., heavy lifting ranging from 10–50 kg), indicated moderate to good evidence that physically demanding occupations such as farming, floor laying, and bricklaying were associated with OLL. Occupational tasks involving lifting/carrying heavy loads, squatting/kneeling, and standing significantly contribute to the development of OLL. With these kinds of demanding occupational tasks being common in the military, it is not surprising that military personnel experience greater rates of OA than do members of the general population.

The historical review indicated there were limited data available regarding military training in general. Therefore, we focussed particularly on physical training (PT) and sport undertaken during initial training. Both PT and sport were found to constitute an employment requirement and were, and had been for many decades, a constant feature of service in the ADF. Little has changed in types of PT over the decades (e.g., obstacle courses, pack marching, battle PT, circuit training), although the volume of training has decreased. Similarly, sports participation in the ADF has changed little over preceding decades, except that in more recent decades sport has been removed from recruit training contexts (although it may still occur in later initial employment training and officer training) in order to reduce injury risks and increase training completion rates. Sport and PT were found to have historically contributed substantially to working days lost due to injuries affecting ADF personnel. These injuries were also found to have been chronically and substantially underreported.

The main findings from the desktop analysis and observations, reflected in the JEM-OLL that accompanies this report, included thresholds of exposure to factors recognised by the RMA as increasing the risk of developing OLL being likely to be met at specific estimated timepoints by personnel in selected occupations of each service. In the Air Force, officers were found to cumulatively lift substantial loads comprising separate loads weighing 20 kg or more during their initial training in the 17-week initial officer course (IOC), which, if continued after completion of training, would have officers reach the RMA threshold for exposure to heavy lifting under its reasonable-hypothesis scenario within 7 years and 31 weeks following commencement of service. Conversely, this threshold could be reached by airfield defence guard trainees within 1 year and 34 weeks following commencement of service under the reasonable-hypothesis scenario for exposure to heavy lifting or within 2 years and 20 weeks following commencement of service under the RMA's balance-of-probabilities scenario. Airfield defence guard trainees also carried loads weighing 20 kg or more for substantial numbers of hours during their initial training and, if this level of heavy carrying continued after completion of their training, trainees would reach the RMA threshold under both its Reasonable-Hypothesis and Balance-of-Probabilities scenarios for exposure to heavy load carrying within 5 years and 40 weeks following commencement of service. Furthermore, at various time points Air Force medical assistant trainees and loadmaster trainees are also likely to meet key thresholds for exposure—typically well within a 10–year period.

Variations in periods to reach the RMA thresholds notwithstanding, the findings for Air Force personnel were similar for the other two services. For example, Navy officers cumulatively lifted substantial loads comprising separate loads weighing 20 kg or more during their initial training in the 22-week New Entry Officers' Course (NEOC). If this level of heavy lifting continues after completion of the NEOC, Navy officers would reach the RMA threshold for exposure to heavy lifting under its Reasonable-Hypothesis scenario within 6 years and 1 week following enlistment, and under its Balance-of-Probabilities scenario within 9 years and 1 week following enlistment. One notable variation, more common in the Navy, related to the climbing of stairs and ladder rungs, with subject matter experts noting that Navy personnel of all ranks climbed well over 150 stairs or ladder rungs daily when posted to sea or to vessels situated 'alongside'. Therefore, all Navy personnel who spend half of their days or more at sea or alongside, or who are posted to sea or to a vessel alongside for more than one year following completion of initial training would meet the RMA-set threshold for climbing stairs and ladder rungs under its Reasonable Hypothesis scenario within 2 years of commencing the time posted to sea or alongside, with the exact timepoint depending on the proportion of days in the year that they spend at sea or alongside.

As can be expected in the Army, cumulative lifting of heavy loads weighing 20 kg or more meant that all the occupations reviewed were predicted to meet the RMA threshold for exposure to heavy lifting within 3 years, some much earlier. Unlike the stairs-and-rung exposure of Navy personnel, Army officer cadets and Infantry trainees were found (via the observations) to spend 1 hour or more squatting or kneeling on more days than not in a typical month. Assuming this rate of exposure continued at similar levels beyond initial training for Infantry trainees particularly (noting that officer training is 18 months in duration), it is likely that officer cadets and Infantry trainees would reach the RMA threshold for exposure to this kneeling/squatting risk factor for OLL within 1 year of enlistment under the RMA's Reasonable Hypothesis scenario. The time frame to reach this threshold under the RMA's Balance-of-Probabilities scenario would be within 2 years of enlistment.

Of note, although generally in agreement with findings in the desktop analysis, in several instances (in the Navy, stairs and ladders; in the Army, kneeling and squatting), the observations revealed notably greater exposures than those the desktop analysis indicated. The desktop analysis results were considered generally conservative in that actual exposures in the selected occupations would likely be at least as great as those identified in the desktop analysis, and in some cases greater.

Because injury, and particularly trauma to lower-limb joints, constitutes another recognised risk factor for osteoarthritis in the lower limbs, the research team completed a review of the occupational exposures of ADF personnel to trauma affecting lower-limb joints. The findings indicated that lower-limb joint injuries represent an important risk factor for development of OLL in all ADF personnel, with exposure to this risk factor beginning very early in a person's military career. It is therefore likely that within 2 years from date of enlistment, nearly all ADF personnel will have experienced a significant injury to a lower-limb joint that will increase their risk of developing OLL and ensure they meet one of the injury thresholds specified by the RMA in its SoPs for OLL. Furthermore, recent research has found that a history of prior foot or ankle symptoms in the same or opposite leg can increase the risk of OA developing in a knee joint. Therefore, lower limb injuries do not necessarily have to have affected the joint exhibiting OA for a contribution to that OA to have come from those injuries.

The surveys of trainees supported a high injury rate, with 419 injuries of types relevant to the development of OLL recorded per 100 full-time equivalent years of service in trainees who were within their first 4 weeks of initial training. Notably, 62% of injuries reported by these early-stage trainee respondents stopped them from playing sport, exercising, or working for a period of 7 days or more, indicating these were substantial injuries.

Analysis of 85,765 claims for OA arising from ADF service that were submitted and assessed by DVA in the years 1994–2018 suggested an average of 75 claims were submitted each year for every 1,000 Army personnel, 54 for every 1,000 Air Force personnel, and 40 for every 1,000 Navy personnel, giving ratios of submitted claims of 1.88 Army : 1.35 Air Force : 1.00 Navy. Overall, 54% of these OA claims arising from ADF service were accepted by the DVA, with the proportion of accepted claims increasing from around 25% of claims in early years of the study period to around 80% in later years, and more accepted in those latter years under the Military Rehabilitation and Compensation Act than Veterans' Entitlements Act and Safety, Rehabilitation and Compensation Act. These rates of OA claims acceptance by the DVA were similar across Navy, Air Force, and Army, but slightly lower for female claimants (60%) than for male claimants (67%).

Eighty percent of accepted claims for OA arising from ADF service related to OA of the knee (55.4%), hip (15.3%), or ankle (9.1%). The proportions of accepted claims relating to these joints were similar across the three services and between genders. However, a higher proportion of accepted claims from women than from men related to OA affecting the sacro-iliac joints (3.5 times higher proportion in women) or patello-femoral joints (3 times higher proportion in women). The average length of service of OA claimants with accepted claims was 11 years, and around half of all accepted OA claims arose from ADF service of 6 years or less.

The average lag time from end date of service to effective date for an accepted claim for OA was 30 years, but varied between 5 and 58 years depending on the joint affected by OA.

Conclusion

ADF service is physically demanding, and personnel perform arduous tasks that in many ways are atypical of professional sports as well as farming, trades, and other physically demanding occupations. This increases relevant exposures to risk factors for OLL among ADF personnel in unrecognised ways.

Notwithstanding those instances where RMA thresholds have been met, exposure to service-related lower-limb joint trauma (as well as other lower-limb injuries) is one of the strongest risk factors for OLL in ADF personnel as well as being the most prevalent. All ADF personnel are most likely to have been exposed to a lower-limb injury that would increase their risk of developing OLL. This occurs within 9 months of service in the Army, 12 months in the Air Force, and 15 months in the Navy.

Finally, the physical demands of ADF initial training have, overall, changed little across 60 years, meaning that exposures to risk factors for OLL measured today apply also to preceding decades. This supposition is supported by consistently high rates of claims for OLL submitted across the last 25 years that arose from ADF service stretching back to at least the 1960s.

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16. APPENDICES

16.1 Appendix 1: Acknowledgment of Subject Matter Experts

The following subject matter experts kindly gave of their time and expertise to inform the desktop analysis of initial training programs and consented to being formally acknowledged in this report:

Navy

LEUT A. McDonald, Officer's Initial Training Faculty, HMAS Creswell

LEUT T. Alan, Recruit School, HMAS Cerberus

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Air Force

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Army

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CAPT G. Wickham, Training Alignment Branch, Royal Military College

LT H. McLaggan, School of Infantry, Singleton

LT W. Fountain, Platoon Commander, Recruit Training Instructor, 1st Recruit Training Battalion, Army Recruit Training School, Wagga Wagga

WO2 M. Brooks, Physical Training Instructor Manager, Australian Defence Force Academy

WO2 M. Steinert, Physical Training Instructor, Australian Defence Force Physical Training School, HMAS Cerberus

SGT R. Copper, Recruit Training Instructor, 1st Recruit Training Battalion, Army Recruit Training School, Wagga Wagga

Paramedic Subject Matter Experts

Ms Kate Lyons, NSW Ambulance Service

Dr Alex MacQuarrie, Griffith University

We also acknowledge the contributions of numerous other subject matter experts who have not been identified here but also gave of their time and expertise to inform the analysis.

16.2 Appendix 2: Additional Published Literature Review: Osteoarthritis

Included in this appendix for information of DVA is a copy of the following review, which is focused on osteoarthritis in military populations and has been led by Professor Joseph Knapik of the US military and co-authored by Rod Pope, Rob Orr, and Ben Schram from the research team for the current project:

Knapik J, Pope R, Orr R, Schram B. Osteoarthritis: pathophysiology, prevalence, risk factors, and exercise for reducing pain and disability. *Journal of Special Operations Medicine*. 2018;18(3):67–73.