Injuries in New Zealand Army Recruits

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Doctor of Philosophy

Injuries in New Zealand Army Recruits

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Declaration by author

This doctoral thesis contains no materials that have been extracted in whole or part of a thesis that I have submitted towards the award of any other degree or diploma in any other tertiary institution. No other individual's work has been used without due acknowledgement in the main text of the thesis. The research procedures reported in the thesis received approval of the relevant Ethics/Military permissions (where required).

Narelle Hall

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PUBLICATIONS AND PRESENTATIONS

Publications

Hall, N., Constantinou, M., Brown, M., Beck, B., & Kuys, S. (2022). Prevalence of musculoskeletal injuries in New Zealand Army recruits as defined by physical therapy service presentations. Military Medicine, 187 (1-2), 174-181. https://doi.org/10.1093/milmed/usab186

Hall, N., Constantinou, M., Brown, M., Beck, B., Steele, M., Rousseau, J., & Kuys, S. (2023). Profiles of recruits entering army basic training in New Zealand. Military Medicine, 188 (7-8), 1895-1902. https://doi 10.1093/milmed/usac090

Presentations and abstracts

Hall, N., Constantinou, M., Brown, M., Beck, B., Steele, M., Rousseau, J., & Kuys, S. (2023, February 24-26). What are the physical performance characteristics of New Zealand Army recruits entering basic training [Conference presentation and abstract]. The 4th International Physical Employment Standards Conference, Bond University, Gold Coast, QLD, Australia.

Hall, N (2023, April 12). New Zealand Army recruit injuries, research progress and personal journey [Keynote address]. Fellowship Fund Inc., Queensland committee meeting, Women's College, the University of Queensland. This was followed by an awarding of the one-year Agnes Whiten Commemorative Fellowship (Scholarship) to the candidate.

Hall, N., Constantinou, M., Brown, M (2013, October 22-25). Does a structured neuromuscular training program reduce the incidence of lower limb injuries in NZDF Army recruits [Conference presentation and abstract]. ASICS Conference of Science and Medicine in Sports. Hilton Phuket Arcadia Resort and Spa, Phuket, Thailand.

Hall, N., Constantinou, M., Brown, M (2013, May 11). Does a structured neuromuscular training program reduce the incidence of lower limb injury in NZDF Army recruits [Conference presentation and abstract]. Sports Medicine Australia, QLD Conference, Brisbane, QLD, Australia.

LIST OF ABBREVIATIONS AND GLOSSARY

AARC	All Arms Recruit Course, recruit training for all trades including infantry
ADF	Australian Defence Force
ANZCTR	Australian New Zealand Clinical Trial Register
Aptitude test	Basic reading and writing skills
Attestation	Recruit sworn into army
Backsquad	Recruit back classed/recycled, will repeat some parts of training
Basic training	Initial entry level training for recruits
BMI	Body mass index
CI	Confidence interval
CG	Control group
cRCT	Cluster randomised controlled trial
DCS	Dynamic integrated movement enhancement cadre supervised
Deployment	Soldier posted overseas to an operational area
DES	Dynamic integrated movement enhancement expert supervised
Discharge	Released from the service/military
DIME	Dynamic Integrated Movement Enhancement
Drill	Formal marching, often on a hard surface parade square
FIFA	Fédération Internationale de Football Association (in French) or International Federation of Association Football (in English)
Field exercise	Practice military skills outdoors in the field
HR	Hazard ratio
ICD	International Classification of Diseases
IOC	International Olympic Committee
IG	Intervention group
Light duties	Reduced or restricted duties due to injury or illness
LoE	Level of evidence
March out	Complete basic training with parade ceremony
Marching	Movement around camp in platoon formation
NZ	New Zealand

NZDF	New Zealand Defence Force
OSIICS	Orchards Sports Injury and Illness Classification System
PEDro	Physiotherapy Evidence Database used for rating scientific research of randomised controlled trials
PT	Physical Training, organised physical fitness training run by army physical training instructors
Recruit	Initial basic training soldier who volunteers to join the service
Reps	Repetitions
RR	Relative risk
TAD	The Army Depot, is the unit where recruit training occurs in New Zealand
TRADOC	Training and Doctrine Command, Headquarters that commands TAD
Trade training	Next phase of army training following basic training
UK	United Kingdom
US	United States
USMA	United States Military Academy

ABSTRACT

Musculoskeletal injuries are a major concern for the military resulting in substantial burdens for both recruits and the service. Recruits report high incidence of musculoskeletal injuries with the majority occurring to the lower limbs. Consequences of recruit injuries can be considerable for the individual including reduced participation, injury chronicity, training time loss and career pathway change due to backsquad or discharge. For the military, recruit injuries can result in increased health care expenditure, additional costs related to training, and recruitment and retention to replace injured recruits. Potentially, deployment capability may be impacted as fewer recruits progress from basic training to trade training or operational units, whereby they gain essential skills to become deployable.

Injury incidence data were limited for New Zealand Army recruits with a current understanding of the recruit injury problem unknown. It was unknown whether recruits present for basic training with pre-existing injuries or risk factors that could predispose them to injury, and if a prevention program using neuromuscular training could lower recruit injury incidence.

The aim of the current program of research was to establish the extent of the New Zealand Army recruit injury problem, the profile and aetiology of recruit injuries and the effect of six weeks neuromuscular training compared to usual training on incidence of lower limb injury of New Zealand Army recruits undertaking basic training. Additionally, this program of research investigated if baseline personal, lifestyle and physical performance characteristics could predict actual injury sustained during training.

This program of research comprised four studies based on the sequence of injury prevention model. The first study explored the extent of the New Zealand Army recruit injury problem through surveillance of four years of physiotherapy provisions for injuries sustained during basic training. Commencing basic training were 1896 recruits (1697 males, 199 females), who

required 1683 physiotherapy provisions for injury sustained during training, across four years. Lower limb injuries accounted for more than 75% (n = 1285) of the total demand for physiotherapy service and injuries sustained at the knee and below accounted for 67% of all injury presentations.

Studies 2, 3 and 4 investigated injury risk and injury outcomes in 248 New Zealand Army recruits (228 male, 20 female). Study 2 investigated personal profiles, lifestyle and physical performance characteristics of recruits presenting to basic training to identify if pre-existing conditions or risk factors for injury existed at the commencement of training. Recruits were predominantly male (91.9%) with an average age of 20.3 ± 2.8 years. Approximately 30% of recruits reported injury in the year prior to training commencing, with 44.8% of those injuries in the lower limbs. Approximately one fifth of recruits were self-reported current smokers. Recruits who passed the 2.4 km timed run for distance were 53.8% of males and 28.6% of females. Weight-bearing dorsiflexion lunge test performance was within a normal range (left = 10.2 ± 3.2 cm); although, 30.9% of recruits had limb asymmetry (>1.5 cm). Outcomes of the Y Balance Test™ for dynamic lower limb stability, found 70% of female recruits had high posterolateral reach asymmetry (8.1 ± 6.0 cm), while normalised composite reach scores were low (right) for male (92.2 ± 8.1%) and female recruits (89.0 ± 7.5%).

Findings from Studies 1 and 2 informed the development of a neuromuscular injury prevention intervention program for army recruit injuries occurring at the knee and below. Study 3, a cluster randomised controlled trial design, was used to investigate if a six-week neuromuscular training program led to fewer lower limb injuries in basic training army recruits, across two intakes compared to usual training. Neuromuscular exercises did not change recruit injury incidence but did lower health care encounters for overall lower limb per recruit (control 4.83 ±7.58, intervention 3.45 ± 5.79, p = 0.041), and overall number of knee injuries (control 262, intervention 120) ($p < 0.010$) during basic training. Additionally, more intervention recruits completed training on time ($p = 0.026$).

Study 4 considered whether personal, lifestyle, and physical performance characteristics can predict actual injuries sustained by recruits during training. From 248 participants commencing basic training, 46 (18.5%) recruits had missing data, which resulted in 202 (81.5%) remaining for the regression analysis. Backwards stepwise logistic regression had two variables associated with injury risk in the final model: passing the 2.4 km timed run and right Y Balance Test™ posterolateral reach. This model accurately predicted 60.9% of recruits with 36 correctly assigned as not injured and 87 correctly assigned as injured. Findings support the use of physical performance injury screening to identify recruits at risk of injury at entry to training so that mitigation measures could be taken to reduce this risk.

This program of research identified several clinical implications and recommendations for future directions. Firstly, knee injuries are common in army recruits and need to be targeted by prevention programs. Secondly, recruits enter training with injury risk factors and therefore screening is important to identify individuals at higher risk so that measures could be taken to lower this risk. Thirdly, neuromuscular training reduces health care burdens associated with common lower limb injuries. Future recommendations include investigation of recruit injury risk factors and neuromuscular training over longer study durations and with larger samples. Investigation of the effectiveness of neuromuscular training delivered prior to basic training or as part of a recruit preconditioning program to lower injury and associated burdens requires consideration. Finally, injury consensus statements are required to improve consistency and accuracy reporting military recruit injury and to improve comparability of findings across military recruit research.

1. INTRODUCTION

Physical training injuries are a major concern for the military resulting in substantial burden for both individuals and the service (Kaufman et al., 2000, p. 54; Molloy, Pendergrass, Lee, Chervak, et al., 2020). High incidences of injuries have been previously reported in recruit training populations and historically, New Zealand Defence Force (NZDF) recruits are five times more likely to sustain a musculoskeletal injury than trained military personnel (Davidson et al., 2008).

The consequences of these training related injuries can be considerable, affecting both recruits and the military. For the recruit, injury can result in reduced performance and participation (Davidson et al., 2009), injury chronicity (Davidson et al., 2009; Molloy, Pendergrass, Lee, Hauret, et al., 2020), training time loss (Davidson et al., 2009; Kaufman et al., 2000; Robinson et al., 2016) and alteration in career advancement due to backsquad or discharge from the service (Coppack et al., 2011; Hall, 2017; Orr et al., 2020). For the military, recruit training injuries can increase medical, dental and psychological costs (Heir & Glomsaker, 1996; Pope et al., 1999), training and work time loss (Davidson et al., 2009; Robinson et al., 2016), costs related to recruitment and retention of recruits (Molloy, Pendergrass, Lee, Chervak, et al., 2020; Pope et al., 1999), costs related to training (Molloy, Pendergrass, Lee, Chervak, et al., 2020; Pope et al., 1999) and long term, can affect deployment readiness and capability (Molloy et al., 2012; Molloy, Pendergrass, Lee, Chervak, et al., 2020).

Injury prevention is therefore important to reduce costs and burdens associated with recruit injury. In accordance with the four-step 'sequence of injury prevention model', prevention of recruit training-related injuries requires initially establishing the extent of the problem using injury surveillance (van Mechelen et al., 1992, p. 84). Injury surveillance, using a set of established codes for injury site and region can be used to report recruit injury incidence

(Phillips, 2000). The next step in injury prevention is to establish the aetiology and mechanisms of recruit injury (van Mechelen et al., 1992). Establishing recruit injury aetiology requires consideration of intrinsic and extrinsic recruit injury risk factors, whether modifiable or non-modifiable (Cowan et al., 2003; Jones & Knapik, 1999; Sammito et al., 2021). Injury incidence data exists for NZDF recruits (Davidson et al., 2008; Stacy & Hungerford, 1984), however it was more than two decades old and included less than one year of recruit intakes. Establishing the current magnitude of the recruit injury problem was essential. The aim of Study 1 was to firstly establish the extent of the injury problem in New Zealand Army recruits through the exploration of four years of physiotherapy provisions during basic training. In addition, it was unknown if recruits presenting for basic training do so with pre-existing conditions or other potential risk factors for injuries. Therefore, research was also required to explore the characteristics of male and female New Zealand Army recruits commencing basic training, to identify the presence of potential risk factors for injury.

Understanding the extent of the New Zealand Army recruit injury problem, the profile of recruits entering basic training and the presence of risk factors for injury informed the development and implementation of a randomised controlled trial as an injury prevention program, the third step of the sequence of injury prevention. Outcomes from the trial will assist in establishing evidence-based injury prevention programs with the aim to reduce the burden of injury experienced by recruits undertaking basic training. The final investigation considered if baseline personal, lifestyle and physical performance characteristics could predict actual injuries sustained for New Zealand Army recruits undertaking basic training.

This thesis comprises nine chapters. Chapter 2 provides background information describing who military recruits are, recruit injury incidence rates and injury consequences, scope to the extent of the recruit injury problem, injury aetiology including intrinsic and extrinsic risk factors, and describes neuromuscular injury prevention programs aiming to lower recruit injury.

Chapter 3 outlines the overall research plan, aims and significance for this doctoral program of research. Additionally, this chapter explores the ethical considerations required for military research undertaken with the New Zealand Defence Force and retrospective trial registration undertaken within this program of research. Chapters 4 to 7 present the findings of the four studies comprising this doctoral program of research. Chapter 8 provides a discussion of this program of research, including clinical implications, future research directions, strengths and limitations.

2. BACKGROUND

Chapter 2 will provide background to military recruit basic training injuries including describing the transition from civilian life to army recruit training, injury incidence rates, and the location, type and periodisation of recruit injury over time. Consequences of injury will be described for both recruits and the military. Establishing the extent to the recruit injury problem will include consideration of factors such as injury diagnosis, classification and coding, injury definition and severity, exposure rates, subsequent injury and physiotherapy-based injury surveillance. Establishing aetiology of recruit injury requires consideration of modifiable or non-modifiable intrinsic and extrinsic injury risk factors and consideration of mechanism of injury. A neuromuscular injury prevention intervention is proposed based on evidence from sports and military populations.

2.1 MILITARY RECRUIT BASIC TRAINING INJURIES

Musculoskeletal physical training-related injuries are a major issue for military services leading to strain on financial resources, medical provision and can result in a decrease in deployment readiness and capability (Cowan et al., 2003; Kaufman et al., 2000).

Achieving and maintaining physical fitness is a requirement for military personnel; both for general on the job physical demands as well as for deployment (Cowan et al., 2003). Maintaining fitness and passing regular physical fitness tests are often a compulsory requirement for service personnel, with those who do not pass at risk of discharge from the service (Cowan et al., 2003). Physical training in general has many suggested benefits for health but by its very nature increases risk of injury, particularly lower limb injuries which are a major problem for military services worldwide (Engebretsen & Bahr, 2009; Jones, Cowan, et al., 1993; Kaufman et al., 2000). Finding the balance between achieving ideal physical fitness for military duties and deployment and lowering the risk of injury, in particular lower limb injury, continues to challenge military services worldwide. This issue is of even greater concern for basic training military recruit populations where the highest incidence of training-related injuries has been reported (Davidson et al., 2008; Davidson et al., 2009; Kaufman et al., 2000).

In New Zealand, army recruits enter the service as civilians. Such civilians who volunteer to join the army and pass an aptitude test (basic reading and writing), a fitness test and who present to military camp for training are referred to as army recruits. Army recruits, in New Zealand, typically undertake a program of 14 to 17 weeks basic training. The program is physically and mentally demanding involving physical fitness training, marching and drill (formal marching), weapon range training and field exercise (outdoor military skills). Basic training takes place both at day and night in challenging environments and throughout all seasons of the year. Standardised uniforms, footwear and equipment are issued to recruits in Week 1, while recruits' sleeping and eating arrangements whether in camp or the field also remain standardised for the duration of training. On completion of basic training, individual recruits are assigned to either trade training (e.g. chefs, carpenters, and medics) or operational units (e.g. infantry, logistics) for career progression.

Injuries during recruit basic training can have serious consequences, therefore it is important to consider recruit injury incidence. Military basic training recruits (Army, Navy, and Air Force) are five times more likely to experience musculoskeletal injuries than regular force personnel in the NZDF (Davidson et al., 2008; Davidson et al., 2009). Comparatively, United States (US) Army basic combat training recruits also demonstrate a higher risk of training-related injury, reporting 1.4 to 2.2 times higher for outpatient clinic visits than an overall US Army average (Technical Bulletin Medical 592, 2011). In the Australian Defence Force (ADF), army recruit injuries are reported to occur at approximately three times the rate of any other active periods in a military career (Schram et al., 2019; Sherrard et al., 2004). The high number of recruit basic training injuries is a distinct and major issue effecting multiple military training populations worldwide.

2.1.1 Injury incidence of male and female recruits

Overall incidence of recruit injuries during training is historically reported to range from 14% to 47% for males (Hall, 2017; Jones, Bovee, et al., 1993; Jones, Cowan, et al., 1993; Jones et al., 2017; Knapik et al., 2009; Rudzki, 1997a) and from 32% to 67% for females (Heller & Stammers, 2020; Jones, Bovee, et al., 1993; Jones et al., 2017; Knapik et al., 2009; Shaffer et al., 1999). More recently, an investigation of 184,670 US Army basic combat training recruits (143,398 males and 41,727 females) found injury risk of females was 2.6 times higher than for males (40.3%/15.7%, 95% CI: 2.5–2.6) (Jones et al., 2017). Similarly, a recent meta-analysis reporting incidence rates of recruits across multiple militaries and countries found higher injury incidence in female compared to male recruits during training (RR = 2.10, 95% CI 1.89-2.33) (Schram, Canetti, et al., 2022). Based on this available data, female recruits appear to have higher incidence rates for injury compared to male recruits. Reasons for these differences could be that compared to male recruits, female recruits tend to be shorter (Jones et al., 2017; Kelly et al., 2000), have lower weight, lower body mass index (BMI) and lower aerobic fitness based on army fitness test results (Jones et al., 2017). Risk factors for recruit injury will be discussed further in coming sections.

Interpretation of recruit injury incidence studies is hampered by varied data sources and injury definitions, the nature of the studies used, and the specific types of injury reviewed (Andersen et al., 2016; Kaufman et al., 2000). For example, one study only reports stress fracture incidence (Knapik et al., 2012) while others use the term musculoskeletal injury (Hall, 2017; Heller & Stammers, 2020) to report incidence based on all injuries sustained, including stress fractures.

It is therefore important that injury incidence is reported for male and female recruits for all anatomical regions using standardised injury definitions and research methodology.

2.1.2 Injury location and type

The majority of injuries reported during basic training occur to the lower limbs (Hauschild et al., 2018; Molloy, Pendergrass, Lee, Chervak, et al., 2020; Schram et al., 2019; Sharma et al., 2015). Lower limb injuries have been reported as high as 75% of all injuries sustained during basic training (Hauschild et al., 2018).

Specific locations and types of lower limb injury have been investigated. Overuse, non-specific soft tissue injuries sustained at the knee or foot were most commonly reported during British Army Infantry training (Robinson et al., 2016). Similarly, a recent study of Australian Army full-time and reservist recruits reported most injuries are sustained at the lower limb (Schram et al., 2019). More specifically, the knee was the most common site for injury, followed by the ankle and the lower leg (Schram et al., 2019). Interestingly, NZDF recruits most commonly reported ankle sprains or strains (37%) followed by knee sprains or strains (16%) based on Accident Compensation Corporation data (Davidson et al., 2008). Accident reporting used in this study may be limited when reporting overuse presentations, which could explain the different patterns of injury location reported between these studies.

To better understand the extent of the injury problem (van Mechelen et al., 1992) in army recruits it is important that epidemiological studies include both the incidence and type of injuries in all body regions as well as other medical conditions (Andersen et al., 2016; International Olympic Committee et al., 2020). In this research program, injury incidence rates are reported for the whole body (Study 1), overall lower limbs (Study 3), per anatomical area (Study 1, Study 3) and include other medical conditions that present to physiotherapy such as women's health (Study 1). All types of injuries were included such as acute and overuse as well as all conditions that could affect recruit performance such as skin blisters, nail injuries and cramps.

2.1.3 Injury periodisation

Injuries appear to occur more frequently early after commencement of recruit basic training. The majority of injuries have been reported within the initial five to seven weeks of training (Coppack et al., 2011; Hall, 2017; Heller & Stammers, 2020; Jordaan & Schwellnus, 1994; Robinson et al., 2016). Peaks in injury rates may be the result of abrupt or sudden onset of training (Almeida et al., 1999; Heir, 1998; Kaufman et al., 2000) and occur during the weeks with the highest total volumes of vigorous physical activity (Almeida et al., 1999). Recruits entering training with low aerobic fitness are at increased risk of injury (Hall, 2017; Heller & Stammers, 2020; Robinson et al., 2016). Potentially, recruits with low aerobic fitness may not be conditioned appropriately to cope with the physical challenges that occur early in basic training (Hall, 2017; Heller & Stammers, 2020; Robinson et al., 2016). Reporting injury incidence per week of training will help identify recruit injury trends overtime. In addition, it is important to investigate known injury risk factors such as low aerobic fitness and previous injury at entry (Rhon, Molloy, et al., 2022; Sammito et al., 2021), as this may help explain early peaks in injury reported by recruits commencing training.

2.2 CONSEQUENCES OF MILITARY RECRUIT INJURIES

The consequences of training-related injury can be substantial for the recruit and for the military leading to significant physical, psychological, and financial costs and potentially risks discharge from the service. Consequences of training-related injuries are summarised below.

2.2.1 Injury consequences for the recruits

For the recruit, the consequences of injury during basic training can be significant. Recruits can suffer physical effects such as decrements in performance and function (Davidson et al., 2009), subsequent or recurrent injury (Fuller et al., 2006; Hamilton et al., 2011; Meeuwisse & Bahr, 2009; Molloy, Pendergrass, Lee, Chervak, et al., 2020; Toohey et al., 2018), injury chronicity and disability (Cameron et al., 2016; Davidson et al., 2009; Jones, Bovee, et al., 1993; Williams et al., 2018) and can lead to training time loss (Davidson et al., 2009; Kaufman et al., 2000).

Recruits can also experience career disruption such as backsquad (back class) and discharge (voluntary, administrative or medical) from the service (Coppack et al., 2011; Hall, 2017). In the ADF, army recruits who sustained an injury during basic training, are reported to be 10 times more likely to be discharged compared to recruits who do not sustain an injury (Pope et al., 1999). Consequently, recruits may also experience psychological consequences such as reduced morale (Gordon et al., 1986), difficulty coping and low motivation as a result of training-related injury (Pope et al., 1999). Detrimental consequences of recruit injury such as career alteration because of backsquad or attrition from the service and injury-time loss are not always reported in military recruit research and were unknown for New Zealand Army recruits. Research of injury prevention interventions which aim to reduce the consequences from recruit injury was required.

2.2.2 Injury consequences for the military

The consequences of recruit injury also have implications for the military. There can be increased demand and costs for medical provision and lost work and training days to rehabilitate injured recruits (Nye et al., 2016; Sharma et al., 2015). For instance, in the United Kingdom (UK), recruits who sustained a femoral, calcaneal, or tibial stress fracture required 116, 92 and 86 days respectively of injury rehabilitation before they could recommence basic training

(Sharma et al., 2015). More common injuries such as ankle sprain required approximately 50 days injury rehabilitation (Sharma et al., 2015). This injury rehabilitation time could lead to additional economic costs related to the provision of training as required while the recruit recovers from the injury. Such economic costs would include increased military training costs due to the alteration in instruction and supervision, and costs to cover uniforms, equipment, accommodation, wages and rations (Nye et al., 2016; Pope et al., 1999).

Consequences of basic training injury can also result in attrition of recruits due to discharge from the military with additional financial costs to replace failed recruits and effects on deployment readiness (Molloy et al., 2012; Molloy, Pendergrass, Lee, Chervak, et al., 2020; Niebuhr et al., 2008; Pope et al., 1999). The cost of acquiring and transporting a recruit to basic training in Australia historically is estimated at AUD $9000 per person based on 1995/1996 costings (Rudzki & Cunningham, 1999). Furthermore, if fewer recruits' complete training on time because of an injury, fewer move onto trade training which affects deployment readiness and operational capability in the longer term (Molloy et al., 2012; Molloy, Pendergrass, Lee, Chervak, et al., 2020).

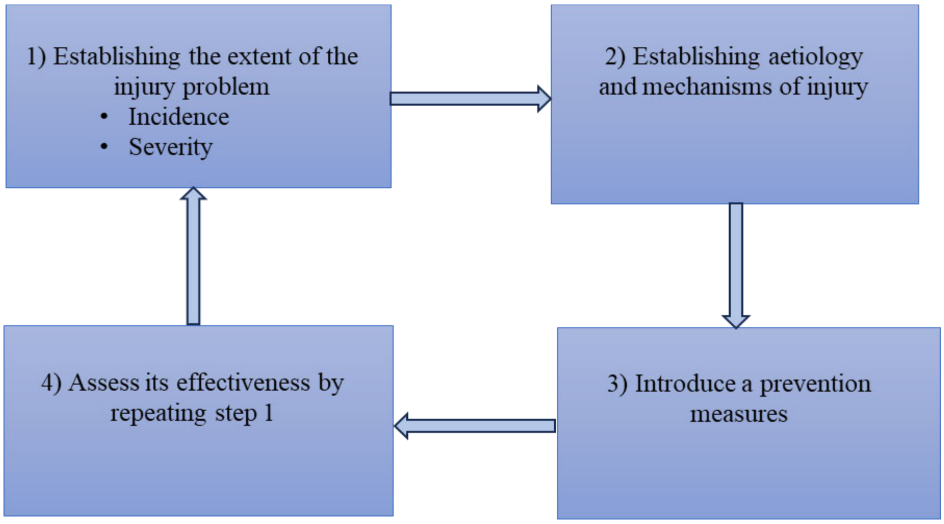
For the military, initial training-related musculoskeletal injuries have been reported to be responsible for over 80% of disability-related discharges of first-year recruits in the US Army historically (Molloy et al., 2012; Niebuhr et al., 2006). These costs are substantial rising from an estimated USD $57,500 per discharged recruit in 2005 (Molloy et al., 2012; Niebuhr et al., 2008) to an estimated USD $75,000 in 2015, while first year attrition costs approached USD $88 million over 6 years (Molloy, Pendergrass, Lee, Chervak, et al., 2020). Given the cost to replace injured recruits only rises over time, initial training-related musculoskeletal injuries present important medical and financial barriers to military capability and force readiness (Molloy, Pendergrass, Lee, Chervak, et al., 2020). Injury prevention initiatives which offer to reduce the burden of recruit injury are therefore highly desired by military organisations worldwide.

2.3 INJURY PREVENTION MODELS FOR MILITARY RECRUIT INJURIES

In order to successfully develop and implement effective recruit injury prevention measures, a systematic approach is required; therefore, it is important to consider use of a conceptual model of injury prevention (Cowan et al., 2003; Phillips, 2000). Historically, for sports populations, the four step ‘sequence of injury prevention’ model (Figure 2.1) has been used and includes, establishing the extent of the injury problem, establishing the aetiology and injury mechanisms of sports injury, introducing an injury prevention intervention and assessing its effectiveness by repeating step one (van Mechelen et al., 1992, p. 84). This model was expanded to take into account efficacy, efficiency and compliance of an injury prevention intervention (Finch, 2006). A further modification to the injury prevention model considers efficiency of stakeholders together with compliance and risk-taking behaviour of the individual (Van Tiggelen et al., 2008).

Figure 2.1

The Four-Step ‘Sequence of Injury Prevention’ Model



Note: The four-step ‘sequence of injury prevention’ model (van Mechelen et al., 1992). Reprinted by permission from Springer Nature: Sports Medicine. Incidence, Severity, Aetiology and Presentation of Sports Injuries, van Mechelen et al. 1992. Copyright 2019.

Several injury prevention models have also been proposed in military populations and some of these have been outlined in Table 2.1. While some similarities are evident across the models, all have their limitations. For example, the first model comprises a six-step evidence-based public health decision-making process for military injury prevention (Jones et al., 2010). Implementation of steps two and three include an expectation that multiple prevention studies exist to evaluate the evidence. Where there are either no or limited studies available of a prevention intervention, step three is difficult.

Table 2.1

Prevention Models

Model	Steps	
Six step evidence-based public health decision-making process (Jones et al., 2010)	1.	Identification of the biggest or most severe problems
	2.	Search evidence of effective prevention
	3.	Evaluation of quality of evidence for prevention
	4.	Recommendations based on strength and consistency of evidence
	5.	Prioritisation of interventions
	6.	Identification of gap in research
University of Pittsburgh Injury Prevention and Performance Optimisation Model (Air Assault soldiers) (Sell et al., 2010)	1.	Injury surveillance
	2.	Task and demand analysis
	3.	Predictors of injury and optimal performance
	4.	Design and validation of interventions
	5.	Program and integration and implementation
	6.	Monitor and determine effectiveness of the program
Composite Risk Management (US Army, 2006).	1.	Identify hazards
	2.	Assess hazards
	3.	Develop controls and make decisions
	4.	Implement controls
	5.	Supervise and evaluate
Seven steps for developing and implementing a preventive training program (Padua et al., 2014)	1.	Establish administrative support
	2.	Develop an interdisciplinary team
	3.	Identify logistical barriers and solutions
	4.	Develop an evidence-based preventative training program
	5.	Train the trainers and users
	6.	Fidelity control
	7.	Exit strategy

Note: Proposed models of military injury prevention adapted from (Johnson, 2007; Jones et al., 2010; Padua et al., 2014; Sell et al., 2010; US Army, 2006).

The second model by Sell et al. (2010) again uses a public health model and similarly compromises six stages. The University of Pittsburgh Injury Prevention and Performance Optimisation Model (Sell et al., 2010, p. 3) was developed specifically for use with US Army Air Assault Division soldiers and includes additional sections on performance and nutrition (Stage 3). This model relies heavily on application of multiple laboratory-based systems including use of a force platform for balance testing, the Biodex Multi-joint System Pro 3 (Biodex Medical Systems, Inc., Shirley, NY) for strength testing and a six high speed camera system for biomechanical analysis of the lower limbs (Sell et al., 2010). Logistical limitations exist with the application of this model, including the high equipment costs and the additional time and staff required for administration, assessment, and data analysis. This is a concern with time constraints associated with delivering recruit basic training programs.

The Composite Risk Management model uses five steps for US military decision-making (US Army, 2006) at the operational and strategic levels (Smith and Yaeger as cited in Johnson, 2007). This model appears more appropriate for battlefield application (Johnson, 2007) and therefore may not likely be well suited for an injury prevention process.

Finally, the seven step developing and implementing a preventative training program model has been proposed for military populations (Padua et al., 2014). This model expands on stages three and five of the Translating Research into Injury Prevention Practice (TRIPP) framework (Finch, 2006). Planning the design and implementation of a preventative measure is emphasised. Specific use of administrative support and identification of barriers and solutions to implementation prior to application of a preventative training program is highlighted to improve real-world application. The seven-step model also demands a high level of competency in trainers before implementation (Padua et al., 2014). A limitation of this model is that it assumes stage one and two of the TRIPP framework has been established.

Regardless of which model is employed, establishing the scope of an injury problem is an essential initial step in injury prevention for military recruit populations (Phillips, 2000; van Mechelen et al., 1992). For simplicity, this research program will focus on steps of the four-step 'sequence of injury prevention' model proposed by van Mechelen et al. (1992) (Figure 2.1). Further consideration of these models will ensue with the development and implementation of a recruit injury prevention intervention.

2.4 ESTABLISHING THE EXTENT OF THE RECRUIT INJURY PROBLEM

The first step in the 'sequence of injury prevention' model is to establish the extent of the injury problem (van Mechelen et al., 1992, p. 84). This is best accomplished through injury surveillance which can be defined as continuous data collection which describes the occurrence of, and important factors associated with injury (Phillips, 2000; van Mechelen et al., 1992). Describing the extent of the recruit injury problem during basic training using injury surveillance requires consideration of injury incidence and severity (Meeuwisse & Bahr, 2009; van Mechelen et al., 1992).

To ensure results of injury surveillance can be compared between different active populations and environments (sports and military), several injury surveillance characteristics require consideration. These include injury diagnosis and classification, injury definition, and methods used to quantify or count injuries and injury severity (Meeuwisse & Bahr, 2009).

2.4.1 Injury diagnosis

Factors to consider if consistent and valid information on injury diagnosis is to be gathered include the number of persons collating injury data and whether they possess a high level of anatomical knowledge and experience in diagnosis of injury (Finch et al., 2014; Phillips, 2000).

Injury diagnosis is best performed by one individual with a high level of knowledge of anatomy and pathology, such as a doctor or physiotherapist, rather than a non-clinician (epidemiologist) (Finch et al., 2014; Phillips, 2000). Using an individual recorder will help ensure accuracy and consistency in medical diagnosis and improve intra-rater reliability (Phillips, 2000).

For NZDF military recruits, diagnosis of an injury is made after initial presentation to the medical centre (or field equivalent) and consultation with a medic at triage. The injury is then followed up by a medical doctor to ensure accuracy in medical diagnosis. If the injury diagnosis is more serious, the person is referred to physiotherapy for diagnosis, assessment and treatment. Very minor injuries that require minimal management would not be referred to physiotherapy but managed through initial medical triage.

Throughout this program of research, injury diagnosis was made by relevant qualified individuals with a background in health. Collation of electronic health data was performed by the candidate to enhance consistency and improves intra-rater reliability of information captured.

2.4.2 Injury classification and coding

Ideally, injury surveillance should report injury incidence information consistently using a classification system (International Olympic Committee et al., 2020; Orchard et al., 2020; Phillips, 2000). An injury classification system compromises a set of codes for anatomical body region and site (joints and segments) along with nature and severity of injury (International Olympic Committee et al., 2020; Orchard et al., 2020; Phillips, 2000). This improves the data’s comparability to other studies and helps identify injuries unique to a sport or military population (Engebretsen & Bahr, 2009; International Olympic Committee et al., 2020; Jones et al., 2010; Phillips, 2000).

Unfortunately, no common or agreed uniform diagnostic coding system is established for military populations internationally (Molloy, Pendergrass, Lee, Hauret, et al., 2020; van Dongen et al., 2017). Even when injury (and illness) surveillance coding systems are used, different models and versions are applied across military research such as the International Classification of Diseases (ICD) (versions 9-11) (Molloy, Pendergrass, Lee, Chervak, et al., 2020) and Orchards Sports Injury and Illness Classification Systems (OSIICS) (Version 2.0 and 10.0) (Gruhn et al., 1999; Psaila & Ranson, 2017). Limitations of using complex coding systems include that the ICD may lack classifications that are important in sports injury (International Olympic Committee et al., 2020), and military populations (Stannard et al., 2022), and the OSIICS has been used in few military recruit studies to report injury incidence (Gruhn et al., 1999; Psaila & Ranson, 2017). This means current comparisons of injury surveillance using large coding systems for military recruit studies may be limited.

More often in military recruit studies, injury diagnostic coding of recruits is performed using basic body site and region categories and this is generally based on body segments and joints (Rudzki, 1997b; 2009, p. 50; Schram et al., 2019). For this program of research, diagnostic coding of recruit injury across body regions and individual sites (joints and segments) was performed.

2.4.3 Injury definition

Establishing a definition of an injury is important for consistency within the surveyed period and to be able to compare injury incidence across different military and sports populations (Engebretsen & Bahr, 2009; Phillips, 2000). Finding a universally accepted and useful definition that can be applied across the majority of active populations is difficult as differences in injury definition will be needed to address specific sports and military injury contexts (International Olympic Committee et al., 2020; Nielsen et al., 2020).

Consensus statements are emerging to provide a framework for injury reporting including consensus for injury definition (Ekegren et al., 2016; International Olympic Committee et al., 2020; Orchard et al., 2020). The International Olympic Committee (IOC) defined an injury as tissue damage or other derangement of regular physical function due to sports participation, as a result of rapid or repetitive transfer of kinetic energy in a recent consensus statement (International Olympic Committee et al., 2020, p. 3).

Another such consensus statement regarding the definition of an injury for use in football/soccer research has also been established (Fuller et al., 2006). An injury in football has been defined as 'any physical complaint sustained by a player that resulted from a football match or football training, irrespective of the need for medical attention or time-loss from football activities' (Fuller et al., 2006, p. 193).

Injuries have been further defined based on whether medical intervention is required. Those injuries requiring medical intervention are deemed a 'medical attention injury' while players who are unable to fully take part in football training or game are defined as a 'time-loss injury' (Fuller et al., 2006, p. 193). By adopting a clear definition of an injury through consensus by a group of experts, consistency and comparability of research results for future studies of general and specific injuries is potentially improved (Fuller et al., 2006; International Olympic Committee et al., 2020).

In military research, no consensus statement currently exists for compatible data collection of recruit injuries or for a common definition of injury (Bullock et al., 2023; Cowan et al., 2003; Molloy, Pendergrass, Lee, Hauret, et al., 2020; van Dongen et al., 2017). Historically, some studies develop their own definition of injury (Heir & Glomsaker, 1996; Rosendal et al., 2003). An example of a definition that has been used for military injury studies defines an injury as 'pain, inflammation or functional disorder that involved the musculoskeletal or soft tissues, was serious enough for the conscript (recruit) to seek and obtain a medical consultation, and could have occurred entirely or in part as a consequence of an external trauma or strain sustained during the period of basic training' (Heir & Glomsaker, 1996, p. 186; Rosendal et al., 2003, p. 159). This definition is referred to as a medical attention injury (Bahr et al., 2020) and was used in this program of research. Musculoskeletal injury will therefore be defined as 'any symptoms of pain, inflammation or functional disorder that: involved the musculoskeletal or soft tissues; was serious enough for the recruit to obtain a medical consultation; could have occurred entirely or in part as a consequence of an external trauma or strain sustained during basic training' (Heir & Glomsaker, 1996, p. 187) and could have included aggravation of a pre-existing injury (International Olympic Committee et al., 2020).

The effects of pre-existing or previous injuries will be discussed further in Section 2.5.1.4.

2.4.4 Injury severity

Injury severity reporting is also part of step one of the 'sequence of injury prevention' model (van Mechelen et al., 1992, p. 84). Injury severity can be described in terms of the tissue damage, injured structures or the nature of the injury (Meeuwisse & Bahr, 2009). More recently the IOC consensus statement defined injury severity according to four categories; injury time-loss, athlete's self-reported consequences, clinical context and societal or economic costs (International Olympic Committee et al., 2020). Self-reported outcomes, clinical context and economic costs are discussed in Study 3, and injury severity due to time loss will be discussed in the following paragraph.

The amount of time an individual is not able to participate in their usual training activity or competition provides a meaningful injury severity description for sports populations (Meeuwisse & Bahr, 2009, p. 9). This is often referred to as 'injury time-loss' which can be counted in sessions or days missed from participation (Fuller et al., 2006; Meeuwisse & Bahr, 2009, p. 9; Phillips, 2000). Alternatively, injury severity can be reported in categories such as mild, moderate or severe based on time lost from training. Mild injury refers to an absence of less than one-week, moderate injury as an absence greater than one week and less than one month, and major (severe) injury as an absence greater than one month (Ekstrand as cited in Wedderkopp et al., 1997, p. 343). Alternatively, moderate injury severity has been described as time loss of eight to 21 days and severe injury as greater than 21 days of time loss (Ekegren et al., 2015). Differences in the classification of injury severity time loss periods limit the ability to directly compare study findings.

For military populations, working or training time loss can be described as the amount of time in days spent on light or limited duties due to injury (Rosendal et al., 2003). Other terms used to describe injury severity in military populations have included restriction days (limited duties days), hospitalisation days and days not fit for duty (Rudzki, 1997b). Limited duty or light duties days reporting have been quantified as: 'one or more days of limited duties' (Robinson et al., 2016; Rosendal et al., 2003, p. 159); days/injury (Knapik et al., 1993; Potter et al., 2002); and days/1000 soldiers/month (British Army medical directorate as cited in Rudzki, 2009, p. 31). A limitation of military injury severity time-loss reporting is that there is no set definition of severity, limiting comparability of results across military studies (Cowan et al., 2003; van Dongen et al., 2017). Caution is also required interpreting injury time-loss severity measures because the demarcation between time-loss or light duties completion and return to normal function is not always clear (International Olympic Committee et al., 2020, p. 11). Additionally, injury time-loss measures could be inappropriate in severe injury cases where permanent disability or even death occur (International Olympic Committee et al., 2020). For this program of research, injury severity was reported based on the number of recruits issued light duties and the number of light duties days for injury sustained during training.

2.4.5 Injury rate and exposure time

A number of terms have been applied to report injury rates in sports and military populations. In sports populations, cumulative incidence of injuries indicates the number of injuries among a specific group of athletes followed for a specified period (Ekegren et al., 2016; Patel & Baker, 2006; Patel et al., 2017, p. 161). Cumulative incidence indicates an individual's risk of injury; while the incidence of first injury is an indicator of any one athlete being injured (Ekegren et al., 2016; Patel & Baker, 2006; Patel et al., 2017, p. 161).

Athlete-exposure time may be considered a more accurate measure to define an injury (Patel et al., 2017, p. 161; Phillips, 2000). Athlete-exposure is defined as one athlete participating in one practice or game (hours or sessions), in which there is a chance of sustaining an injury (Patel et al., 2017, p. 161). It can be reported as rate per 1000 athlete-exposures which allows injury risk comparisons to different sports and active populations (Meeuwisse & Bahr, 2009; Patel et al., 2017; Phillips, 2000).

Other commonly used injury incidence terms described in sports injury research include prevalence and clinical incidence (Knowles et al., 2006; Rothman & Greenland, 1998). Prevalence is the proportion of the population who have a disease (or injury) at a specific time (Knowles et al., 2006, p. 208; Rothman & Greenland, 1998), whereas clinical incidence can be referred to as the occurrence of sports injury per athlete, defined as the number of incidence injuries divided by the total number of athletes at risk (Knowles et al., 2006, p. 208). Clinical incidence can be used as an indicator of clinical utilisation (Knowles et al., 2006).

Across military research injury rates have been calculated in different ways including: injuries/1000 recruits (Rudzki, 1997b; Rudzki & Cunningham, 1999), injuries/1000 recruit days (Rosendal et al., 2003), injuries/100 recruits/week (Jordaan & Schwellnus, 1994), injuries/100 or 1000 recruit months (Heir & Glomsaker, 1996) and percentage of recruits injured (Jordaan & Schwellnus, 1994). In military population research, injury incidence rates (injuries/1000 person-days) have been calculated as: recruits with one or more injuries/total time in company for all recruits × 1000 (Knapik et al., 2011, p. 498). Whereas, cumulative injury incidence has been calculated as: recruits with one or more injuries/all recruits × 100% (Knapik et al., 2011, p. 498).

Another consideration when investigating injury rates in military recruits is the training regime basic recruits undergo. In the military, recruits are training night and day, and for the first month may not be allowed to leave basic training. To account for this training load, it could be suggested that athlete-exposure rate should be calculated based on the entire time recruits are on basic training and reported in hours of exposure. For example, if 473 injuries were reported for 14 weeks (14 weeks x 7 days x 24 hours per day = 2352 hours) training, calculating recruit (athlete) exposure would include:

Athlete (recruit) exposure rate = 473 injuries/2352 hrs *1000 = 2.01 (injury per 1000hrs)

Alternatively, if 473 injuries were reported across 17 weeks (2856 hours) basic training, calculating recruit exposure would include:

Athlete (recruit) exposure rate = 473 injuries/2856hrs *1000 = 1.66 (injury per 1000 hrs)

Considering exposure time in military studies, recruit injury incidence rates are higher than that of trained soldiers. For instance, British Army Infantry recruits (untrained soldiers) injury incidence was reported at a rate of 3.5 recruits/1000 person-days and new injury diagnosis rate at 5.9 injuries/1000 person-days (Robinson et al., 2016, p. 4). Similarly, injury incidence was reported at a rate of 4.1 recruits/1000 person-days with Norwegian infantry recruits (Heir & Eide, 1997), and US basic combat training recruits reported injury incidence of 5.6 recruits/1000 person-days (Knapik et al., 2001). In comparison, British Army Infantry soldiers (trained personnel) reported less than half the injury incidence rate at 1.6 recruits/1000 person-days and new injury diagnosis as 2.4 recruits/1000 person-days when compared to British Army

Infantry recruit rates (Robinson et al., 2016; Wilkinson et al., 2014). Reasons for the higher exposure time rates in recruits could be due to the intensity of infantry recruit training, lack of specific military training experience and potentially lower levels of physical fitness compared to trained soldiers (Davidson et al., 2008; Robinson et al., 2016). Caution is required interpreting exposure time as it assumes recruit injury exposure remains constant per unit of time (International Olympic Committee et al., 2020). Varying levels of injury exposure exist across recruit basic training. For instance, injury exposure risk is likely to be higher in the weeks with sudden increases in training and high volumes of vigorous physical training (Almeida et al., 1999). For this program of research, calculation of recruit injury per 1000 person-days will be reported.

2.4.6 Injury reoccurrence and subsequent injury

Injuries are not always isolated events, and some injuries are considered to be recurrent (Fuller et al., 2006, p. 84; Meeuwisse & Bahr, 2009), secondary (Knowles et al., 2006, p. 209) or subsequent (Toohey et al., 2018, p. 2200). Historically, recurrent injuries were further classified into exacerbations and re-injuries (Fuller et al., 2006; Meeuwisse & Bahr, 2009). Exacerbations are not counted as new injuries, but rather time lost to injury should be attributed to the first or initial injury. Alternatively, re-injuries are counted separately with their own time loss (Fuller et al., 2006; Meeuwisse & Bahr, 2009). A high rate of recurrent injuries could help identify if return to sport or basic training has occurred too early or if the rehabilitation of an injury was adequate (Meeuwisse & Bahr, 2009, p. 9).

More recently, accounting for a subsequent injury in sports injury epidemiology has been proposed. A subsequent injury is described as any injury following an initial (index) injury, that can considerably burden individual athletes and sporting organisations (Brooks et al., 2006; Ekstrand et al., 2011; Finch & Cook, 2014; Toohey et al., 2018, p. 2200). The subsequent injury categorisation (SIC-2.0) model has been developed to provide a framework for accuracy categorising subsequent injuries (Toohey et al., 2018).

Consideration of subsequent injuries reporting (Hamilton et al., 2011; Toohey & Drew, 2020; Toohey et al., 2018) for reoccurring and pre-existing injury in army recruit populations is challenging. This terminology continues to evolve (Toohey & Drew, 2020), and it is not possible to retrospectively retrieve this information for this program of research. Establishing subsequent injury terminology effectively in recruit populations will require prospective research which clearly defines subsequent injury categories to ensure accuracy in injury data collection in the future.

Subsequent injury reporting may still be important for recruits entering basic training with pre-existing injury. For instance, recruits who sustain an ankle sprain prior to basic training may be at greater risk of a subsequent injury during training and, if serious enough, could result in backsquad or even discharge from the service (Robinson et al., 2016). Therefore, establishing prior recruit injury history and potentially risk of subsequent injury during training is explored in Study 2 using four questions in a self-reported questionnaire.

2.4.7 Physiotherapy presentations to report injury incidence

Physiotherapists are well placed to conduct injury surveillance as they routinely provide point of care contact for military populations (Pope & Orr, 2017). In addition, physiotherapists possess a high level of knowledge of anatomy and pathology, which is essential for accuracy in injury diagnosis (Finch et al., 2014). Physiotherapy-based injury surveillance has previously been used to report injury incidence rates of military recruits (Heagerty & Sharma, 2018; Heagerty et al., 2018; Heagerty et al., 2017a, 2017b; Heagerty et al., 2017c; Rudzki & Cunningham, 1999; Sharma et al., 2017; Sharma et al., 2015), trained personnel (Gruhn et al., 1999; Hebert & Rowe, 2007) and Brazilian military school students (Melloni & Coimbra, 2014). These surveillance studies are however limited to one year duration in Australian Army recruits (Rudzki & Cunningham, 1999), are based predominantly on male UK infantry recruits (Heagerty & Sharma, 2018; Heagerty et al., 2017b; Heagerty et al., 2017c; Sharma et al., 2015), or represent trained or deployed military populations (Gruhn et al., 1999; Hebert & Rowe, 2007). Two studies are also more than two decades old (Gruhn et al., 1999; Rudzki & Cunningham, 1999). This suggests contemporary recruit entry requirements and training regimes may not be represented. Research investigating male and female recruit injury incidence using physiotherapy-based injury surveillance is required for periods exceeding 12 months.

Physiotherapy-based injury surveillance provides scope to the recruit injury problem and lays the foundation for the future development and implementation of targeted interventions for the prevention of recruit injury (Meeuwisse & Bahr, 2009; van Mechelen et al., 1992, p. 84). Further analysis of physiotherapy-based recruit injury surveillance with New Zealand Army recruits is presented in Study 1.

Summary establishing the extent of the recruit injury problem

Establishing the extent of the recruit injury problem (van Mechelen et al., 1992) for New Zealand Army recruits requires injury diagnosis to be made by a single recorder with a high degree of knowledge in anatomy and pathology, which was a physiotherapist (candidate) for Study 1. For this program of research, the same medical attention injury was used throughout and includes exacerbation of previous injury, which can describe subsequent injury. Injury incidence will be categorised according to body region and sites. Injury severity is defined as recruits requiring light duties and days of light duties for injuries sustained training. Calculation of injury incidence rates and exposure time is reported based on those established from previous military recruit studies.

2.5 INJURY AETIOLOGY AND MECHANISM OF INJURY

The second step in the 'sequence of injury prevention' model is to establish aetiology and mechanisms of injury (Figure 2.1) (van Mechelen et al., 1992, p. 84). This step requires consideration of intrinsic and extrinsic injury risk factors for military training recruits.

Aetiological factors in sports injury are defined as those factors that result in a change to the incidence, prevalence, duration and possible seriousness of the sports injury problem if manipulated under controlled circumstances (Bouter, Van Dongen et al., 1993 as cited in van Mechelen, 1997; van Mechelen et al., 1992).

Establishing the aetiology of recruit injury requires consideration of intrinsic and extrinsic injury risk factors and consideration of whether these factors are modifiable and non-modifiable (Meeuwisse & Bahr, 2009). Modifiable risk factors can be potentially changed, eliminated, or modified to reduce recruit injury (Cowan et al., 2003; Meeuwisse & Bahr, 2009) while non-modifiable cannot be controlled by the individual and are unlikely to significantly change just before or during basic training (Abbott et al., 2023). Consideration of aetiological risk factors are important because they impact on the potential risk of injury for military recruits undertaking basic training, and measures could be taken to mitigate these risks.

2.5.1 Intrinsic risk factors

Intrinsic risk factors are defined as within or internal to the body and often refer to individual characteristics such as weight, height, age, sex, smoking status and physical fitness (Meeuwisse & Bahr, 2009). Intrinsic risk factors can work independently or can interact to predispose recruits to injury (Cowan et al., 2003). Several modifiable and non-modifiable intrinsic risk factors for injury have been identified in research of military basic training recruits and these are summarised in Table 2.2. Recruit intrinsic risk factors will be expanded further in the following sections.

Table 2.2

Intrinsic Modifiable and Non-Modifiable Recruit Injury Risk Factors at Week 1 of training

Modifiable	**Non-modifiable**
Physical characteristics	**Personal characteristics**
Low physical fitness on entry	Older Age
Reduced cardiorespiratory fitness	Female Sex
Reduced muscular endurance	Previous injury (unresolved)
Reduced strength	
High/low flexibility	
Body composition: BMI, low body mass	**Anatomical**
Reduced dynamic lower limb stability	High arches
Reduced/altered ankle range of motion	Increased quadriceps angle
	Increased genu valgus
Behavioural/lifestyle	Short stature
Diet/nutrition	
Smoking	**Physical characteristics**
Alcohol	Low physical activity prior to entry
Sleep	
Non-reporting/conceal injury	

Note: Data for intrinsic risk factors in (Cowan et al., 2003, p. 200; Jones & Knapik, 1999, p. 116; Miller et al., 2008; Robinson et al., 2016).

2.5.1.1 **Age.**

Age has been identified as an intrinsic injury risk factor for military recruits; however, the data are inconsistent (Cowan et al., 2003). Recruits of older age are generally associated with increased risk of injury during basic training (Cowan et al., 2011; Jones, Cowan, et al., 1993; Knapik et al., 2013a), with the trend of increasing risk with increasing age (Jones, Cowan, et al., 1993). Recruits aged 20 to 24 years are 30% more likely to have overuse injury compared to recruits aged 19 years or less undertaking basic training (Cowan et al., 2011).

This risk increases up to 55% with recruits aged 25 years or older more likely to experience overuse injuries (Cowan et al., 2011). Additionally, being more than 25 years old has been associated with higher risk of injury during training in both male and female military police recruits (Knapik et al., 2013a), while male recruits aged 25-30 years were also associated with increased risk of injury in US basic combat engineer recruit training (Knapik et al., 2013b). Alternatively, a younger age has been associated with increased risk of injury in young male infantry soldiers in Alaska (Knapik et al., 1993) and increased risk of attrition in recruits (Knapik, Jones, et al., 2004). One proposed reason for the greater injury risk for younger infantry soldiers observed could be due to a greater exposure to injury risk compared to older staff who may be more sedentary in higher rank positions and therefore at less risk of injury.

Age as a risk factor for injury may also be influenced by other injury risk factors such as sex, physical fitness, smoking history, and many others. Age remains part of a complex set of issues associated with risk of injury during basic training (Cowan et al., 2003).

To be eligible for entry to the New Zealand Army, recruits need to be physically and medically fit, a citizen of New Zealand or hold a New Zealand residency visa, free of criminal convictions and at least 17 years of age (New Zealand Defence Force: Defence Careers, 2019a). There appears to be no policy or restriction for entry to basic training in New Zealand based on maximum age. Age is therefore considered a non-modifiable recruit intrinsic risk factor.

2.5.1.2 **Female sex.**

Female sex is often reported as an injury risk factor during basic training across military research (Cowan et al., 2003). Female recruits have historically been reported to be more than twice as likely to be injured as male basic combat training recruits in the US Army (Knapik et al., 2001). A recent meta-analysis reporting incidence rates of recruits across multiple militaries and countries supports the finding of higher injury incidence in female compared to males recruits during training (RR = 2.10, 95% CI 1.89-2.33) (Schram, Canetti, et al., 2022). Additionally, female recruits have been shown to be at greater risk of stress fracture (Jones, Bovee, et al., 1993; Knapik et al., 2012; Shaffer et al., 2006). Stress fracture rates of 8% have been reported for females compared to only 1.9% of males in a large study of over 580, 000 US recruits over an 11-year study period (Knapik et al., 2012). Similarly, stress fracture rates for female recruits were 1.5 to five times higher than male recruits undertaking similar training (Shaffer et al., 2006).

Increased injury risk in female recruits is also associated with slow run times and a history of menstrual irregularity. A significant association has been observed between stress fracture incidence, a slow 1.5-mile run time (>14.4 min), absence of menses for six or more consecutive months over the last year, and less than seven months of lower-extremity weight training in female US Marine Corps recruits (Rauh et al., 2006). Similarly, female US Army Military Police recruits who went at least six months without a menstrual cycle in the previous year or had a history of pregnancy were found to be at higher risk of injury (Knapik et al., 2013a).

Even within female recruits' differences are apparent. Short female recruits were significantly more likely to be injured than tall female recruits (Relative Risk (RR) = 1.7; 90% CI: 1.2 to 2.4; p = 0.02) (Jones, Bovee, et al., 1993, p. 707). Body mass index also appears to influence injury risk in female recruits. Those female recruits with high or low BMI were at greater risk of injury than females with average scores (median 22.5 kg/m2 range 18-27 kg/m2) BMI (Jones, Bovee, et al., 1993).

One suggested reason for sex differences in injury reporting may be because in most instances, females entering training are less fit than their male counterparts (Blacker et al., 2009; Jones, Bovee, et al., 1993; Schram, Orr, et al., 2022; Shaffer et al., 2006). When the level of fitness of female recruits was controlled for on entry to training, no significant difference in risk of injury was observed between US male and female recruits (Bell et al., 2000; Jones et al., 1992) and also between US male and female soldiers from Army Light Infantry Brigades (Anderson et al., 2017). Interestingly, an inverse association was observed with female UK Royal Air Force recruits who reported 40% lower injury risk than males when controlling for physical fitness (Fallowfield et al., 2018). Possibly, these differences could be explained due to inclusion of trained (Anderson et al., 2017) versus untrained participants (Bell et al., 2000; Jones et al., 1992) or different military services for example army (Bell et al., 2000; Jones et al., 1992) versus the Royal Air Force (Fallowfield et al., 2018). Regardless, it is likely that recruits with lower cardiovascular fitness and lower musculoskeletal strength may experience greater physical and physiological strain for training activities (Fallowfield et al., 2018). These findings suggest risk of recruit injury may be related to low aerobic fitness at entry, rather than sex (Fallowfield et al., 2018).

The higher incidence of injury in female recruits or soldiers could also be explained by injury reporting behaviour. Compared to male recruits, female recruits are more likely to report an injury which could influence injury rates recorded (Cohen et al., 2019; Schram, Canetti, et al., 2022).

Another reason for the higher incidence of injury observed in female recruits may be explained due to altered hormone status. Decreased bone mineral density secondary to hypoestrogenemia has been suggested as a reason for higher risk of stress fractures observed in female recruits during basic training (Shaffer et al., 2006). Hormonal status and risk of injury will not be investigated in this program of research.

2.5.1.3 **Physical fitness level at entry.**

Low levels of physical fitness have been considered a recruit injury risk factor across military research. Reported health-related measures of low physical fitness may include cardiorespiratory endurance, muscle endurance, strength, and flexibility (Caspersen et al., 1985; Cowan et al., 2003; Jones & Knapik, 1999). Measurement of body composition will also be discussed. While not all factors are equal or consistently reported in association with recruit injury, some factors will have a greater association with recruit injury risk than others (Cowan et al., 2003).

2.5.1.3.1 Cardiorespiratory endurance.

Cardiorespiratory endurance of military recruits is often associated with maximal effort running performance (Jones & Knapik, 1999, pp. 117-118). Maximal effort running performance is often taken from results of military fitness tests which can vary in distance, though usually from 1.5 to two miles (2.4 to 3.2 km) (Jones & Knapik, 1999; Robinson et al., 2016). A trend of an increasing risk of injury is associated with slower run time and low cardiovascular fitness in both males and female recruits (Hall, 2017; Heller & Stammers, 2020; Jones et al., 2017; Jones & Knapik, 1999).

Endurance measured by timed run has been reported as one of the best predictors of injury risk in recruits commencing training (Cowan et al., 2003; Molloy, Pendergrass, Lee, Chervak, et al., 2020). Male and female recruits who had faster running times had lower injury risk than recruits who had slower run times during basic training (Jones et al., 1992; Jones et al., 2017). Faster run times in female recruits have also been associated with fewer stress fractures (Jones, Bovee, et al., 1993; Rauh et al., 2006). A significant association has also been observed between a slow 1.5-mile run time (>14.4 min) and stress fracture incidence in female marine corps recruits (Rauh et al., 2006).

Timed running performance (over 1.5 mile) has been described as a surrogate measure of aerobic fitness in British Army recruits (Hall, 2017; Heller & Stammers, 2020). Slow run times (>13 min 20 sec) predicted musculoskeletal injury risk in UK female recruits (χ^2 (1) = 12.91, p < 0.0005) (Heller & Stammers, 2020). While male recruits with the slowest run times (>16 min) were more likely to sustain a musculoskeletal injury compared to recruits with the fastest run times (6 min to 7 min) (χ^2 (1) = 59.3, p < 0.001) (Hall, 2017). In British Army female recruits, injury-free recruits ran faster (12 min 13 sec) compared to injured recruits (12 min 43 sec) and for every additional increase of 10 seconds, there was an 8.3% increased risk of injury (Heller & Stammers, 2020). Similarly, in a study of over 187,000 US trainees Jones et al. (2017) found as run time slowed, the risk of injury increased from 26.5% to 56.0% in females ($RR_{slowest/highest}$, χ^2 p < 0.001) and 9.8% to 24.3% in male recruits ($RR_{slowest/highest}$, χ^2 trend, p < 0.001). In addition to predicting musculoskeletal injury, slow run times also predicted attrition from initial basic training (phase one) in a study of over 3,000 British Army male recruits (χ^2(1) = 66.87, p < 0.001) (Hall, 2017).

Low aerobic capacity has also been independently associated with high risk of injury in men and women during standardised basic combat training in the US (Knapik et al., 2001). An explanation could be that recruits who have low aerobic capacity may experience greater physiological strain relative to their maximum capacity at any given absolute level of function (Knapik et al., 2001), potentially leading to a higher risk of injury (Jones & Knapik, 1999).

Despite previous investigations identifying an association between recruit run time and injury risk, pass time standards appear to differ between militaries in different countries. Furthermore, comparison is often difficult across militaries and countries due to sex and age different standards employed as minimum requirements. For instance, a pass standard for New Zealand Army female recruits aged 16 to 24 years is 12 minutes, 20 seconds (10.1 Appendix A), while 12 minutes and 30 seconds is reported for UK female recruits (Heller & Stammers, 2020), and

13 minutes and 30 seconds is required in the Australian Army (aged 17-25 years) (Defence Jobs, 2023). Cardiorespiratory endurance needs to be measured to investigate injury risk in New Zealand Army recruits, due to the specific contextual requirements.

2.5.1.3.2 Muscle endurance.

Muscular endurance is described as the ability of a muscle or muscle groups to perform repeated contractions against a resistance over time (Coulson & Archer, 2009, p. 138). Resistance can be applied using body weight (press ups and sit ups) or free weights and resistance machines (Coulson & Archer, 2009). Press ups and sit ups have been used to measure muscle endurance as these tests form part of regular fitness testing and may be convenient for mass screening of military populations (Jones et al., 2017; Jones & Knapik, 1999).

Higher injury risk has been observed with lower push up performance in male army infantry recruits (lowest 20%, push ups < 16) (Jones, Cowan, et al., 1993), male army recruits (lowest 3 quartiles, push ups < 36) (Jones, Bovee, et al., 1993), male only air force basic military training recruits (push ups 0-28) (Knapik et al., 2010), and male (push ups < 31) and female (female push ups < 13) army basic combat training recruits (Knapik et al., 2001). These findings are supported in a systematic review reporting a strong association of poor maximum 2-minute push up performance and risk of musculoskeletal injury in military and civilian males (1.2 to 3.2 times the risk) (de la Motte et al., 2017).

Alternatively, no association with injury risk and push up performance was reported among female army recruits (Jones, Bovee, et al., 1993) and female air force recruits in the US (Knapik et al., 2010). Furthermore, a recent systematic review suggests limited evidence supporting push up performance as a risk factor for musculoskeletal in military female populations (de la Motte et al., 2017). Potentially different findings for an association between injury incidence and push up performance may be because push ups do not reflect common tasks performed by recruits such running and marching, which require less upper body (Jones et al., 2017).

The association between sit up performance and risk of injury appears to follow a similar pattern as push up performance. Lower sit up performance was associated with higher injury among male air force recruits (sit ups 0-30) (Knapik et al., 2010). No association between sit up performance and risk of injury was found for female air force recruits (sit ups 0-19) (Knapik et al., 2010) or army recruits (sit ups 0 to 17) (Jones, Bovee, et al., 1993). Additionally, sit up performance has been measured as maximum number in one minute (Knapik et al., 2010) or two minutes (Jones, Bovee, et al., 1993).

The association between muscular endurance using push ups and sit ups does not appear to be as strongly and consistently associated with risk of injury as measures of aerobic fitness (Jones et al., 2017). Therefore, testing upper limb and abdominal endurance using push ups and sit ups were not included in this program of research.

2.5.1.3.3 Strength.

The relationship between strength and injury risk in military recruits is not clear. Dynamic lifting strength (maximum weight lifted from the floor above the head) measured using an incremental weights machine was not associated with injury in infantry male recruits (Jones, Cowan, et al., 1993). Conversely, a maximal, one repetition maximum leg press test for strength using a universal gym station was found to predict injury in male military basic training recruits (Hoffman et al., 1999). Recruits who performed at one standard deviation lower than the population mean in absolute and relative strength were five times more likely to sustain a stress fracture injury compared to stronger recruits (Hoffman et al., 1999). Similarly, women who reported to have participated in weight training in the seven or more months prior to basic training were less likely to suffer stress fracture, however these results were not found with non-stress fracture overuse injury (Rauh et al., 2006).

A limitation of these strength-based studies investigating injury risk with military recruits is wide variation of strength measures used. Some studies include equipment (Hoffman et al., 1999) while others use history of strength training in self-reported questionnaire (Rauh et al., 2006) which limits comparison of findings. In addition, strength testing large groups of recruits presents issues relating to time, space and access to equipment and testing must integrate into the recruit training schedule in Week 1 (Jones et al., 2017; Sefton et al., 2016). Strength testing is not routinely performed with New Zealand Army recruits and absence of essential strength equipment for testing large groups meant it was not included in this program of research.

2.5.1.3.4 Flexibility.

Flexibility measures investigating injury risk in recruit populations predominantly include hamstring length and ankle dorsiflexion range of motion measures (de la Motte, Lisman, et al., 2019). Hamstring length has been performed using sit and reach tests with military recruits (Bell et al., 2000; Jones, Cowan, et al., 1993; Knapik et al., 2001). Ankle dorsiflexion range of motion which can measure aspects of gastrocnemius and soleus muscle length (Pope et al., 1998) has been measured using various methods and will be discussed further in Section 2.5.1.9.

Male US Infantry basic training recruits with both low and high levels of flexibility are reported to be at greater risk of injury (Jones, Cowan, et al., 1993). Performing a sit and reach test for back and hamstrings length, male recruits with high and low flexibility had more than two times the risk of injury (RR = 2.5 and 2.2, respectively) compared to recruits with average flexibility (Jones, Cowan, et al., 1993). Similarly, Knapik et al. (2001) found male recruits with both high and low hamstring flexibility using the sit and reach test had a higher likelihood of injury during training. However, hamstring flexibility was not associated with injury in female recruits and an explanation for this difference was not clear.

In contrast, a randomised controlled trial of pre-exercise warm up stretching (static stretching) performed to six major lower limb muscle groups to improve musculotendinous compliance (flexibility) compared to no stretching in Australian Army male infantry recruits did not result in clinically meaningful reductions in recruit injury (Pope et al., 2000). The authors reported that as stretching took 5 minutes per exercise, approximately 260 hours would be required to prevent one injury.

While poor flexibility is typically regarded as a risk factor for injury, and stretching is often considered as an injury prevention intervention, evidence supporting muscular flexibility and risk of injury in sports and military recruit populations is equivocal (de la Motte, Lisman, et al., 2019) or insufficient for military populations (Bulzacchelli et al., 2014; Sammito et al., 2021). Measuring the flexibility of common major lower limb muscle groups such as hamstrings, hip flexors, hip adductors and quadriceps is important, however requires extra time, staff and space to execute for individual recruits and to measure right and left limbs. Measuring the length of common lower limb muscle groups for each recruit was not feasible for this program of research due to additional equipment and staff resources required for testing and was not undertaken.

2.5.1.3.5 Body composition.

Associations between recruit injury risk and body composition measures such as BMI, skin fold thickness and circumference measures have been reported in military research (Harty et al., 2022; Jones & Knapik, 1999; Sammito et al., 2021). Modern digital measures of body composition including bioelectrical impedance analysis and/or 3-dimensional optical scanners are available and have been used to measure body fat percentage and possible risk of injury

(Harty et al., 2022). A detailed overview of body composition measurement tools is beyond the scope of this thesis.

Body mass index is an indirect measure for body composition in adults (Coulson & Archer, 2009). Body mass index is defined as a person's 'weight in kilograms divided by the square of the person's height in metres' (kg/m^2) (World Health Organisation, 2019). Advantages of measuring BMI is that it is low cost and quickly administered following height and weight measurements. Limitations exist with the use of BMI as there is no discrimination between lean or fat mass in its calculation, and therefore may not be applicable across all populations for an index of fatness or as an indication of physical fitness (Coulson & Archer, 2009).

Body mass index is often used as a surrogate measure of body composition in military studies (Jones & Knapik, 1999) with some evidence supporting an association with injury risk. A systematic review of injury risk in military populations suggests that there is strong evidence for obesity (BMI ≥ 30 kg/m^2), strong scientific evidence for being overweight (BMI ≥ 25 and < 30 kg/m^2), and strong scientific evidence for being underweight (BMI < 18.5 kg/m^2) as modifiable risk factors for musculoskeletal injury in military populations (Sammito et al., 2021).

A bimodal association of high injury risk to high or low BMI was also found with male and female recruits compared to those of average BMI undertaking training (Jones, Bovee, et al., 1993; Jones et al., 2017). More specifically, men in the highest (>28.7 kg/m^2) and lowest quartiles (< 22.1 kg/m^2) for BMI were 2.8 times and 2.3 times respectively at risk of injury (Jones, Bovee, et al., 1993). Similarly, Jones et al. (2017) found the highest risk of injury was observed with male and female US basic combat training recruits with the lowest BMI scores (< 21.7 kg/m^2 and < 20.7 kg/m^2 respectively).

Body fat percentage based on skin fold thickness and circumference measures have historically been used to report body composition. A high percentage of body fat (>24.4%) appears to be a risk factor for injury in men but not in women based on skin-fold measurement (Jones, Bovee, et al., 1993) and body fat percentage based on waist and neck circumference did not consistently predict risk of injury in male US Army Infantry basic training recruits (Jones, Cowan, et al., 1993). Waist measure circumference greater than or equal to 102 cm predicted injury in male Finnish conscripts, however this outcome was limited to any overuse and severe overuse injury (Taanila et al., 2015). More recently, a large study of more than half a million participants over an 11-year period found a relationship between lower percentage of body fat and high risk of stress fracture in US Army basic training recruits (Knapik et al., 2018).

Evidence exists for the use of body composition measures and injury risk in recruit populations. As height and weight are routinely collected in recruit populations at entry medicals, BMI is the most time and resource efficient body composition measure to be included in this program of research. Future research could investigate body composition using more traditional measures such as skin callipers and circumference tape measurement methods or consider modern digital anthropometric measures such as bioelectrical impedance analysis and/or 3-dimentsional optical scanners to calculate body fat percentage and possible risk of injury incidence in military recruits (Harty, Friedl 2022).

2.5.1.4 **Previous injury.**

A history of previous injury is another recruit injury risk factor reported in the literature. British Army Infantry recruits with a past history of injury were at high risk of injury during basic training (Robinson et al., 2016). Specifically, a significant association was observed between recruits' self-reported injury over the last 12 months which prevented exercise participation or sport for more than a week, and any injury during training (Hazard Ratio 1.19, 95% CI 1.01 to 1.39) (Robinson et al., 2016, p. 5). In addition, previous shin pain was independently associated with any injury (Hazard Ratio 1.21, 95% CI 1.01 to 1.46) and time-loss due to injury (Hazard Ratio 1.55, 95% CI 1.24 to 1.95) (Robinson et al., 2016). Another two studies found male recruits who reported a prior injury that had restricted training for more than one week or had 'not totally recovered' were at greater risk of injury compared to recruits who had 'totally recovered' (Knapik et al., 2013a, 2013b).

Presence of a pre-existing injury is potentially a non-modifiable intrinsic risk factor at entry to basic training. Ideally, medical screening of recruits prior to entry should address this issue. Currently, it is unknown how many New Zealand Army recruits present for basic training with a history of previous injury and go on to experience a subsequent injury during training. An investigation into the self-reported injury history of recruits presenting to basic training was required to better understand this recruit injury risk factor and is presented in Study 2.

2.5.1.5 **History of smoking.**

Cigarette smoking appears to be a strong risk factor for injury in military recruit populations (Cowan et al., 2003). Recruits who smoke more than 10 cigarettes per day were approximately 50% more likely to sustain a training injury than non-smokers in a population of US Infantry recruits (Jones, Cowan, et al., 1993). Smoking more than 100 cigarettes in the past was an independent risk factor for both male US Army Combat Engineer recruits (Hazard Ratio 1.17 95% CI 1.01 to 1.35) (Knapik et al., 2013b) and male and female US Army Military Police recruits (Hazard Ratio 1.37, 95% CI 1.17 to 1.61) (Knapik et al., 2013a). In addition, male recruits who commenced smoking early in life and who had also smoked more than 20 cigarettes in the 30 days before basic combat training (Hazard Ratio 1.45, 95% CI 1.19 to 1.77) were at higher risk of injury with a dose-response relationship (Knapik et al., 2013a). Overall, it appears that the more a recruit smokes, the greater the risk of injury (Knapik et al., 2013a).

Smoking is potentially a modifiable recruit injury risk factor; however, the detrimental effects of smoking on injury can persist even several weeks after smoking cessation (Altarac et al., 2000). Given the burden of injuries experienced by recruits with a history of smoking reported in the literature, it is imperative that the smoking status of New Zealand Army recruits is investigated, as modifying this risk factor could improve injury outcomes for recruits during training. The pre-entry smoking habits of New Zealand Army recruits was previously unknown; therefore, pre-entry smoking history of army recruits will be recorded and association with injury risk in New Zealand Army recruits undertaking basic training will be investigated in Study 4.

2.5.1.6 **Alcohol.**

Few studies have investigated alcohol consumption and incidence of musculoskeletal injury in recruits. No association was found in a study of male and female recruits regarding injury and alcohol consumption in the year before entering the army (Henderson et al., 2000). In contrast, female army recruits who had an excessive alcohol intake, that is, consumed greater than 10 drinks per week were more susceptible to stress fractures than those consuming less than 10 drinks per week based on self-reported questionnaire reporting pre-entry drinking habits (Lappe et al., 2001, p. 35). This risk was still present when controlled for by age, bone density, for race and also smoking status (Lappe et al., 2001). Drunkenness at least once per week before entry to basic training was also associated with overuse injury in Finnish conscripts (Taanila et al., 2015).

Wide variation exists with questionnaires and methods used to gather information on alcohol consumption and risk for recruit injury. Questionnaires tend to report pre-entry alcohol consumption because typically recruits do not have access to alcohol whilst undertaking training. The association between pre-entry alcohol consumption and injury risk during recruit basic training is unclear across research and unknown in New Zealand Army recruits. The pre-entry alcohol habits of recruits in this program of research are investigated using a self-reported questionnaire at entry to training (Study 2).

2.5.1.7 **Diet.**

Diet or nutritional habits of recruits prior to basic training and the association to risk of future injury is less clear (Robinson et al., 2010). It has been speculated that women who are vegetarian or avoid meat in their diet may affect their iron and zinc levels (Bergman & Miller, 2001). These nutrients may be linked to overuse type injuries (Bergman & Miller, 2001; Cordova & Alvarez-Mon, 1995). One study investigating 8570 Indian Army recruits found an increased risk of stress fracture with recruits consuming a vegetarian compared to non-vegetarian diet (Dash & Kushwaha, 2012). Although, a recent systematic review has reported that the scientific evidence is weak for an association of vegetarian diet and risk of injury in military populations (Sammito et al., 2021). Nutritional habits of New Zealand Army recruits are currently unknown; therefore, pre-entry nutritional habits are investigated using a self-reported questionnaire in Study 2.

2.5.1.8 **Lower limb dynamic stability.**

Reduced lower limb dynamic stability (balance or control) is reported as a risk factor for injury in sports populations (Butler et al., 2013; Gonell et al., 2015; Plisky et al., 2006; Steffen et al., 2013).

Few studies have investigated dynamic stability of the lower limbs and risk of injury for military and recruit populations. US active service military personnel were suggested to be at risk of impaired balance symmetry and potential injury risk based on performance of the anterior direction of the Y Balance Test™ measuring dynamic lower limb stability (Shaffer et al., 2013). Brazilian male military recruits (n = 135) with a Y Balance Test™ posterolateral reach direction asymmetry greater than or equal to 4.08 cm were approximately 5.5 times greater risk of developing patellofemoral pain over six weeks basic training (Nakagawa et al., 2020).

While normative baseline data for dynamic lower limb stability in military populations is emerging (Shaffer et al., 2013; Teyhen et al., 2016; Teyhen et al., 2020), researched populations are mostly male. Further research is needed to explore lower limb dynamic stability baseline values and injury risk for male and female military recruit populations.

2.5.1.9 **Ankle range of motion.**

Altered ankle dorsiflexion range of motion has had some investigation as an intrinsic risk factor for recruit injury. Reduced ankle dorsiflexion range of motion has been associated with lower limb injury in Australian Army recruits undertaking basic training (Pope et al., 1998). Low dorsiflexion range of motion (≤ 34 degrees) was associated with 2.5 times the injury risk compared to average dorsiflexion range of motion (~45 degrees). Low dorsiflexion range of motion was also reported as a good predictor of ankle sprain risk and was associated with five times the risk of ankle sprain compared to recruits with average dorsiflexion (45 degrees) (Pope et al., 1998). In this study, maximal dorsiflexion angle was reported using a functional weight-bearing position (Pope et al., 1998). Because army recruits spend a great deal of time weight-bearing during military tasks such as drill, marching and running, it is important that dorsiflexion range of motion is performed and measured in a standing lunge position.

Reduced ankle dorsiflexion range of motion has also been associated with greater risk of Achilles tendinitis in Navy Special Warfare trainees (Kaufman et al., 1999). In civilian and sports populations reduced ankle range of motion has been associated with an increased risk of injury including plantar fasciitis in people with unilateral plantar fasciitis (Riddle et al., 2003), ankle sprains in young physically active females (Willems et al., 2005), patellar tendinopathy in junior basketball players (Backman & Danielson, 2011) and anterior cruciate ligament injury in people seeking care in two Swedish physiotherapy clinics (Wahlstedt & Rasmussen-Barr, 2015).

Alternatively, high dorsiflexion (≥ 58 degrees) has been associated with up to eight times the risk of lower limb injury in Australian Army recruits compared to average dorsiflexion range of motion (~45 degrees) using a fixed meter ruler and T square measurement method and calculation by trigonometry (Pope et al., 1998). Additionally, female US Marine Corps with excessive dorsiflexion range of motion (≥ 21°) measured using a movable goniometer were two to three times more likely to sustain shin splint injury than recruits with dorsiflexion range between 11 and 20 degrees (Right OR = 0.4; 95% CI 1.1-6.0; Left OR =3.4; 95% CI 1.4-1.8) (Rauh et al., 2010).

It was unknown if altered ankle dorsiflexion range of motion was a risk factor for injury in New Zealand Army recruits undergoing training. An investigation into the ankle weight-bearing dorsiflexion range of motion including high and low range of motion and the risk of injury for New Zealand Army recruits undertaking basic training is presented in Study 2 and Study 4.

2.5.1.10 **Anatomical features.**

Common anatomical features identified as intrinsic risk factors for recruit injury include foot posture and quadriceps angle.

Historically, higher arch foot posture has been reported as a risk factor for recruit injury across multiple studies (Cowan et al., 1996; Cowan et al., 1993; Giladi et al., 1987). Alternatively, recruits with flexible pes planus (flat feet) had a greater risk of anterior knee pain in Israeli Defence Force recruits compared to recruits with normal feet (Lakstein et al., 2010). The prevalence of anterior knee pain was also significantly higher for rigid pes planus (flat) than recruits with normal feet and flexible pes planus (Lakstein et al., 2010). Arch height was measured subjectively with recruits in standing and then with toes raised to determine a change in arch height. With mild pes planus, the arch was mildly depressed, moderate pes planus the arch was more severely depressed however because in both categories the arch reconstituted, they were joined to make a single category labelled flexible pes planus. Severe pes planus was determined when the arch height was depressed and did not reconstitute on toe raise. This group was classified as rigid pes planus (Lakstein et al., 2010).

Arch height has also been investigated as a possible risk factor of injury risk in a meta-analysis of US Army, Air Force and Marine Corps recruit populations (Knapik et al., 2014). However, arch height described as low, medium or high using visualisation of plantar shape was reported as having little influence on injury risk when selecting running shoes in male (Summary rate ratio = 0.97; 95% CI 0.88-1.66) or female (Summary rate ratio = 0.97; 95% CI 0.85-1.08) military recruit populations (Knapik et al., 2014).

Variation in methods used to measure foot posture may explain differences in outcomes across foot posture studies, but also limit comparison between study findings. Foot posture may not consistently predict injury across research of military recruits and a recent systematic review based on US military research suggests evidence is insufficient to support an association between arch height and injury risk for male or female recruits during combat basic training (Bulzacchelli et al., 2014).

Anatomical characteristics such as quadriceps angle greater than 15 degrees and genu valgum (knocked knees) in male recruits have been associated with a higher incidence of overuse injuries (41%) compared to normal knees (22%) (Cowan et al., 1996). This issue may be greater in female recruits who have an increased quadriceps angle and a greater degree of genu valgum compared to males (Hsu et al., 1990). Female US Marine Corps recruits with a quadriceps angle greater than or equal to 20 degrees were twice as likely to develop patellofemoral pain syndrome than recruits less than 20 degrees during basic training (Rauh et al., 2010). Military studies reporting anatomical characteristics are limited as extreme anatomical variations would be excluded during army medical screening (Cowan et al., 1996). Investigation of anatomical characteristics and injury risk is beyond the scope of this research program.

2.5.1.11 **Non-reporting or concealing injuries**

Non-reporting or concealing injuries may be a behavioural reporting issue with basic training recruits. In the US Army, 64% of recruits sustained a self-reported musculoskeletal injury during basic training that they did not seek medical treatment for (Cohen et al., 2019). One reason for non-reporting is that recruits may be highly motivated to complete (march out) basic training on time and therefore conceal an injury to avoid graduation delay (backsquad) or discharge (attrition) from the service (Cohen et al., 2019; Orr et al., 2020). Unfortunately, recruits who conceal an injury during basic training risk subsequent and/or chronic injury (Cohen et al., 2019; Orr et al., 2020). Non-reporting can also lead to underestimation of the magnitude to the recruit injury problem affecting accuracy of military injury surveillance (Cohen et al., 2019) and similar issues are also identified with law enforcement recruits (Murphy et al., 2023). Due to difficulty capturing non-reporting injury data and challenges accessing recruits after march out, capturing non-reported recruit injury was logistically beyond the scope of this program of research.

2.5.1.12 **Summary of intrinsic risk factors.**

Intrinsic risk factors associated with an increased risk of recruit injury include older age, female sex, low physical fitness prior to entry, previous injury, a history of smoking and reduced ankle dorsiflexion range of motion (Cowan et al., 2003). Intrinsic risk factors such as alcohol history, diet and lower limb dynamic stability require further research to identify the level of association with recruit injury risk during training. These intrinsic risk factors and the relationship with injury risk will be investigated with New Zealand Army recruits at entry to training, as intervention could lead to lower injury risk. Intrinsic injury risk factors of New Zealand Army recruits at entry to training were previously unknown.

2.5.2 Extrinsic risk factors

Extrinsic risk factors refer to factors outside or external to the body that predispose an individual to injury (Meeuwisse & Bahr, 2009, p. 9). Extrinsic risk factors can include equipment, weather and seasonal conditions and type and suitability of footwear (Meeuwisse & Bahr, 2009, p. 9). Modifiable and non-modifiable extrinsic risk factors for recruit injury are summarised in Table 2.3. Extrinsic risk factors such as higher running mileage, accelerated or surged initial training, pattern of training, combat boots, and hard surface training and the risk for injury will be discussed further.

Table 2.3

Extrinsic Modifiable and Non-Modifiable Recruit Injury Risk Factors

Modifiable	**Non-modifiable**
Training parameters	**Training parameters**
High running mileage/distance	Hard training surface (no alternative)
Higher impact training	
Surged initial training	**Equipment/uniform - standard single issue/no choice**
Pattern of training (frequency, intensity, duration, and type of activity)	Uniform
	Combat boots
Equipment/uniform	Military load carriage
Combat boots	Weapons
	Environment
	Seasons/weather/terrain/volcano eruption/earthquakes

Note: Data for extrinsic risk factors in (Birrell & Haslam, 2008; Birrell et al., 2007; Cowan et al., 2003, p. 200; Jones & Knapik, 1999, p. 116; Orr et al., 2010).

2.5.2.1 **High running mileage.**

High total running distance (mileage/kilometres) has been associated with risk of injury in basic training recruits. In Australian Army recruits, an additional running distance of approximately 26.5 km more kilometres run over basic training was associated with increased lower limb musculoskeletal injury risk compared to other training activity (Rudzki & Cunningham, 1999).

Similarly, lower limb injury rates were compared for two US infantry recruit companies with different running mileage. The first company performing more running, 130 miles running distance, had significantly higher lower limb injury rates at 41.8% compared to 32.5% for the other company with 56 miles running distance (RR = 1/3, 95% CI 1-1.7, p = 0.09) over 12 weeks of training (Jones, Cowan, et al., 1993). Interestingly, both companies completed approximately the same overall distance across training when running was combined with marching distance (198 miles vs 178 miles). Furthermore, recruits across the two companies had similar final physical test results suggesting no benefit of high running mileage during basic training for endurance performance (Cowan et al., 2003; Jones et al., 1994; Jones, Cowan, et al., 1993).

Running distance is a modifiable extrinsic risk factor during recruit basic training. Understanding the volume of weight-bearing activities performed across basic training is important, as excessive amounts of running could lead to recruit injury (Cowan et al., 2003). Based on these findings, excessive running distance should be avoided and potentially reducing the time recruits spend running should be considered when developing recruit injury prevention training programs.

2.5.2.2 **High impact exercise.**

High impact exercise types such as running rather than marching and walking may be associated with a high risk of injury. A higher incidence of lower limb injury (79.8%) was observed for recruits undertaking standard physical training which included running, compared to 61.1% of recruits who had running activities replaced with lower impact activities that included weighted-marching (Rudzki, 1997a).

Lowering exposure to high impact exercise through strict adherence to standardised road marching by controlling speed (approximately 6 km/hr) and using a marked-out course, gradual load introduction, with reducing running distance across basic training (<26.5 km), and with the introduction of deep water running collectively helped to reduce the total injury presentation rate by 46.6% to the physiotherapy department by Australian Army recruits (Rudzki &

Cunningham, 1999). Additionally, lower medical discharge rates were observed for injury of male recruits with an estimated cost saving of AUD $1,267,805 in 1995/1996 (Rudzki & Cunningham, 1999).

Understanding recruit's history of exposure to running and impact exercise prior to basic training may provide important information that identifies recruits at higher risk of injury at entry, particularly those with a history of sedentary lifestyle. To better understand New Zealand Army recruit's past physical fitness and exposure to high impact exercise, Study 2 investigates pre-entry physical activity using a self-reported questionnaire.

2.5.2.3 **Surged physical training.**

A surge or acceleration in physical training may result in higher risk of recruit injury. A surge in physical training occurs when there is an abrupt increase and/or high volumes of vigorous training (Almeida et al., 1999). Weeks of basic training with high hours of vigorous training (running and marching) correlated to acute ($r = 0.633$, $p = 0.027$) and overuse injury ($r = 0.667$, $p = 0.018$) with incidence rate calculated as number of injuries/ recruit hours of training in US Marine Corps recruits (Almeida et al., 1999). The highest injury rates were observed in the earliest weeks of basic training (Almeida et al., 1999). Recruits who are more sedentary may experience a surge of activity upon entering basic training and be at a higher risk of injury than those recruits who were more physically active prior to training (Cowan et al., 2003; Jones, Cowan, et al., 1993). Some authors suggest that the initial weeks of basic training may be too strenuous for recruits transitioning from civilian to military life (Andersen et al., 2016).

Consideration of the pattern of training such as frequency, intensity, duration and type of activity is important for recruit training, however gradual delivery is suggested in an effort to accommodate low fitness recruits and potentially reduce injury risk (Almeida et al., 1997;

Cowan et al., 2003, p. 205; Jones, Cowan, et al., 1993; Kaufman et al., 2000). Unfortunately, the need to surge training to meet military recruit training outputs and timeframes, means this is rarely an option. Therefore, the rates of injury occurrence should be mapped against weeks of training to quantify the impact of training surge that is likely to occur. Study 3 maps injury rates against weeks of basic training.

2.5.2.4 **Combat boots.**

Controversially, use of combat boot footwear has been proposed as an injury hazard during recruit training historically.

Wearing in of stiff new boots and appropriate footwear fit have been historically cited as potential risk factors for friction injury such as blisters and development of cellulitis for military recruits (Bensel & Kish, 1983). Higher incidence of lower extremity injuries including blisters and lace lesions were observed for US Army recruits wearing hot weather boots compared to black leather boots (Bensel & Kish, 1983). Limitations of this study include the authors did not compare boots to a shoe alternative for training and due to the time elapsed, standard issue boots design will have changed.

Other alternative shoes to the use of combat boots and the impact on injuries has been investigated. Little or no difference in injury rate for recruits using boots (Finestone et al., 1992; Milgrom et al., 1992; Paisis et al., 2013; Scott et al., 2015) or a preference for a running shoe over a military boot for comfort was reported during physical activities (Paisis et al., 2013). Additionally, a meta-analysis of studies spanning 22 years (1976 to 1998) report little evidence exists for the use of running shoes instead of combat boots for physical training periods on overall injury incidence rates (Males RR (boot/shoe) = 1.04, 95% CI 0.91-1.18; Females RR = 0.94, 95% CI 0.85-1.05) or for lower extremity injuries (Males RR (boot/shoe) = 0.91, 95% CI

0.64-1.30, p = 0.66; Females RR = 1.06, 95% CI 0.89 – 1.27, p = 0.51) for US basic combat recruits (Knapik et al., 2015).

More recently, studies examining the effects of military combat boots on lower limb injuries in male New Zealand Army recruits found that the shaft of the boot crossing the ankle joint restricts dorsiflexion-plantarflexion range of motion and in turn, potentially effects dynamic function of the ankle joint (Rousseau et al., 2022). In addition, a stiff combat boot sole may negatively impact gait and potentially leads to greater fatigue of ankle dorsiflexors and plantarflexors. Therefore, when soldiers or recruits are not wearing a boot, muscles around the ankle joint such as plantarflexors must increase activation during weight-bearing activities to maintain balance and this potentially leads to fatigue and risk of injury (Rousseau, 2022).

Because standard issuing of boots occurs at entry to basic training and research has already been undertaken with New Zealand Army populations, the issue of boots and possible risk of injury in recruits is beyond the scope of this research program.

2.5.2.5 **Military load carriage**

Recruit basic training includes pack marches and field exercises which require carrying standard issue military occupational loads. Military load carriage (packs, webbing, body armour, helmet, weapon) has been associated with injury in soldiers and recruit populations (Knapik, Reynolds, et al., 2004; Orr et al., 2010; Orr et al., 2014). Recruits most at risk from occupational load carrying injuries may include those entering training with low fitness (Orr et al., 2014) and female recruits (Abbott et al., 2023; Bulathsinhala et al., 2017; Orr & Pope, 2016). Reasons for the greater injury risk observed in female recruits is that military equipment is often designed for men and loads carried may be the same weight as males, rather than body-weight proportion loads (Abbott et al., 2023; Bulathsinhala et al., 2017; Orr & Pope, 2016). Injury prevention for load carriage injuries have targeted innovations aiming to minimise load weight, improve load distribution and improve fitness (Knapik, Reynolds, et al., 2004). Progressive load carriage programs have shown promise to improve load carriage fitness and lower injury risk in military populations (Orr et al., 2021; Orr et al., 2010; Orr et al., 2014). Further investigation of military load carriage is beyond the scope of this program of research.

2.5.2.6 **Hard surface training.**

Research of recruit training surfaces is important as several military specific tasks are undertaken on hard surfaces. These activities include drill, marching, running fitness testing and transition of recruit platoons between classrooms, barracks and the mess (eating hall) via asphalt roads. Research of recruit training surface (hard surfaces running) as a risk factor for injury is however limited (Cowan et al., 2003; Molloy, 2016). One study observed US Navy Sea, Air and Land (SEAL) recruits who undertook running training on hard surfaces in preparation for entry to elite military training experienced lower injury risk compared to those running on soft surfaces (Shwayhat et al., 1994). Recruits who ran on soft surfaces in the 6 months prior to training were more likely to develop overuse injuries during basic training in univariate analysis (OR =2.0, 95% CI 1.2-3.5, $p < 0.05$) and in multivariate analysis (OR 1.9, 95% CI 1.1-3.3, $p < 0.05$). Soft surfaces were defined as grass, dirt, sand, and artificial track. Hard surfaces included asphalt and concrete (Shwayhat et al., 1994).

Due to limited evidence, it is difficult to draw conclusions with respect to the influence of hard surface training and recruits' susceptibility to injury during basic training.

2.5.2.7 **Summary of recruit intrinsic and extrinsic injury risk factors.**

In summary, understanding recruit injury aetiology including intrinsic and extrinsic risk factors and whether they are modifiable and non-modifiable is important for future development of injury prevention programs. Modifiable risk factors can be potentially changed, eliminated, or modified to reduce recruit injury (Cowan et al., 2003; Meeuwisse & Bahr, 2009). Understanding non-modifiable injury risk factors could also positively contribute to the development of injury prevention measures by specifically targeting individuals predisposed or at higher risk of injury, for instance modified training for female recruits (Blacker et al., 2009; Meeuwisse & Bahr, 2009). A better understanding of these recruit injury risk factors will help guide the formulation and development of targeted injury prevention measures which aim to reduce the detrimental effects of injury for recruits undertaking basic training. Study 2 of this program of research investigates the presentation of new army recruit intrinsic risk factors and Study 3 examines modification of some training parameters (extrinsic risk factors) by investigating the effectiveness of a neuromuscular prevention training program for army recruits.

2.5.3 Mechanism of Injury

Consideration of the mechanisms of injury is an important element of step two of the 'sequence of injury prevention' model (Meeuwisse & Bahr, 2009; van Mechelen et al., 1992, p. 84).

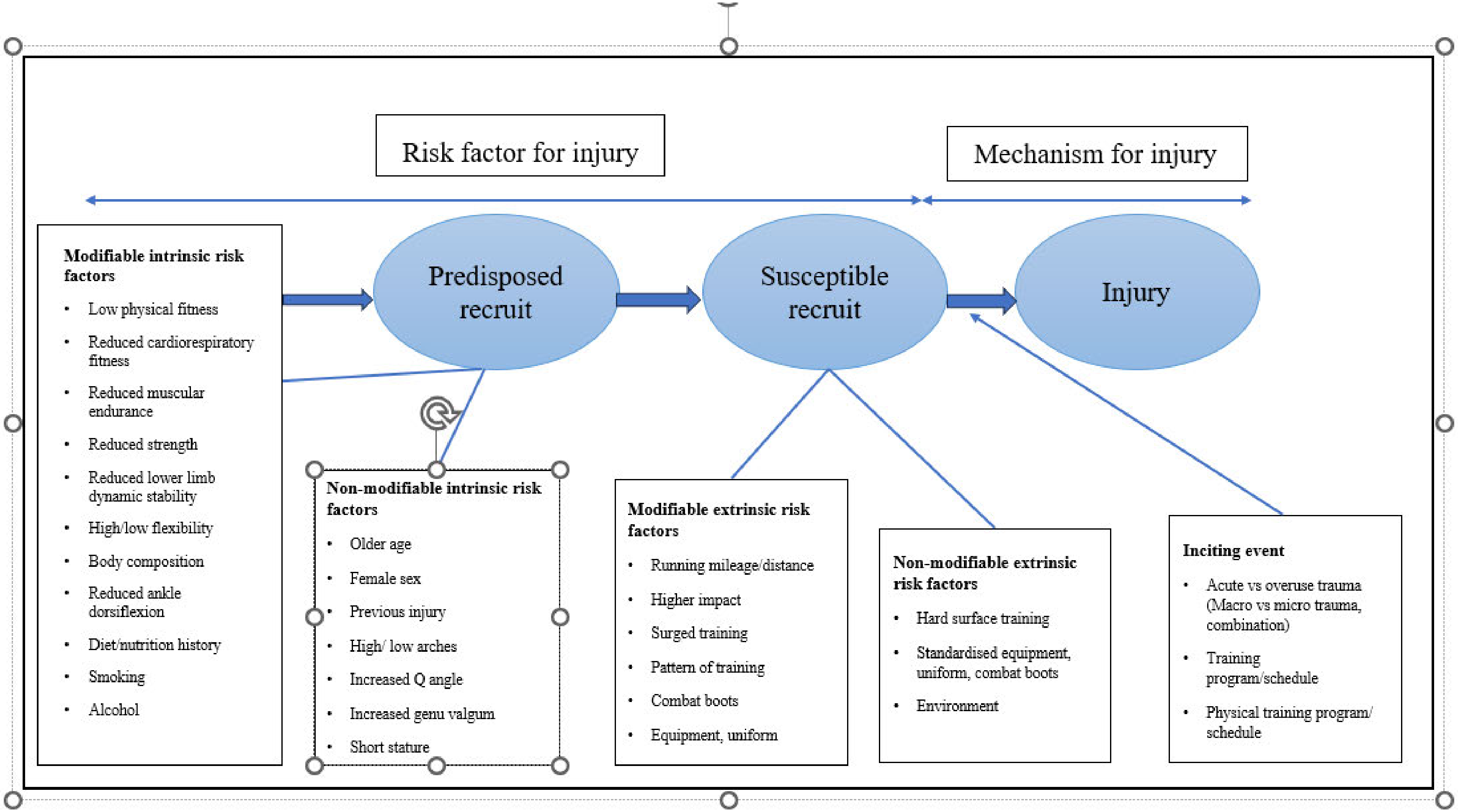
The mechanism of injury refers to the actual mechanism or conditions by which the amount of stress imposed to the human body during a sports situation (or military task) eventually leads to tissue damage (Noyes et al., 1988). The mechanism of injury is sometimes referred to as the 'inciting event' which considers all events leading up to the injury situation (Meeuwisse & Bahr, 2009). To better understand the inciting event requires consideration of a 'model of injury causation' (Meeuwisse & Bahr, 2009, p. 10). Such a model not only considers the events leading up to the injury situation, but also a description of factors such as the training program at the time of the injury (Bahr & Krosshaug, 2005; Meeuwisse, 1994). While this model is useful for acute injury events, further description is required for overuse injury when causative factors are distant from the outcome (Meeuwisse & Bahr, 2009).

Meeuwisse (1994) suggests an acute injury (for example a fracture) is associated with a macro-traumatic inciting event, such trauma from a fall or kick. An overuse injury may stem from repetitive micro-trauma (Meeuwisse, 1994), for example impact exercise resulting in a stress fracture (Rauh et al., 2006). A combination of both acute and overuse injury is also possible in some diagnoses such as muscle strain (International Olympic Committee et al., 2020; Meeuwisse, 1994). Recruits, like athletes, are likely to suffer both acute and overuse injury which could include macro-trauma and/or micro-trauma (Meeuwisse, 1994). Therefore, a modified version of the 'Comprehensive Model of Injury Causation' by Bahr and Krosshaug (2005) is proposed with emphasis on known intrinsic and extrinsic injury risk factors and injury inciting events commonly experienced by army recruits undertaking training (Figure 2.2).

In summary, following authors van Mechelen et al. (1992) 'sequence of injury prevention' model (Figure 2.1) this program of research firstly establishes the extent of the injury problem and common injury trends of recruits undertaking basic training in the New Zealand Army (Study 1). An investigation of recruit injury risk factors is the second step in injury prevention and will provide better understanding of the indicators for risk that could be modified, changed or eliminated to reduce recruit injury and is presented in Study 2 (Meeuwisse & Bahr, 2009; van Mechelen et al., 1992). Consideration of both steps helps inform research of the effectiveness of an injury prevention intervention which aims to lower recruit injury. In turn, Study 3 fulfills the third step in injury prevention by examining an injury prevention intervention designed to lower injury incidence with New Zealand Army (van Mechelen et al., 1992).

Figure 2.2

Proposed Military Recruit Comprehensive Model of Injury Causation



Note: Adapted and modified from Bahr and Krosshaug (2005); and Meeuwisse (1994).

2.6 INTRODUCING A MILITARY RECRUIT INJURY PREVENTION

Introducing an injury prevention measure or intervention is the third step of the 'sequence of injury prevention model' (van Mechelen et al., 1992, p. 84). This step involves introducing a measure or measures that are likely to lower the future risk and/or severity of sports injury (van Mechelen et al., 1992, p. 84). Ideally, this step of the injury prevention model should be based on the extent of the injury problem (Step 1) (Section 2.4) and the aetiological factors and the mechanisms of injury identified (Step 2) (Section 2.5) (van Mechelen et al., 1992). Introducing an injury prevention measure is important to help prevent or reduce the high numbers of injuries experienced by New Zealand Army recruits undertaking basic training.

This section will outline a proposed injury prevention measure for military recruits that includes neuromuscular training, a definition of neuromuscular training, a review of the effectiveness of neuromuscular training from sports and available military studies and considerations for implementation.

While the phrase an injury prevention 'measure' is used in the 'sequence of injury prevention' model (van Mechelen et al., 1992, p. 84), terms such as intervention, tool, program and strategy have also been used synonymously in published injury prevention research. For the purpose of this program of research, injury prevention interventions will be used instead of injury prevention measure.

2.6.1 Neuromuscular injury prevention intervention proposed for military

Many injury prevention interventions have been proposed to prevent or reduce military recruit injury. Up to 40 physical training-related injury prevention strategies were identified in a systematic review led by a joint US military task force (Army, Navy, Air Force and Marine Corps) to reduce military training injury (Bullock et al., 2010). Six evidenced-based injury prevention recommendations were proposed for immediate implementation to reduce US military training-related injury and are summarised in Table 2.4 (Bullock et al., 2010). Recommendations for performing neuromuscular, proprioceptive and agility training will be discussed in more detail.

Table 2.4

United States Military Recommendations for Injury Prevention

Number	Recommendation
1.	Prevent overtraining
2.	Perform multiaxial, neuromuscular, proprioceptive, and agility training
3.	Wear mouthguards during high-risk activities
4.	Wear semi-rigid ankle braces for high-risk activity
5.	Consume nutrients to restore energy balance within one hour following high-intensity activity
6.	Wear synthetic-blend socks to prevent blisters.

Note: Adapted from Bullock et al. (2010, pp. S168-169).

The second recommendation (Table 2.4) promotes the implementation of multiaxial, neuromuscular, proprioceptive and agility training for injury prevention in US military populations (Bullock et al., 2010). Bullock et al. (2010) based this recommendation on injury reduction observed in both sports and military populations. Sports studies included a wide variation of pivoting sports such as soccer, handball and basketball (Hewett, Myer, & Ford, 2005; Mandelbaum et al., 2005; Olsen et al., 2005). Injuries tended to be acute in nature such as ankle sprain and/or anterior cruciate ligament injury (Hewett, Myer, & Ford, 2005; Mandelbaum et al., 2005; Olsen et al., 2005; Wedderkopp et al., 2003), and populations studied were predominantly female (Hewett, Myer, & Ford, 2005; Hewett, Myer, Ford, et al., 2005; Mandelbaum et al., 2005; Olsen et al., 2005).

The military populations informing Bullock et al. (2010) recommendations were largely trained army and navy populations. Two studies were included that comprised US recruit populations (Knapik, Darakjy, et al., 2004; Knapik et al., 2003) and are two decades old. Differences in training loads between sports and military populations should be noted. For example, military recruits often train for long periods, usually seven days a week for the duration of basic training, they sustain more overuse than acute injuries and are predominantly male (Jones et al., 2017; Molloy, Pendergrass, Lee, Chervak, et al., 2020). Generalisability of sports study findings to military recruits is difficult as they are less likely to reflect the tasks and population undertaking military basic training. Further investigation in recruit populations is needed.

Before exploring the evidence for neuromuscular training as a possible intervention for New Zealand Army recruits, it is necessary to understand the terminology used in research and proposed definitions of neuromuscular training to secure an operational definition of neuromuscular training for this program of research.

2.6.1.1 **Neuromuscular training definition.**

Neuromuscular training has been used as either a stand-alone term or inclusive of multiple synonymous terms. Neuromuscular training has been described as or incorporates terms such as proprioception (Bullock et al., 2010; Hubscher et al., 2010), stability (Davidson et al., 2009), balance (Emery et al., 2005; McGuine & Keene, 2006), sensorimotor (Hubscher et al., 2010), perturbation or coordination (Bullock et al., 2010), multi-interventional (Bullock et al., 2010; Hubscher et al., 2010) and multi-faceted integrative training (Myer et al., 2011).

Bullock et al. (2010) also uses neuromuscular training separate to multiaxial, proprioceptive and agility training terminology providing brief definitions for each. Bullock et al. (2010) defined neuromuscular as coordinated muscular movement, defined multiaxial as many planes of motion, proprioceptive referred to body position sense and agility was defined as nonlinear movement (Bullock et al., 2010, p. S168).

An early definition of neuromuscular control suggests neuromuscular training enhances unconscious motor responses through stimulation of afferent and also central mechanisms needed for dynamic joint control (Risberg et al., 2001, p. 620). It was suggested that neuromuscular training may improve the neural system's ability to generate fast and optimal muscle firing patterns, increases dynamic joint stability, reduces joint forces and enhances the relearning of movement patterns and skills (Risberg et al., 2001, p. 620).

Myer et al. (2011, p. 3) further defined integrative neuromuscular training as 'a conceptual model' whereby a supplemental training program includes both general and specific exercises. General exercises involve fundamental movements (such as running drills to warm up the body), while specific exercises target motor control deficits. Specific exercises focus on strength and conditioning activities, such as resistance, dynamic stability, core strength, plyometric and agility training. The aim of specific exercises is to improve health and skill-based components of physical fitness, preferably delivered by qualified professionals (Myer et al., 2011, p. 3). The neuromuscular definition by Myer et al. (2011) which describes general and specific conditioning informs this program of research.

Over the last two decades neuromuscular training has gained attention as an effective injury prevention intervention in high-quality studies of sports populations (Hubscher et al., 2010; Olsen et al., 2005; Owoeye, Palacios-Derflingher, et al., 2018; Pasanen et al., 2008; Thorborg et al., 2017). The effectiveness of neuromuscular injury prevention programs with military recruits has received some investigation, however few studies exist, and results are mixed (Brushoj et al., 2008; Coppack et al., 2011; Dijksma, Arslan, et al., 2020; Goodall et al., 2013; Parkkari et al., 2011). Evidence of the effectiveness of neuromuscular training in both sports and military studies will now be discussed in the following section.

2.6.1.2 **Neuromuscular injury prevention programs in sports populations.**

Injury prevention programs using neuromuscular training have been shown to be effective in reducing injuries and training-related injury costs with sports populations.

A systematic review and meta-analysis of football (soccer) assessed six cluster randomised controlled trials using an intervention of either the FIFA 11 (two studies) or FIFA 11+ (four studies) prevention program compared to a control group (sham or no intervention) on the overall incidence of football injury (Thorborg et al., 2017). FIFA is the Fédération Internationale de Football Association (in French) or International Federation of Association Football (in English) (Fuller et al., 2006). The FIFA 11+ is a revised version of the FIFA 11 that includes a more dynamic warm up and more specific progressions of included exercises (Thorborg et al., 2017).

In this systematic review, a total of 3806 participants from 186 teams of recreational and sub elite players were included in the intervention and 180 teams (3645 participants) in the control group for analysis (Thorborg et al., 2017). Mean age ranged from 15-45 years old. All injuries including overuse and traumatic were included from match and training time exposure (Thorborg et al., 2017). Follow up periods ranged from five to nine months. FIFA 11+ programs substantially reduced football injuries by 39% when results of four randomised controlled trials were compared (Thorborg et al., 2017). Interestingly, no injury prevention effect could be found based on two studies using the FIFA 11 program. Additional benefits of neuromuscular training in football did include a 40% reduction in training-related injury costs (Krist et al., 2013; Marshall et al., 2016; Thorborg et al., 2017). One study projected a saving of $2.7 million (Canadian Dollars) in healthcare costs across one season following implementation of neuromuscular training program with young Canadian soccer players (Marshall et al., 2016).

Another systematic review also reports evidence for the effectiveness of proprioception and neuromuscular training for sports that incorporate pivoting movements to reduce certain types of sports injury in adolescent and young adult athletes (Hubscher et al., 2010). Seven high quality studies reviewed reported an average sample size of 1078 (range 114-2020) with participants aged between 12-24 years. The sports reviewed included organised club and school sports, basketball, volleyball, soccer, team handball, floorball and hockey (Hubscher et al., 2010). The authors appear to use the enhancement of ‘proprioception’, ‘neuromuscular’ and ‘sensorimotor’ terminology interchangeably. The term ‘multi-intervention’ was also used to describe combinations of neuromuscular exercise (running drills, cutting and landing technique, stretching, strengthening, plyometric, balance and agility) or balance training alone (wobble board or wobble board and sport-specific) from the exercise programs evaluated in their systematic review (Hubscher et al., 2010, p. 413). Pooled data from the seven high quality studies reported that multi-intervention training was effective in reducing lower limb injury risk (RR = 0.61, 95% Cl 0.49 to 0.77, $p < 0.01$), acute knee injuries (RR = 0.46, 95% Cl 0.28 to 0.76, $p < 0.01$) and ankle sprain injury (RR = 0.50, 95% Cl 0.31 to 0.79, $p < 0.01$) (Hubscher et al., 2010). A significant reduction in ankle sprain injury was also observed with balance training alone (RR = 0.64, 95% Cl 0.46 to 0.9, $p < 0.01$) and a non-significant reduction in overall injury risk was observed (RR = 0.49, 95% Cl 0.13 to 1.8, p = 0.28) (Hubscher et al., 2010).

In summary, multiple high-quality studies investigating the use of neuromuscular training in sports populations has provided evidence of a reduction in the incidence of injury compared to control groups that did not use neuromuscular training.

These systematic reviews may be difficult to generalise to army recruit populations. The sports systematic reviews mostly report pivoting type sports such as soccer (Hubscher et al., 2010; Steib et al., 2017; Thorborg et al., 2017), use exclusively or predominantly female athletes (Gilchrist et al., 2008; Hewett, Myer, & Ford, 2005; Steffen et al., 2008; Steib et al., 2017) and often concentrate on specific injury types such as anterior cruciate ligament and ankle ligament sprains as a result of acute and traumatic injury (Gilchrist et al., 2008; Hewett, Myer, & Ford, 2005; Olsen et al., 2005; Owoeye, Palacios-Derflingher, et al., 2018; Pasanen et al., 2008). Generalisation of these results to army recruit basic training injuries may be difficult; in particular, considering recruit injury exposure time, training activities undertaken by army recruits, army recruits are predominantly male (New Zealand Ministry of Defence, 2015) and are at risk of acute or traumatic and overuse injury (Robinson et al., 2016).

2.6.1.3 **Neuromuscular injury prevention programs for military recruits.**

Neuromuscular training has been suggested to be a potentially effective intervention to reduce the incidence of military recruit training-related lower limb injury (Almeida et al., 1999; Davidson et al., 2009). Collateral benefits of neuromuscular prevention training may also include improved occupational outcomes and less time loss due to injury (Coppack et al., 2011; Parkkari et al., 2011).

A search of the literature was undertaken in June 2020 for military recruit prevention programs that involved neuromuscular training or components of neuromuscular training from 2000 to 2020. Search terminology included neuromuscular, proprioception, sensorimotor, strength, agility, plyometric, exercise, recruit, conscript, military, and army. Reference lists were reviewed for relevant additional studies.

Five studies were found which investigated the effectiveness of neuromuscular injury prevention training in military training populations. Four studies include military recruit populations (Brushoj et al., 2008; Coppack et al., 2011; Goodall et al., 2013; Parkkari et al., 2011) and one of military academy cadets (Carow et al., 2016). Characteristics of military studies using neuromuscular training are presented in Table 2.5.

Table 2.5

Study Characteristics of Military Recruit Research for Neuromuscular Injury Prevention Programs (RCTs, cRCTs, block stratified cRCTs and Intervention studies)

Study & Design	Participants	Intervention	Program Details & Exercise Prescription	Outcomes/Results	PEDro score
Brushoj et al. (2008) cRCT LoE: 2	1020 Danish Life Guard recruits (IC:507, CG:513) Age: 19-26 (mean 20.9 years) Sex: not specified Dropout: Attrition in IG:20, CG:23	Based on identified intrinsic risk factors for recruit injury.	IG: Five exercises involving lower body strength, flexibility, and coordination. CG: Five exercises for the upper body. Prescription both groups 5-25 reps per exercise, x3/week, 15 minutes for 3 months.	Primary: No significant risk of sustaining overuse knee injury IG: 27, CG 23 (P = 0.546) and medial tibial stress syndrome IG: 23, CG: 25 (P = 0.784). Secondary: Overall injury incidence to the lower extremity (Incidence 0.22-0.19, P = 0.162; RR = 1.05 [range, 0.98-1.11]) 12-minute maximum run distance test (Coopers test). IG: 82m, CG: 43m (P = 0.37).	4/10
Carow et al. (2016) cRCT LoE: 2	1313 US Military Academy cadets. Age: 18-22 years. Males: 1070 Females: 243 Dropouts: no loss to follow up	3 groups: DIME Cadre Supervised (DCS) or DIME Expert Supervised (DES) with health professional supervision and Active Warm-Up (AWU).	IG: Two groups. DIME DCS or DIME DES. CG: Standard army warm up (AWU). Prescription: all three groups x3/week, 10 minutes for 6 weeks. Progression of exercise for DIME groups at 3 weeks.	Primary: No significant difference in lower extremity injury risk between AWU and combined DIME (DCS & DES) during cadet basic or academic year. Lower extremity injury risk in the DES group decreased 41% (RR = 0.59; 95% CI = 0.38-0.93; P = 0.02) compared to DCS group. Non-significant 25% decrease in DES compared to AWU (RR = 0.75; 95% CI 0.49-1.14, P = 0.18). Non-significant 27% increased risk of injury (RR = 1.27; 95% CI = 0.90-1.78, p = 0.17) in academic year for DCS compared to AWU.	6/10
Coppack et al. (2011) cRCT LoE: 2	1502 UK Army phase one basic training recruits (IC: 759, CG: 743)	Supervised strengthening and stretching exercises during warm ups and cool downs targeting	IG: Four strength and four stretching exercises during supervised physical training sessions. Isometric hip adduction, lunges, single leg step downs and single leg squats to 45°.	Primary: 75% reduction in risk of anterior knee pain in the IG vs CG groups (unadjusted hazard ratio = 0.25; 95% CI, 0.13-0.52; P < 0.001). Total new cases of anterior knee pain 46 (3.1%; 95% CI, 2.3-4.1). IG: 10 (cumulative incidence	8/10

Study & Design	**Participants**	**Intervention**	**Program Details & Exercise Prescription**	**Outcomes/Results**	**PEDro score**
	Age: 17-25 (median 19.7 years) Males: IC: 556 CG:536 Females: IG:203 CG:207 Dropouts: no loss to follow up	incidence of anterior knee pain.	Stretches of quadriceps, iliotibial band, hamstrings, and calf. CG: Followed existing syllabus warm-up exercises. Prescription both groups x7/week for 14 weeks.	1.3%; 0.7-2.4). CG: 36 (cumulative incidence 4.8%; 95% CI, 3.5-6.7). Secondary: Occupational outcomes: Medical discharges IG: 3 (0.4%), CG: 25 (3.4%). Unfit for service for army discharges IG: 6 (0.8%), CG: 23 (3.1%). Voluntary discharge IG: 76 (10%) CG: 71 (9.6%). Successful graduation IG: 605 (79.7%) CG: 504 (67.8%).	
Goodall et al. (2013) Block stratified cRCT LoE: 2	867 Australian Army recruits (IG:380 CG:487) Age: 17-50 (Mean not available) Males 732: Females 47 Dropouts: IG: 55, CG:33 discharged from army. IC: 46, CG: 39 backsquaded (injuries monitored)	Balance and agility exercise additional to normal training over 80-days basic training.	Balance exercises: 5 minutes every warm up session of standard 43 physical training lessons. Approx. 3-4x/week, 2x 25 second bouts each leg, ground based in sagittal, frontal, and transverse planes. Difficulty progressed each subsequent session. Agility exercises 5 minutes during 13 of the physical training lessons. Intervention exercises in addition to normal physical training. Duration: 80 days (<12wks)	Primary: Intervention had no significant effect on lower limb injury incidence (RR = 1.25, 95% CI 0.97-1.53) or on knee or ankle injury incidence (RR = 1.08, 95% CI 0.83-1.38) and on knee and ankle ligament injury (RR = 0.98, 95% CI 0.64-1.47). Possible 25% increase in lower limb injury for intervention group.	7/10
Parkkari et al. (2011) RCT LoE: 2	968 Finnish Defence Force conscripts (IG: 501 CG: 467 at randomisation). Age: 18-28 years (median and mean 19 years).	Exercises for balance and posture, coordination and agility, lumbar neutral zone control, core stability and trunk endurance, eccentric hamstrings, thoracic mobility, and injury	IG: 9 exercises: two exercises for balance and posture; one improved coordination and agility; three improved control of the lumbar neutral zone; two improved core (trunk) stability and endurance of trunk muscles; one involved eccentric hamstring strengthening; two improved extensibility of lower extremity muscles; and one exercise improved	Primary: Risk of acute ankle injury significantly reduced IG vs CG in low and moderate to high baseline fitness level subjects (adjusted HR = 0.34, 95% CI 0.15-0.78, P = 0.011). Secondary: Significant decrease in upper extremity injuries in the moderate to high baseline fitness group for IG vs CG (adjusted HR = 0.37, 95% CI 0.14 -0.99, P = 0.047).	7/10

Study & Design	**Participants**	**Intervention**	**Program Details & Exercise Prescription**	**Outcomes/Results**	**PEDro score**
	Males only, no females Dropouts at follow up IG: 163, CG: 167. Drop out for MSKI was IG: 20, CG: 29 injuries analysis included until drop out.	prevention counselling.	thoracic spine mobility together with injury prevention counselling. CG: Usual regimen for the Finnish Army. Weeks 1-8 exercises performed x3/week., 30-45 minutes at moderate intensity. Weeks 9-26 exercises performed x 1/week, exercised independently with weekly logbooks audit and injury prevention counselling.	IG tendency for less time loss due to injury (adjusted HR = 0.55, 95% CI 0.29-1.04).	

Note: AWU: Active warm up, AKP: Anterior knee pain, CI: Confidence interval, CG: Control group, cRCT: Cluster randomised controlled trial, DIME: Dynamic Integrated Movement Enhancement, DCS: DIME cadre supervised, DES: DIME expert supervised, HR: Hazards ratio, IG: Intervention group, LoE: Level of evidence; m: Meters, MSKI: Musculoskeletal injury, RCT: Randomised controlled trial, reps: Repetitions and RR: Relative risk.

Note. PEDro is an abbreviation for the Physiotherapy Evidence Data used for rating scientific research of randomised controlled trials.

Brushoj et al. (2008) conducted a cluster randomised controlled trial which investigated the effects of a three-month injury preventative training program with Danish Life Guard military conscripts (compulsory training recruits). The intervention group performed five exercises involving strength, flexibility and coordination, while the placebo group performed five exercises for the upper body (Brushoj et al., 2008). No significant difference was observed between the intervention and placebo group for injury incidence (incidence 0.22 vs 0.19) (RR = 1.05, 95% CI 0.98 to 1.11, P = 0.162). Additionally, no significant differences were reported in the primary outcomes for risk of sustaining an overuse knee injury (p = 0.546) or shin pain (P = 0.784) (Brushoj et al., 2008). Recruits in the intervention group achieved greater distances undertaking a 12-minute run test (82m versus 43m improved; P = 0.037) (Brushoj et al., 2008).

Coppack et al. (2011) conducted a cluster randomised control trial investigating neuromuscular training with UK Army recruits. The effect of a preventative exercise program on anterior knee pain incidence was investigated during basic military training. The intervention group performed eight exercises during the warm up and warm down seven times per week for 14 weeks, while the control group followed the existing training syllabus (Table 2.5) (Coppack et al., 2011). Anterior knee pain incidence was reduced by 75% in the intervention compared to control group (unadjusted hazard ratio = 0.25; 95% CI 0.13 to 0.52; P < 0.001) (Coppack et al., 2011). There was also improvement in occupational outcomes from the intervention group with fewer recruits discharged from the service (medical/unfit) and a greater proportion of recruits successfully completed training (79% vs 68%) compared to the control group (Table 2.5) (Coppack et al., 2011).

Goodall et al. (2013) used a block stratified cluster randomised controlled trial to investigate if structured balance and agility type training reduced lower limb injury in Australian Army recruits. Intervention exercises were performed for 43 physical training sessions, comprising 5 minutes balance exercises, with a total duration of approximately 215 minutes across basic training. Balance exercises were performed 3-4 times weekly, for 2 x 25 seconds on right and left lower limbs. Exercise difficulty progressed fortnightly. Agility exercises involving jumping, propping, stopping, and dynamic balance were performed for 5 minutes across 13 physical training sessions, with a total duration of approximately 70 minutes. All exercises were in addition to the existing physical training program. Results of this study suggest that the addition of balance and agility training increased lower limb injury by approximately 25% and could be potentially harmful. It is possible that the additional warm up training potentially increased risk of training overload or training error, which may have led to increased risk of lower limb injury in the intervention compared to the control group. The authors recommend that future injury prevention consisting of balance and agility exercises should be implemented within the existing physical training program rather than as additional training (Goodall et al., 2013).

A fourth randomised control trial investigated neuromuscular training programs with injury prevention counselling to prevent acute musculoskeletal injuries in young Finnish male military conscripts (compulsory training recruits) (Parkkari et al., 2011). Nine exercises were performed three times per week initially for the first eight weeks of training. Thereafter, exercises were performed once per week until six months and combined with injury prevention counselling (Table 2.5). A significantly decreased risk of acute ankle injuries was observed for those recruits who began training with low and moderate to high baseline fitness level in the intervention group (adjusted HR = 0.34, 95% CI 0.15 to 0.78, P = 0.011) (Parkkari et al., 2011). There was also a significant decrease in upper extremity injuries in individuals with moderate to high baseline fitness (adjusted HR = 0.37, 95% CI 0.14 to 0.99, P = 0.047) (Parkkari et al., 2011). Additionally, the intervention group also tended to have less injury time-loss (adjusted HR = 0.55, 95% CI 0.29 to 1) (Parkkari et al., 2011).

A fifth cluster randomised control trial investigated the risk of lower extremity injury in United States Military Academy (USMA) cadets using Dynamic Integrated Movement Enhancement (DIME) (Carow et al., 2016). An active warm up control group was compared to two DIME groups involving either cadre supervised (upper-class cadet instructors only) or expert supervised exercise (certified athletic trainer or physiotherapist). Exercises were performed for 10 minutes, three times weekly for six weeks. After three weeks, the DIME exercises progressed from bilateral to unilateral type exercises (Table 2.5) (Carow et al., 2016). Incidence was reported to the first musculoskeletal injury. Multiple injuries, contusions, skin or lacerations were excluded. No differences in cumulative incidence of lower extremity injury risk were observed between the active warm up group and the two DIME groups during the academic training year (Carow et al., 2016). Lower extremity injury risk in the DIME expert supervised group decreased by 41% (RR = 0.59; 95% CI 0.38 to 0.93; P = 0.02) compared with the DIME cadre supervised group. A critical analysis of these five studies is presented in the next section.

Another randomised controlled trail has investigated agility training performed three times per week for 20 minutes compared to usual physical training with Dutch Air Manoeuvre Brigade military recruits (n = 64) (Dijksma et al., 2019). Intervention group commenced training after week six for a total of 12 weeks duration. Outcomes of this study only reported on attrition rates due to injury, and did not report incidence of musculoskeletal injury rates (Dijksma et al., 2019). As injury incidence is not reported, no further analysis of this research will be discussed.

2.6.1.4 **Methodological considerations of neuromuscular studies of military recruits.**

A number of methodological strengths and limitations require consideration when examining neuromuscular injury prevention training for military recruit populations. As all studies reviewed are randomised controlled trials, methodological quality was examined using the 11 item Physiotherapy Evidence Database (PEDro) scale (Maher et al., 2003; PEDro, 2020) and is summarised in Table 2.5 and Table 2.6.

Eligibility criteria were provided for inclusion of participants from three studies (Coppack et al., 2011; Goodall et al., 2013; Parkkari et al., 2011). Randomisation was performed across all five studies, with three using cluster randomisation methods for whole platoons or troops and one using block-stratified cluster method (Goodall et al., 2013). Randomisation by individual participant was lacking in all five studies which may increase the risk of selection bias (Portney & Watkins, 2009), however individual randomisation may not have been feasible with mass screening of military recruit populations.

Concealment of group allocation occurred in two studies whereby randomisation was performed off-site by an independent person (Coppack et al., 2011; Parkkari et al., 2011). Two studies did not achieve concealment, or concealment was unclear during the allocation process (Brushoj et al., 2008; Carow et al., 2016).

Similar baseline characteristics were achieved in one study and questioned in another (Coppack et al., 2011; Parkkari et al., 2011). Parkkari et al. (2011) reported significant differences in initial baseline characteristics; however, these differences were later adjusted with statistical analysis. Blinding of subjects and therapists was not achieved by any of the reviewed studies. Blinding of recruits (subjects) and therapist may be difficult in a military setting due to the close proximity within barrack accommodation and the army training environment (Parkkari et al., 2011).

Table 2.6

PEDro Rating of Military Studies Using Neuromuscular Injury Prevention Training

Study	Eligibility data	1 Randomly allocated to groups	2 Concealment	3 Groups similar at baseline	4 Blinding of subjects	5 Blinding of therapists	6 Blinding of assessors	7 Outcomes >85%	8 Intention to treat analysis	9 Between group comparison	10 Mean and variability data	Total PEDro score
Brushoj et al. (2008)	✕	N	N	N	N	N	Y	Y	N	Y	Y	4/10
Carow et al. (2016)	✕	Y	N	N	N	N	Y	Y	Y	Y	Y	6/10
Coppack et al. (2011)	✓	Y	Y	Y	N	N	Y	Y	Y	Y	Y	8/10
Goodall et al. (2013)	✓	Y	Y	N	N	N	Y	Y	Y	Y	Y	7/10
Parkkari et al. (2011)	✓	Y	Y	N	N	N	Y	Y	Y	Y	Y	7/10

Note: PEDro is an abbreviation of the physiotherapy evidence database. Above ratings have been confirmed by PEDro (PEDro, 2020).

Blinding of assessors was achieved in four studies (Brushoj et al., 2008; Carow et al., 2016; Goodall et al., 2013; Parkkari et al., 2011), and was questioned in one study where the assessor became aware of participant allocation in approximately one third of the research population (Coppack et al., 2011).

Outcomes of 85% or greater were obtained for at least one key outcome across all reviewed studies. Intention-to-treat analysis was included in four studies (Brushoj et al., 2008; Carow et al., 2016; Coppack et al., 2011; Goodall et al., 2013) and questioned (Parkkari et al., 2011) or absent in others (Brushoj et al., 2008).

Between group differences were reported for at least one key outcome measure across all reviewed studies. This was usually the primary outcome measure of injury incidence.

Point measures and measures of variability of at least one key outcome (PEDro, 2020; Portney & Watkins, 2009) were provided by each of the five reviewed studies.

Considering the overall PEDro score (PEDro, 2020; Portney & Watkins, 2009), four studies achieved moderate to high quality score of ≥ 6/10 (Carow et al., 2016; Coppack et al., 2011; Goodall et al., 2013; Parkkari et al., 2011), while the fifth study received a low score of ≤ 4/10 (Brushoj et al., 2008) (Table 2.6).

Other factors such as training circumstances, participant personal characteristics, injury location, injury type and definition also require consideration when interpreting results of neuromuscular training for military recruits. Differences in exercise prescription will be discussed in the following section (Section 2.6.1.5).

Recruit's living conditions, food, uniforms, equipment, military training syllabus and injury exposure time were likely to be similar through basic training between intervention and control groups. This suggests internal validity is enhanced as the risk that other extraneous variables that may affect outcomes following neuromuscular intervention is reduced (Coppack et al., 2011).

Research was performed predominantly with young male military populations. The generalisation of results to similar male military populations improves the overall external validity of these studies. Limitations exist however with generalisation to female military recruits. Only three studies included female recruits who represented approximately one fifth or less of total training populations studied (Carow et al., 2016; Coppack et al., 2011; Goodall et al., 2013).

Another limitation is the variation or heterogeneity of anatomical location and type of injury reported between studies. Two studies report primary outcomes as individual anatomical sites such as incidence of anterior knee pain (Coppack et al., 2011) or overuse knee injury and shin pain (Brushoj et al., 2008). Another study reports a primary outcome measure involving risk of acute injury of generalised regions of the upper limb and lower limb rather than anatomical sites (Parkkari et al., 2011). Comparing injury incidence results of studies which use acute versus overuse injury type and whole extremities versus specific anatomical locations is difficult as each study is focused on different outcomes.

Finally, injury definitions mostly included those deemed a medical-attention injury (Carow et al., 2016; Coppack et al., 2011; Goodall et al., 2013; International Olympic Committee et al., 2020), medical attention and injury time-loss (Parkkari et al., 2011), or a combination of self-reported and medical attention injury (Brushoj et al., 2008). The different military populations (recruits versus compulsory conscript training), training environments and programs as well as different study aims limits direct comparisons of neuromuscular training outcomes between studies.

A comparison of exercise prescription strengths and limitations is presented in the following section. Based on the strengths and limitations of neuromuscular injury prevention training studies, future research should aim to use both male and female populations, blind participants, therapists and assessors where possible, standardised injury definition and use of individual anatomical sites (joints and segments) to explain injury incidence and improve comparability of prevention study findings (International Olympic Committee et al., 2020; Orchard et al., 2020).

2.6.1.5 **Neuromuscular exercise prescription from military studies.**

Variation exists for neuromuscular exercise prescription across military injury prevention studies presented and may account for some of the varied results observed for injury incidence.

The injury prevention exercises used by Brushoj et al. (2008) included five exercises for strength, flexibility and coordination (Table 2.5). A limitation of this program was the use of only one coordination exercise. The coordination exercise was performed with instructions to start in a standing position then 'flex the knees and lift the heels; extend and then flex the knees; lower the heels' (Brushoj et al., 2008, p. 666). Potentially, this exercise minimally challenges lower limb stability because it was performed in a bilateral position. Included were hip abduction and external rotation exercise using a theraband performed on a single leg and the quadriceps stretch on a single leg which are more likely to challenge lower limb stability, although challenging stability was possibly not the primary intention of these exercises. Another limitation of this exercise prescription is the absence of core stability training. Core or trunk stability exercises have been included in successful injury prevention programs for floorball and handball players (Olsen et al., 2005; Pasanen et al., 2008) and are also included as part of the definition of neuromuscular training proposed by Myer et al. (2011).

Brushoj et al. (2008) prescribes an exercise frequency of three to five exercises for 15 minutes, three times per week for 12 weeks (Table 2.5). Olsen et al. (2005) has previously used an exercise duration of 15 minutes for handball players, however the exercise type, number, frequency and session duration used by Brushoj et al. (2008) may have been insufficient to lower injury incidence in their intervention group of Danish Life Guard conscripts. The execution of correct exercise technique and consistency in performance has also been questioned (Coppack et al., 2011). Supervision of exercise may not have been provided by qualified staff (Myer et al., 2011) which could have affected recruits compliance and possibly negatively affected the studies outcomes (Coppack et al., 2011).

Coppack et al. (2011) used eight exercises during the warm up and warm down periods to prevent anterior knee pain in UK Army recruits. Exercises were performed up to seven times per week (Table 2.5). The eight exercises included four strengthening exercises of the quadriceps and gluteal muscles. Strengthening exercises included single leg stability exercises such as isometric hip abduction, single-leg step downs, and single-legged squats. Four exercises involved soft tissue stretches of the hamstrings, quadriceps, gastrocnemius, and iliotibial band. At least three of these included exercises, hip abduction against a wall, single-leg step down, and single-legged squats could also challenge stability and the neuromuscular system. Whilst a specific reference to core exercise was not given, exercises aimed at strengthening the gluteal region could be considered a type of core strengthening exercise. Core stability exercises are included in high-quality neuromuscular training research (Olsen et al., 2005; Pasanen et al., 2008).

Coppack et al. (2011) suggests an exercise frequency with a gradual progression of 10 to 14 sets, seven times per week for 14 weeks to lower anterior knee pain incidence. The total weekly exercise time duration was 105 minutes, with emphasis on movement quality, specifically the hip and knee in relation to the foot (Table 2.5). This exercise prescription resulted in a 75%

reduction in anterior knee pain of the intervention group and the improvement in occupational outcomes compared to the control group. The results suggest the type of exercise and exercise prescription is effective for reducing the incidence of anterior knee pain in military recruits undertaking initial basic training. It was unclear if this program had any effect on the incidence of lower limb injuries other than knee and ankle injuries, although incidence of ankle injuries was not described in detail in this paper.

Goodall et al. (2013) included structured balance and agility training over 43 physical warm up training sessions during 26 weeks of basic training in Australia Army recruits. Balance exercises were performed approximately three to four times per week, involving two 25 second bouts each leg, in sagittal, frontal and transverse planes. Exercise difficulty was progressed each subsequent session. Agility training of 5 minutes was performed for 13 warm up sessions. Intervention exercises were in addition to the existing physical training workload, while the control group continued regular physical training without the balance or agility exercises (Goodall et al., 2013). A negative association was found. Recruits receiving balance and agility exercises had a 25% increase of lower limb injury compared to the control group (Goodall et al., 2013). A limitation of this research is that balance and agility exercises were additional to existing physical training. The increase in physical load and time for intervention recruits potentially leads to greater physical fatigue and could be responsible for increased lower limb injuries; a limitation acknowledged by the authors.

The injury prevention program used by Parkkari et al. (2011) included eight weeks of neuromuscular training together with injury prevention education and counselling. The neuromuscular program consisted of nine exercises performed three times per week, for a total weekly duration of 30 to 45 minutes (Parkkari et al., 2011) (Table 2.5). Emphasis was given to proper exercise technique with use of core, and knee over toe position for each exercise. The nine exercises with progressions included: 1) two exercises for balance and posture; 2) one for coordination and agility; 3) three for control of the lumbar neutral zone; 4) two for core (trunk) stability and trunk muscle endurance; 5) one involved eccentric hamstring strengthening; 6) two for lower extremity muscle extensibility; and 8) one exercise (exercise nine) targeting thoracic spine mobility (Parkkari et al., 2011, p. 5). After week nine, conscripts continued to exercise independently at least once a week, with logbooks checked by exercise instructors once weekly. Conscripts also received educational counselling of musculoskeletal injury and injury hazards at various times in training (Parkkari et al., 2011). A booklet was also issued to explain situations that could pose a high risk of injury such as uneven surfaces and basic education was given on how to manage acute injury (Parkkari et al., 2011).

Parkkari et al. (2011) found that the intervention group had a significant decrease in risk of acute ankle injury for conscripts with low to high baseline fitness level (adjusted HR = 0.34, 95% CI 0.15 to 0.78, P = 0.011). A significant decrease in upper extremity injuries was also found in the high baseline fitness group (adjusted HR = 0.37, 95% CI 0.14 -0.99, P = 0.047). The intervention group also tended to have less time-loss due to injury (adjusted HR = 0.55, 95% CI 0.29 to 1) (Parkkari et al., 2011).

It appears that the type, the number, duration, and frequency of exercise prescribed by Parkkari et al. (2011) was effective for the prevention of acute ankle injury in young male conscripts when combined with injury prevention counselling. It is difficult to determine the magnitude of effect from the exercise program itself, or the injury prevention counselling and weekly exercise logbook audits, on the overall results of this research. This needs careful consideration when comparing the results of this study to other studies using exercise only interventions.

Carow et al. (2016) investigated USMA cadets comparing an active warm up (control) group to two DIME exercise groups supervised by either cadre staff (performed by upper-class cadet instructors only) or expert supervisors (certified athletic trainer or physical therapist) directing upper class cadets. Exercises were performed for 10 minutes, three times per week for six weeks (Table 2.5). Only the DIME groups progressed their exercises at week three to further challenge core, strength, and stability as they moved from bilateral to unilateral positions. This exercise prescription did not result in significant injury reduction outcomes compared to active warm up control (Carow et al., 2016). Expert supervised DIME did however decrease lower extremity injury risk by 41% compared with the cadre supervised group suggesting expert supervision is important for better outcomes with injury prevention programs (Carow et al., 2016). A limitation of this study was that lower extremity injury was only reported to first time injuries, and multiple injuries, skin injury, lacerations and contusion were not included, possibly underestimating the injury problem.

2.6.2 Proposed neuromuscular exercise prescription for military recruits.

This section describes a proposed neuromuscular exercise program for military recruits using general and specific warm up exercises. Prescription of neuromuscular exercise type, frequency, total and weekly duration, period of training time, and number of exercises will be discussed.

2.6.2.1 Neuromuscular exercise prescription for military recruit populations.

Neuromuscular exercise prescription integrates principles of general warm up running drills and specific exercises that include strength and conditioning activities, such as resistance, dynamic stability, core strength, plyometric and agility training (Myer et al., 2011). The proposed neuromuscular exercise prescription was based predominantly on available military recruit neuromuscular prevention programs but also includes neuromuscular prescription from sports populations when information was limited.

Neuromuscular exercise prescription should include both general and specific warm up exercises (Myer et al., 2011). General warm up running drills were not included or not clearly reported preceding specific exercises in military recruit neuromuscular training studies (Brushoj et al., 2008; Coppack et al., 2011; Goodall et al., 2013). Standardising time and intensity of general running drills is important, therefore the running drills from sports populations help inform development of the proposed neuromuscular training for this recruit cohort (Olsen et al., 2005; Pasanen et al., 2008). Running drills previously used in sports studies that reflect recruit specific tasks (marching, drill, running, physical training and pack walking) included forward, backwards running, heel flicks and knee raises, side-ways, carioca and speed running (Olsen et al., 2005; Pasanen et al., 2008). Two phases of running drills were identified and aim to gradually warm up the body. These phases include light jogging of approximately 2 to 7 minutes and could include running techniques (for example forward, backward, sideways running), followed by speed running of approximately 30 seconds to 2 minutes (Olsen et al., 2005; Pasanen et al., 2008). The proposed neuromuscular program includes 3 minutes light jogging with running techniques consisting of forwards, backwards, sideways, with heel flicks, knee raises and carioca. This is followed by 2 minutes medium speed running. Running warm up was performed across the length of the gymnasium.

Based on the limited number of available military recruit studies, neuromuscular injury prevention training programs for specific exercise types could include lower limb strength (Brushoj et al., 2008; Coppack et al., 2011; Parkkari et al., 2011), balance (Goodall et al., 2013; Parkkari et al., 2011), agility (Goodall et al., 2013; Parkkari et al., 2011), flexibility/stretching (Brushoj et al., 2008; Coppack et al., 2011), core stability and thoracic spine mobility (Parkkari et al., 2011). Plyometric type exercises such as jumping from side-to-side (Parkkari et al., 2011), single knee step downs from 20 cm step (Coppack et al., 2011), lateral or front hop/jump and jump were also included in neuromuscular training programs in previous research (Goodall et al., 2013). A combination of specific exercise types is proposed for neuromuscular training with army recruits.

Exercise frequency is described between three to seven times per week for recruit neuromuscular programs (Brushoj et al., 2008; Coppack et al., 2011; Parkkari et al., 2011). A training frequency of two to three alternative days is suggested for resistance training of untrained individuals (American College of Sports Medicine, 2009). This is because the volume of strength and conditioning training (> three times weekly) influences the ability to recover and adapt to training and may contribute to overtraining and injury risk if the frequency is too high (Andersen et al., 2016; Myer et al., 2011). The exercise frequency of two to five times per week (average > 3 per week) was proposed for this recruit cohort due to the physical training program timings scheduled within the army training program.

Neuromuscular session duration has been suggested between 15 and 35 minutes with the total weekly exercise duration between 45 and 105 minutes in military recruit populations (Brushoj et al., 2008; Coppack et al., 2011; Parkkari et al., 2011). The proposed recruit neuromuscular session duration is between 36 and 100 minutes, based on a frequency of 2 to 5 neuromuscular warm up sessions per week. In sports studies, Olsen et al. (2005) reported a 50% reduction in acute knee and ankle injuries using a structured neuromuscular warm up program of 15-20 minutes across 15 subsequent sessions in adolescent handball players. Additionally, a session duration of 20-30 minutes for neuromuscular warm up training two to three times weekly for a period of 16 weeks resulted in a 66% fewer non-contact leg injury in floorball players (Pasanen et al., 2008). It is possible a minimum volume of exercise is required for improvements in motor control and reductions in injury incidence to be observed (Coppack et al., 2011). For instance, a six-week injury prevention program performed for 10 minutes three times a week, and total weekly exercise duration of 30 minutes did not achieve significant reductions in lower extremity injury compared to an active control group for military academy cadets (Carow et al., 2016). Alternatively, balance and agility training applied in addition to existing warm up exercise may have increased recruit workload (training error) and fatigue, and potentially increased lower limb injury risk (Goodall et al., 2013).

Based on the military recruit research reviewed, an intervention period between eight weeks and six months commencing at the start of basic training was suggested (Brushoj et al., 2008; Coppack et al., 2011; Parkkari et al., 2011). A similar exercise period between three and six months is suggested from a systematic review of sports injury populations, however further research of the dose-response relationships is required (Hubscher et al., 2010). More recently, a meta-analysis suggests neuromuscular training period between 1.5 to 6 months is effective to prevent injury in youth athletes (Steib et al., 2017). Neuromuscular training which targets the initial five to seven weeks of recruit training is important as this is when the majority of recruit injuries occur (Coppack et al., 2011; Hall, 2017; Heller & Stammers, 2020; Jordaan & Schwellnus, 1994; Robinson et al., 2016). The proposed intervention period was limited to six-weeks. This was because New Zealand Army recruits undertake administrative activities' week one and at mid-course, transition into the field phase of training (out of camp). Only week two to seven of basic training were available for implementation of neuromuscular training.

For recruit populations, the total number of specific exercises reported in prevention programs ranged from eight to ten to for injury prevention (Brushoj et al., 2008; Coppack et al., 2011; Parkkari et al., 2011). This number reflects only specific exercise types, because general running warm up exercises were not included in military recruit neuromuscular type programs. For this program of research, 12 to 13 specific exercises were included to target injuries pertaining to the whole lower limb. Military recruit studies targeting specific diagnosis such as anterior knee pain used fewer exercise number (Coppack et al., 2011).

The effectiveness of the proposed six-week neuromuscular training program aiming to lower incidence of lower limb injury sustained by New Zealand Army recruits during basic training will be investigated in Study 3.

Table 2.7 summarises the neuromuscular injury prevention prescription proposed based on previous military recruit studies.

Table 2.7

Proposed Neuromuscular Injury Prevention Exercises for Military Recruits

Exercise description	Exercise prescription
Exercise type	Neuromuscular, strength/conditioning, stretches, core/trunk stability, agility, plyometric
Frequency	3-7x per week
Duration	15-35 minutes
Total weekly duration	45-105 minutes
Period	8-26 weeks
Number of exercises	8-10 exercises

Note: Table data based on summarised information (Brushoj et al., 2008; Coppack et al., 2011; Myer et al., 2011; Parkkari et al., 2011).

2.6.2.2 Neuromuscular training implementation considerations for military recruits

For implementation of neuromuscular training programs to be successful, factors such as execution of correct exercise technique, supervision by qualified staff and compliance to the exercise program are important, as is the culture and environment of military recruit training.

Attention needs to be given to the performance of correct exercise technique and movement control for neuromuscular training (Almeida et al., 1997; Carow et al., 2016; Coppack et al., 2011; Myer et al., 2011; Olsen et al., 2005; Parkkari et al., 2011). Particular emphasis for 'knee over toes' position achieved through improved alignment of the hip and knee in relation to the foot together with a focus on core/trunk stability are common components of effective lower limb injury prevention programs in sports and military recruit studies (Coppack et al., 2011; Olsen et al., 2005; Parkkari et al., 2011; Pasanen et al., 2008). Emphasis of correct alignment in sagittal and frontal planes of movement, including frontal knee projection angle, is also important (Nakagawa et al., 2020).

Supervision by qualified staff is important to ensure correct execution of exercises, as improper exercise technique may increase the risk of injury (Carow et al., 2016; Myer et al., 2011). Qualified staff were identified as physiotherapists, certified athletic trainers (Carow et al., 2016) or qualified army physical training instructors (Coppack et al., 2011) rather than recruits or upper-class cadet instructors trained by the trainer (Carow et al., 2016).

Supervision of exercise by qualified staff may also contribute to high exercise compliance. High exercise compliance, suggested being equal to or greater than 90%, potentially contributes to improved exercise outcomes and reduced risk of injury (Coppack et al., 2011; Parkkari et al., 2011). Alternatively, low compliance to exercise program participation may not induce the necessary training effect or neuromuscular adaption required to reduce injury (Hubscher et al., 2010, p. 418; Owoeye, Rauvola, et al., 2020; Steffen et al., 2008).

Ideally a neuromuscular injury prevention program for military recruits should be effective for periods of high physical intensity, challenging climate and environmental conditions and not impede performance or risk further injury (Andersen et al., 2016; Davidson et al., 2009; Owoeye, Rauvola, et al., 2020). It should also be suitable for all individuals whether recruits or trained personnel (Davidson et al., 2009; Myer et al., 2011).

Incorporating injury prevention exercises into the existing physical training program and recruit military training syllabus may be difficult as it may challenge the existing military culture and established military physical training methods (Davidson et al., 2009). Effective neuromuscular training will only succeed if it is accepted, adapted and performed with optimal compliance by all parties involved (Finch, 2006). Overcoming potential implementation obstacles required careful consideration, planning, education, and negotiation with the recruit military training unit (The Army Depot), camp headquarters and physical training instructors in the New Zealand Army.

2.6.2.3 **Summary of neuromuscular exercise prescription for military recruits**

Military recruits undergoing basic training experience a high incidence of training-related musculoskeletal injuries. Many of these injuries may be preventable or modifiable. Research about sports-specific injury prevention programs based on neuromuscular training principles has achieved significant reductions in the incidence of lower limb injury of athletic and sports populations. Caution is required in the generalisation of sports injury outcomes to military recruit populations.

Minimal research has been conducted on the effectiveness of neuromuscular injury prevention programs for basic training military recruits. Significant reductions in the incidence of anterior knee pain (Coppack et al., 2011) and incidence of acute ankle injury have been observed in recruits (Parkkari et al., 2011), however the effectiveness of such programs on other common lower limb injuries incidence remains less clear.

A lack of research, methodological flaws of available research and variation in neuromuscular exercise prescription may account for the current lack of knowledge of the effectiveness of military specific neuromuscular injury prevention programs. Investigating the prescription of an effective neuromuscular injury prevention program for New Zealand Army recruits undergoing basic training informs Study 3 of this doctoral program of research.

3. RESEARCH METHODS AND OVERVIEW

The extent of the injury problem in military recruits during basic training is considerable. While the injury profile of military recruits has been investigated in some countries, there is a lack of detailed and current information for New Zealand Army recruits. Differences in entry eligibility criteria, training period and process and equipment and uniform mean that previous findings cannot be necessarily applied to New Zealand Army recruits. This is of particular importance as New Zealand Army recruits have previously been shown to have some of the highest injury incidence in the world (Davidson et al., 2008). In addition, implementation of effective injury prevention measures for New Zealand Army recruits can only be achieved if the full extent of the injury problem is first established and recruit injury risk factors identified.

This Doctor of Philosophy program of research comprises four studies to address these gaps in the literature.

These studies are further described below.

3.1 AIMS AND SIGNIFICANCE OF THE RESEARCH

3.1.1 Aims

The aim of the current program of research was to establish the extent to the New Zealand Army recruit injury problem, the profile and aetiology of recruit injuries and the effect of six weeks neuromuscular training compared to usual training on incidence of lower limb injury of New Zealand Army recruits undertaking basic training. Secondary goals are to determine the number of health care encounters, occupation endpoints achieved (successful completion, discharge, backsquad) and injury time loss for injuries sustained during basic training between study groups. A final analysis will consider predictors of baseline characteristics and actual injuries sustained to identify New Zealand Army recruits at heightened risk of injury upon entry.

The aims of the studies were:

Study 1:

1. To identify incidence and patterns of injuries reported from physiotherapy presentations for New Zealand Army recruits undertaking basic training over a four-year period.

Study 2:

2. To describe the profile of male and female New Zealand Army recruits entering basic training across two recruit intakes including personal, lifestyle and physical performance characteristics

Study 3:

1. To investigate if a six-week neuromuscular training program would lead to fewer lower limb injuries in New Zealand Army recruits undertaking 17 weeks of military basic training compared to usual training.

2. Secondary aims will investigate if six weeks neuromuscular training:
    a) Lowers the number of total health care encounters.
    b) Improves occupation endpoint achieved (successful graduation, backsquad, discharge); and
    c) Lowers training time loss for injuries sustained during basic training.

Study 4:

1. To investigate if baseline personal, lifestyle and physical performance characteristics reported at entry to training could identify recruits who sustained lower limb injury during New Zealand Army basic training.

3.1.2 Significance

While injury rates for NZDF (tri-service) recruits have been reported in the past, the data are from 2002-2003 or older. Furthermore, study periods are less than one year duration and may not represent current training regimes and recruit injuries sustained over a longer period of time (Davidson et al., 2008; Stacy & Hungerford, 1984). More recent New Zealand Army recruit injury incidence data were needed to identify the current extent of the recruit injury problem (van Mechelen et al., 1992). In addition, information describing recruit's personal, lifestyle and physical performance profiles entering the service was unknown, and it was unclear if recruits were entering with pre-existing injury risk factors at the commencement of basic training.

Understanding recruit injury risk factors assists with the planning and implementation of injury prevention interventions which aim to reduce the burden of injury experienced by recruits on basic training. Neuromuscular training has been identified as a cost-effective intervention to help reduce injury in sports populations; however, research was lacking to investigate its effectiveness with New Zealand Army recruits.

An investigation of the effectiveness of neuromuscular training for injury prevention specific for New Zealand Army recruits is presented in this Doctor of Philosophy. Additionally, health care encounters, occupational endpoint outcome and injury time loss, are investigated between neuromuscular training and usual training groups. A final analysis of predictors of injuries sustained by New Zealand Army recruits undertaking basic training from personal, lifestyle and physical performance profiles will help to identify recruits at heightened risk of injury at commencement of training.

This research was supported by NZDF who were eager to promote and support injury surveillance and injury prevention initiatives which aim to improve the health and wellbeing of their military personnel. The outcomes of this research program have potential implications for other recruit populations, regular military personnel, other tactical populations and may also be applicable to sporting and active adventure training groups.

Findings of this program of research contribute to the expanding knowledge of military recruit injury incidence, injury risk factors, and potential effectiveness of a neuromuscular injury prevention program for army basic training recruits. Implementation of an effective injury prevention program has the potential to reduce recruit injury incidence, injury time loss and discharge from the service (Davidson et al., 2009; Kaufman et al., 2000; Pope et al., 1999). For the military, lowering the incidence of recruit injury avoids training time delays (Davidson et al., 2009; Kaufman et al., 2000), lowers demand for health resources (Gordon et al., 1986; Heir & Glomsaker, 1996; Pope et al., 1999; Rudzki, 2009) and potentially results in greater numbers of recruits successfully graduating onto the next phase of training (trades and operational units) improving operational readiness and deployment capability (Kaufman et al., 2000; Molloy et al., 2012; Pope et al., 1999).

3.2 Research methods

The research methods of four individual studies will be presented within Chapters 4 to 7. Ethical approvals, permissions to publish, trial registrations and ethical considerations will be discussed in the following sections.

3.3 Ethical approvals and considerations

3.3.1 Permission to publish

A requirement of research with the NZDF is permission must be obtained to present information of military populations within the public domain. Permission to publish non-identified New Zealand Army recruit information was granted by the Principal Advisor, People Capability Portfolio Headquarters Organisational Research, NZDF for Study 1 on the 25 November 2020, Study 2 on the 30 November 2021 and Study 3 on the 28 May 2024. Similar permissions will be obtained for Study 4 with a future application for publication.

3.3.2 Ethical approvals

For Study 1 ethical approval was obtained from Australian Catholic University Human Research Ethics Committee (2019-363N) and through a New Zealand Official Information Act request for the use of non-identified physiotherapy presentation data for army recruits presenting to basic training from 2008 to 2011 (Air Cdre A. Woods, personal email communication 8th March 2019). Permission for use of additional retrospective non-identified physiotherapy injury data was obtained through the Principal Advisor Organisational Research, People Capability Portfolio Headquarters NZDF (15 July 2019). Recruit graduation rates were retrieved from publicly available sources for the reporting period (New Zealand Ministry of Defence, 2015).

For data collected for Study 2 to 4, ethical clearance was granted by the Commander of Training and Doctrine from the NZDF February 2012 (Updated 2019) and from Griffith University Human Research Ethics Committee May 2012 (PES/36/11/HREC) (10.2 Appendix B). Ethical permission was addressed to M. Constantinou who was working for Griffith University at the time of application.

3.3.3 Trial registration

Study 3 was retrospectively registered with Australian New Zealand Clinical Trial Register ANZCTR (ANZCTR12619001651178, 26/11/2019).

3.3.4 Ethical and other considerations

Permission to use non-identified data of New Zealand Army recruit populations was possible under The New Zealand Privacy Act 1993. Relevant permissions are detailed in Part 2, Information on privacy principles, Principle 2, Source of personal information (2g) that information will be used for statistical or research purposes and will not be published in a form that could reasonably be expected to identify the individual concerned (New Zealand Government: Parliamentary Counsel Office, 2019).

4. Study 1: Prevalence of musculoskeletal injuries in New Zealand Army Recruits as defined by physiotherapy service presentations

Study 1 was accepted by the journal of Military Medicine 29th Apr 2021 and has been published.

The publication uses physical therapy as this was an American journal. This has been amended to physiotherapy in this chapter for consistency within the thesis.

Hall, N., Constantinou, M., Brown, M., Beck, B., & Kuys, S. (2022). Prevalence of musculoskeletal injuries in New Zealand Army recruits as defined by physical therapy service presentations. Military Medicine 187, (1-2), 174-181. https://doi.org/10.1093/milmed/usab186

4.1 ABSTRACT

Introduction: Army recruit injuries occurring during basic training can lead to high personal and organisational burdens potentially threatening deployment capability. Previous military surveillance describing recruit injury as defined by physiotherapy presentations is limited to one-year duration or includes only male infantry recruits or trained personnel. Research describing injury incidence and trends specific to New Zealand Army basic training recruits over a longer period will better inform future injury prevention programs.

Aims: To identify annual incidence and patterns of injuries reported from physiotherapy presentations for New Zealand Army recruits undertaking basic training, over a four-year period.

Methods: This retrospective observational study identified injuries from physiotherapy service presentations in New Zealand Army recruits from 2008 to 2011. All male and female New Zealand Army recruits who presented to physiotherapy, following medical triage, were included. Recruit physiotherapy presentations for injury and respiratory and other conditions were collated. Injury incidence was grouped by body region (upper limbs, lower limbs and combined spinal regions) and site (joint or segment) and cumulative and injury incidence rates were calculated.

Results: One thousand eight hundred and ninety-six (1697 males, 199 females) New Zealand Army recruits commenced basic training between 2008 to 2011. One thousand six hundred and eighty-three physiotherapy presentations occurred for recruit injury during New Zealand Army basic training over four years. Lower limb injuries accounted for over 75% (n = 1285) of the overall demand for physiotherapy service during recruit basic training. Injuries sustained at the knee and below accounted for 67% of all reported injury presentations.

Conclusion: Four years of injury surveillance using physiotherapy presentations identified the lower limb, with the knee and below as the most commonly injured regions in New Zealand Army recruits. Injury prevention interventions for New Zealand Army recruits should aim to reduce lower limb injuries. Future research on injury surveillance would benefit from incorporating clear injury and severity definitions, established injury classification systems and standardised incidence calculations.

4.2 BACKGROUND

Army recruit injuries are an important issue for militaries that result in high personal and organisational burdens and potentially undermine deployment capability (Almeida et al., 1999; Kaufman et al., 2000; Molloy, Pendergrass, Lee, Chervak, et al., 2020; Orr et al., 2020; Pope et al., 1999; Rudzki & Cunningham, 1999). Historically, higher incidences of injury have been reported by basic training recruits compared to trained personnel (Davidson et al., 2008; Molloy, Pendergrass, Lee, Chervak, et al., 2020; Schram et al., 2019) with recruit injury rates being five times higher in the NZDF (Davidson et al., 2008) and three times higher than other physical training periods in Australian Defence Force recruits (Schram et al., 2019; Sherrard et al., 2004). The majority of recruit injuries are of the lower limb, with incidence rates as high as 80% of all injuries sustained (Almeida et al., 1999; Jordaan & Schwellnus, 1994; Robinson et al., 2016). Recruit overuse injuries (>65%) are more commonly reported than acute injuries (13% to 35%) in several countries (Almeida et al., 1999; Jordaan & Schwellnus, 1994; Robinson et al., 2016; Rosendal et al., 2003) while more acute over-exertion (61%) injuries have been reported in NZDF tri-service recruits (Davidson et al., 2008).

Low level entry fitness (Hall, 2017; Heller & Stammers, 2020; Jones, Cowan, et al., 1993; Orr et al., 2020; Robinson et al., 2016), previous injury (Jones, Cowan, et al., 1993; Robinson et al.,

2016) smoking history (Jones, Cowan, et al., 1993; Knapik et al., 2013a), older age (Jones, Cowan, et al., 1993; Knapik et al., 2013a), female sex (Knapik et al., 2013a; Molloy, Pendergrass, Lee, Chervak, et al., 2020), abrupt or sudden onset of training (Almeida et al., 1999), high volumes of vigorous physical exercise (Almeida et al., 1999; Kaufman et al., 2000) and lack of specific military training experience (Davidson et al., 2008) are some of the complex factors that may contribute to the high injury incidence experienced by recruits during training.

Musculoskeletal injuries occurring during training can have detrimental consequences for both recruits and the military (Andersen et al., 2016; Molloy, Pendergrass, Lee, Chervak, et al., 2020; Pope et al., 1999). For individual recruits, consequences include the risk of subsequent injury (Andersen et al., 2016; Molloy, Pendergrass, Lee, Chervak, et al., 2020), injury chronicity (Cameron et al., 2016; Molloy, Pendergrass, Lee, Chervak, et al., 2020), time loss (Kaufman et al., 2000; Robinson et al., 2016) and alteration in career progression due to backsquad (training delay) and discharge (attrition) from the service (Orr et al., 2020; Rudzki & Cunningham, 1999). For instance, recruits who sustain a lower limb injury during basic training in the Australian Army are 10 times more likely to be discharged than recruits sustaining no injury (Pope et al., 1999).

For the military, consequences of recruit injury can result in increased financial and training costs (Molloy, Pendergrass, Lee, Chervak, et al., 2020; Pope et al., 1999; Rudzki & Cunningham, 1999), work and training time loss (Kaufman et al., 2000), increased demand and cost on health resources (Molloy, Pendergrass, Lee, Chervak, et al., 2020; Pope et al., 1999; Rudzki & Cunningham, 1999; Sharma et al., 2015) and higher recruitment and retention costs (Heagerty & Sharma, 2018; Molloy, Pendergrass, Lee, Chervak, et al., 2020; Pope et al., 1999; Rudzki & Cunningham, 1999; Sharma et al., 2015). For instance, overall replacement costs for medically discharged US military recruits are estimated at USD $88 million (approximately 1177 recruits) at a rate of USD $75,000 per injured recruit (Molloy, Pendergrass, Lee, Chervak, et al., 2020). Operational effectiveness is also impacted as fewer recruits move onto trades and operational units which in-turn impact supply of trained soldiers available for deployment (Heagerty & Sharma, 2018; Heagerty et al., 2017b; Molloy, Pendergrass, Lee, Chervak, et al., 2020). Entry-level basic training-related injuries therefore present a significant medical impediment to operational efficiency and military readiness (Heagerty & Sharma, 2018; Molloy et al., 2012; Molloy, Pendergrass, Lee, Chervak, et al., 2020).

Prevention of recruit injury during basic training is paramount to achieve reductions in associated burdens and consequences. Injury surveillance is therefore required to understand the injury context and scale of the recruit injury problem; a fundamental first step in sports injury prevention models (Bolling et al., 2018; van Mechelen et al., 1992, p. 84) and one that can be adapted to the military population.

Physiotherapists are well placed to conduct injury surveillance as they typically provide point of care contact for military populations (Pope & Orr, 2017). Injury surveillance obtained from physiotherapy presentations has previously reported injury incidence rates of both military recruits (Heagerty & Sharma, 2018; Heagerty et al., 2017b; Heagerty et al., 2017c; Rudzki & Cunningham, 1999; Sharma et al., 2015) and trained personnel (Gruhn et al., 1999; Hebert & Rowe, 2007). However, these surveillance studies are limited to one year duration in Australian Army recruit intakes (Rudzki & Cunningham, 1999), are based on predominantly male UK infantry recruits (Heagerty & Sharma, 2018; Heagerty et al., 2017b; Heagerty et al., 2017c; Sharma et al., 2015) or based on trained or deployed military populations (Gruhn et al., 1999; Hebert & Rowe, 2007). Therefore, contemporary entry requirements, training regimes and injury trends may not be represented for New Zealand Army basic training recruits over time.

4.2.1 Aims

To identify incidence and patterns of injuries reported from physiotherapy presentations for New Zealand Army recruits undertaking basic training over a four-year period.

4.3 METHODS

4.3.1 Design

An observational study of New Zealand Army recruit injury over four years based on physiotherapy presentations.

4.3.2 Participants

All male and female New Zealand Army recruits who presented to physiotherapy between 2008 and 2011 were included. To be eligible for inclusion, New Zealand Army recruits needed to attest (be sworn in) into the New Zealand Army, be regular force army recruits from All Arms Recruit Courses, and be referred to physiotherapy services for assessment and management following medical triage. All physiotherapy presentations were included for injury, respiratory, or other conditions. New Zealand Army recruits who were not referred to physiotherapy services via medical triage or failed to attend physiotherapy were not included.

To enter basic training in the New Zealand Army, recruits must successfully complete an entry fitness level test, a medical review and basic literacy testing. Recruit training is undertaken at an army camp in the Central North Island of New Zealand for 14 to 16 weeks. Each intake of approximately 120 recruits is issued standardised military uniforms and equipment and experience the same sleeping and eating arrangements throughout basic training. Only recruits who pass an on-site medical review and attest to the army in week one of basic training stay in the service and continue training. Recruits who commence basic training undergo physically and mentally demanding challenges (Heller & Stammers, 2020) designed to develop basic soldier skills comprising physical fitness, drill, marching, weapons range training, field exercise and classroom-based learning (New Zealand Defence Force: Defence Careers, 2019b). Recruits are exposed to a range of difficult terrain and training environments with varying training intensities. On successful completion of basic training, recruits move onto operational units (e.g. infantry and logistics) or trade training (e.g. chef and mechanic) for career progression.

4.3.3 Physiotherapy presentation data

Data regarding recruit injury incidence by body region (upper limbs, lower limbs, combined spinal regions, respiratory and other) and site (joint or segment) (International Olympic Committee et al., 2020) were retrieved from physiotherapy service records (manual and electronic) over a four-year period and entered in a non-identified format in Microsoft Excel (Version 2010). All recruits who were referred to and attended physiotherapy services (outpatients and inpatients) following medical triage and underwent assessment and treatment for their condition were included. Data were tallied into a yearly tabulated document by a single physiotherapy (the Candidate) working on-site.

Physiotherapy presentations were included if management was provided for musculoskeletal, respiratory, and other conditions. Musculoskeletal injury conditions were defined as any symptoms of pain, inflammation or functional disorder that: involved the musculoskeletal or soft tissues; was serious enough for the recruit to seek and obtain a medical consultation; could have occurred entirely or in part as a consequence of an external trauma or strain sustained during basic training (Heir & Glomsaker, 1996, p. 187; Rosendal et al., 2003, p. 159); and could have included an exacerbated pre-existing injury requiring physiotherapy during basic training. Respiratory provision included any physiotherapy advice or techniques to assess and manage a respiratory presentation such as pneumonia. Other categories refer to any physiotherapy presentations that did not fit into the above categories such as women's health and exercise advice.

Non-identified baseline recruit demographics were collated by the NZDF research administration staff. This was a requirement due to privacy regulations of the NZDF for the collection of retrospective data.

4.3.4 Analysis

Injury data were recorded by body region and site. The cumulative injury incidence (%) was calculated as: recruits with one or more injuries divided by all recruits × 100 (Knapik et al., 2011, p. 498). Recruit injuries reported from physiotherapy usage data included both new patient and follow up data. Recruit injury incidence rates (injuries/1000 person-days) were calculated as: recruits with one or more injuries divided by total time in company for all recruits × 1000 (Knapik et al., 2011).

4.3.5 Ethical approvals

Ethical approval information is presented in Chapter 3.3.

4.4 RESULTS

In total, 1683 physiotherapy presentations occurred for recruit injury during New Zealand Army basic training over four years. A total of 1896 recruits commenced training over this period comprising 1697 male (90%) and 199 female (10%) recruits. Mean age was 19.9 years (range 17.0-49.3 years). The duration of basic training was initially 14 weeks (2352 hours) in 2008 increasing to 16 weeks (2688 hours) across four years (Table 4.1).

Table 4.1

Recruit Demographics

Year		2008	2009	2010	2011
No. of recruits	Enlisted	707	458	313	418
	Graduated	633 (89.5%)	422 (92.1%)	280 (89.4%)	367 (87.8%)
Age, years	Median	18.5	18.5	19.0	19.2
	(Range)	(17.0-42.0)	(17.0-49.3)	(17.0-36.9)	(17.0-42.4)
	Mean (SD)	19.3 (2.6)	19.8 (3.8)	20.1 (3.1)	20.2 (3.1)
Sex	Male	633 (89.5%)	408 (89.1%)	278 (88.8%)	378 (90.4%)
	Female	74 (10.5%)	50 (10.9%)	35 (11.2%)	40 (9.6%)
Training exposure time[a]	Days	98	98	112	112
	Hours	2352	2352	2688	2688

Note. SD = Standard Deviation.

[a]Training exposure time is the number of days (or hours) an athlete (recruit) is considered at risk of injury (International Olympic Committee et al., 2020).

Recruit musculoskeletal injuries or conditions to the lower limb accounted for over 75% (n = 1285) of the overall demand for physiotherapy service. This was followed by musculoskeletal injuries or conditions to spinal (12.4%, n = 208) and upper limb regions (10.2%, n = 172) (Table 4.2).

Table 4.2

Physiotherapy Presentations of Service by Injury Region and Site 2008 to 2011

Region	2008	2009	2010	2011	Total injuries per site	Proportion of all injuries (%)
Lower limbs						
Hip/Groin	35	21	32	20	108	6.4
Thigh	20	12	5	20	57	3.4
Knee	112	95	105	92	404	24
Shin/Calf	168	63	77	62	370	22
Ankle/Foot	62	45	88	151	346	20
Total	397	236	307	345	1285	76.4
Upper Limb						
Shoulder	45	13	20	47	125	7.4
Upper arm	0	0	0	0	0	0.0
Elbow	1	0	3	9	13	0.8
Forearm	0	0	0	5	5	0.3
Wrist/Hand/Thumb	16	8	2	3	29	1.7
Total	62	21	25	64	172	10.2
Respiratory	0	0	4	3	7	0.4
Spinal						
Cervical Spine	1	2	7	23	33	2.0
Head/Face	0	0	0	7	7	0.4
Thoracic Spine	0	2	9	17	28	1.7
Ribs/Sternum	0	0	7	8	15	0.9
Lumbar Spine	11	18	47	49	125	7.4
Sacrum/Coccyx	0	0	0	0	0	0.0
Total	12	22	70	104	208	12.4
Other	2	1	6	2	11	0.7
Total injuries	473	280	412	518	1683	100

Note. Duration of physiotherapy service was typically 30 minutes.

From 2008 to 2011, average cumulative injury incidence was greatest for the lower limb (14.4%) body region, followed by spinal (2.2%) and upper limb regions (1.8%) (Table 4.3).

Across the lower limb, average cumulative injury incidence was greatest at the knee (23.0%) followed by the ankle/foot (20.7%) and the shin/calf (19.2%) (Table 4.3).

Table 4.3

Cumulative Injury Incidence Reported from Physiotherapy Presentations 2008-2011

Region	Cumulative injury incidence % per year				
	2008	2009	2010	2011	Average
Lower Limb					
Hip/Groin	5.0	4.6	10.2	4.8	6.1
Thigh	2.8	2.6	1.6	4.8	3.0
Knee	15.8	20.7	33.5	22.0	23.0
Shin/Calf	23.8	13.8	24.6	14.8	19.2
Ankle/Foot	8.8	9.8	28.1	36.1	20.7
All Lower limb					14.4
Upper Limb					
Shoulder	6.4	2.8	6.4	11.2	6.7
Upper arm	0.0	0.0	0.0	0.0	0.0
Elbow	0.1	0.0	1.0	2.2	0.8
Forearm	0.0	0.0	0.0	1.2	0.3
Wrist/Hand/Thumb	2.3	1.7	0.6	0.7	1.3
All Upper Limb					1.8
Respiratory	0.0	0.0	1.3	0.7	0.5
Spinal					
Cervical spine	0.1	0.4	2.2	5.5	2.1
Head/Face	0.0	0.0	0.0	1.7	0.4
Thoracic spine	0.0	0.4	2.9	4.1	1.8
Ribs/Sternum	0.0	0.0	2.2	1.9	1.0
Lumbar spine	1.6	3.9	15.0	11.7	8.1
Sacrum/Coccyx	0.0	0.0	0.0	0.0	0.0
All Spinal					2.2
Other	0.3	0.2	1.9	0.5	0.7

Note. Cumulative injury incidence (%) = recruits with one or more injuries (physiotherapy services)/all recruits × 100 (Knapik et al., 2011, p. 498). Cumulative incidence based on total physiotherapy presentations for injury (new and follow-up).

When injury exposure time was considered, average total injury incidence over four years was 8.97 injuries /1000 person-days (Table 4.4).

Table 4.4

Recruit Injury Incidence Rates Reported by Physiotherapy Presentations per 1000 Days 2008-2011

Region	2008	2009	2010	2011	Average over 4yrs.
Lower limbs					
Hip/Groin	0.51	0.47	0.91	0.43	0.58
Thigh	0.29	0.27	0.14	0.43	0.28
Knee	1.62	2.12	3.00	1.97	2.17
Shin/Calf	2.42	1.40	2.20	1.32	1.84
Ankle/Foot	0.89	1.00	2.51	3.23	1.91
Lower Limb Total	5.73	5.26	8.76	7.37	6.78
Upper Limb					
Shoulder	0.65	0.29	0.57	1.00	0.63
Upper arm	0.00	0.00	0.00	0.00	0.00
Elbow	0.01	0.00	0.09	0.19	0.07
Forearm	0.00	0.00	0.00	0.11	0.03
Wrist/Hand/Thumb	0.23	0.18	0.06	0.06	0.13
Upper Limb Total	0.89	0.47	0.71	1.37	0.86
Respiratory	0.00	0.00	0.11	0.06	0.04
Spinal					
Cervical Spine	0.01	0.04	0.20	0.49	0.19
Head/Face	0.00	0.00	0.00	0.15	0.04
Thoracic Spine	0.00	0.04	0.26	0.36	0.17
Ribs/Sternum	0.00	0.00	0.20	0.17	0.09
Lumbar Spine	0.16	0.40	1.34	1.05	0.74
Sacrum/Coccyx	0.00	0.00	0.00	0.00	0.00
Spinal Total	0.17	0.49	2.00	2.22	1.22
Other	0.03	0.02	0.17	0.04	0.07
Total Injuries	6.83	6.24	11.75	11.06	8.97

Note. Injury exposure time = Injuries/1000 person-days (Knapik et al., 2011). Injuries reported based on physiotherapy service presentations (new and follow up).

Average total injury incidence was greatest for the lower limb body region (6.78 /1000 person-days) followed by spinal (1.22 /1000 person-days) and upper limb regions (0.86 injuries /1000 person-days).

4.5 Discussion

Four years of physiotherapy-based injury surveillance of New Zealand Army recruits found that lower limb musculoskeletal conditions and injuries accounted for over 75% of all physiotherapy presentations. Injuries sustained at the knee and below represented the highest proportion of all injuries sustained (67%) and the greatest demand for physiotherapy service during training.

Our findings are in line with other studies that similarly found high incidence of lower limb injuries at the knee and below in military recruits (Heller & Stammers, 2020; Knapik et al., 2001; Schram et al., 2019), although the rates vary. For example, injuries sustained at the knee and below accounted for approximately 45% of Australian Army regular force and approximately 39% of Australian Army reserve basic training recruits total injury incidence (Schram et al., 2019). Higher incidence rates at the knee and below are reported in UK female basic training army recruits (approximately 64%) (Heller & Stammers, 2020) and US Army basic combat training recruits (59% male, 69% female) as a percentage of total injuries reported (Knapik et al., 2001). In contrast, the highest injury incidence reported for UK male army recruits was sustained predominantly above and below the knee (25%), though the category included injuries of the hip, thigh and lower limb (Hall, 2017). One reason for this difference is likely that medial tibial stress syndrome was included with upper leg (hip and thigh) injury reporting (Hall, 2017). Reporting injuries by individual anatomical joint and segment categories is currently recommended by an International Olympic Committee Consensus Statement (International Olympic Committee et al., 2020). If recruit injury incidence is reported using only individual anatomical joints or segments, injuries occurring predominantly at the knee and below (shin/calf and ankle/foot) remain the greatest area of concern in this study and also for military services across multiple countries (Heller & Stammers, 2020; Knapik et al., 2001; Schram et al., 2019).

Interestingly, lumbar spine injury was the fourth highest site for cumulative injury incidence in the current study, however represented less than 8% of all physiotherapy presentations. Similarly, low incidence of low back pain is reported for both regular force (5.2%) and reservist (6.7%) Australian Army recruits (Schram et al., 2019) and US Army basic combat training recruits (7-11%) (Knapik et al., 2001). In contrast, low back pain was the most common injury reported (approximately 19%) in a study of 6488 Norwegian Army, Navy and Air Force conscripts (Heir & Glomsaker, 1996). This higher presentation of low back pain in the study by Heir and Glomsaker (1996) may be due to compulsory national service whereby recruits with existing low back pain may be unable to avoid compulsory military basic training resulting in aggravation of their back injury.

Differences reported in recruit injury rates could be due to several factors. Variation in the training terrain and environment, culture, socioeconomic and care structure, and whether within the same country or not, require consideration when interpreting recruit injury data (Andersen et al., 2016; Bolling et al., 2018; Hall, 2017; Heller & Stammers, 2020; Robinson et al., 2016). Additionally, higher injury incidence is reported of recruits with low entry fitness (Hall, 2017; Heller & Stammers, 2020; Robinson et al., 2016) possibly attributed to deconditioning from initial army fitness application testing or lower entry fitness pass requirement (to meet recruit entry numbers) (Hall, 2017; Rudzki & Cunningham, 1999). Higher recruit injury rates could be expected in these populations compared to military recruit populations with more stringent entry fitness requirements.

Gender streaming of recruits into single sex platoons while following the same training program could also result in different training exposure for females who potentially train at lower intensity (Heller & Stammers, 2020; Richmond et al., 2012, p. 709). Consequently, injury incidence results from male only training populations may not be generalisable to mixed or all female recruit training populations and therefore may account for some variation in injury incidence rates reported across military research (Hall, 2017; Heagerty & Sharma, 2018). While beyond the scope of this study, future research could investigate gender differences and injury incidence in New Zealand Army recruits.

Varied recruit injury incidence reporting may also be due to a lack of standardised musculoskeletal injury definitions, injury rate calculations and research methodology across military research (Andersen et al., 2016; Heller & Stammers, 2020; Kaufman et al., 2000; Molloy, Pendergrass, Lee, Chervak, et al., 2020; Sherrard et al., 2004). Recruit definitions vary and have included injury requiring medical attention (Fuller et al., 2006; International Olympic Committee et al., 2020, p. 84) involving presentations to physiotherapy (Heagerty & Sharma, 2018; Heagerty et al., 2017b; Heagerty et al., 2017c; Rudzki & Cunningham, 1999) and seeking and obtaining medical care (Robinson et al., 2016). Other studies use an injury time loss definition (Fuller et al., 2006, p. 84; International Olympic Committee et al., 2020) such as an injury unresolved within 1 day (24 hours) (Hall, 2017, p. 377) or time away from training as a result of physical injury (Heller & Stammers, 2020, p. 2). The current study used a medical attention injury definition (Fuller et al., 2006; Heir & Glomsaker, 1996, p. 187; International Olympic Committee et al., 2020, p. 84; Rosendal et al., 2003, p. 159) and reported injury exposure based on a rate of injuries per 1000 person-days of total recruit training time (Knapik et al., 2011) from physiotherapy presentations. Military studies that use physiotherapy presentation-based injury data provide either specific injury exposure time calculation or present unclear or absent injury exposure time calculation. One Australian study uses the number of new patients per 5,000 personnel per month requiring physiotherapy (Gruhn et al., 1999, p. 147), while others only describe the total length of time on deployment (Hebert & Rowe, 2007) or time in basic training (Heagerty & Sharma, 2018; Heagerty et al., 2017b; Heagerty et al., 2017c; Rudzki & Cunningham, 1999; Sharma et al., 2015). Given these limitations, a comparison of exposure time calculation from our study to other military research with physiotherapy presentation-based data is not possible. Future research of military recruit populations would benefit from use of standardised injury definitions, injury calculations and methodology to improve comparability of results (Andersen et al., 2016; International Olympic Committee et al., 2020; Kaufman et al., 2000; Molloy, Pendergrass, Lee, Chervak, et al., 2020; Sherrard et al., 2004).

Finally, injury incidence rates will likely be influenced by the type of recruit training program undertaken (Kaufman et al., 2000; Robinson et al., 2016; Sherrard et al., 2004; Wilkinson et al., 2008). The current study involved both infantry and non-infantry recruit populations. Infantry recruit training is considered the most challenging and arduous of all recruit training programs, reporting high injury-related medical discharge rates in the UK (Heagerty & Sharma, 2018; Heagerty et al., 2017c; Robinson et al., 2016; Wilkinson et al., 2008). Recruits who undertake other non-infantry all arms recruit training may not experience the same exposure to arduous training and potentially report lower injury incidence rates. Regardless, given the costs to replace injured (medically discharged) recruits only increases over time (USD $57,500 to USD $75,000 over 10 years in the United States) (Molloy et al., 2012; Molloy, Pendergrass, Lee, Chervak, et al., 2020), the next crucial step in injury prevention research of New Zealand Army recruits will be the identification and mitigation of injury risk factors.

4.5.1 Strengths

This is the first known study to use physiotherapy presentation-based injury surveillance across a four-year period to describe the context and scale of the injury problem for New Zealand Army basic training recruits. Physiotherapy presentations represent point of care injury incidence reporting which is considered more accurate than work health and safety incident reporting (Pope & Orr, 2017). In fact, point of care injury incidence identified under-reporting of actual injuries by 80 to 90% with Australian Defence Force soldiers (Pope & Orr, 2017, p. 23). Other strengths of the study include: the four years of recruit injury data (inpatient and outpatient) was collated by one physiotherapist with extensive military health experience; injury diagnosis was performed by a single injury rater with clinical allied health experience, which improves accuracy and consistency in medical diagnosis (Finch et al., 2014); and provides higher intra-rater reliability reporting injury data (Phillips, 2000).

The overall finding of this study that lower limb injuries reported to physiotherapy in New Zealand Army recruits are the most common injuries may be generalisable to other military and active service recruit populations. This knowledge contributes to the growing understanding of military recruit injury and will help inform future injury prevention interventions that aim to reduce the burdens from injuries sustained by recruits undertaking basic training. Outcomes from this study may also assist in understanding the demand for physiotherapy as a health resource provision for New Zealand Army recruits.

4.5.2 Limitations

While injury data is based on a convenience sample from 2008 to 2011, recruit entry requirements, training regimes (basic soldiering skills) and geographical location of training have not substantially changed. Results of this study therefore remain relevant to current New Zealand Army recruit populations. Injury incidence was based on physiotherapy presentations which may have influenced reported rates. Recruits with minor injuries managed through the initial medical review process, and recruits who failed to attend appointments, did not receive physiotherapy, potentially under-estimating injuries. Additionally, physiotherapy presentation data represented both new and follow up sessions collectively, potentially overestimating injuries. This method of reporting more likely represents injury severity; an important component of injury prevention (Bolling et al., 2018; van Mechelen et al., 1992). The current study was unable to report injury aetiology, mechanism of injury (van Mechelen et al., 1992) and timelines of when an injury was sustained. All are important considerations in military injury prevention research (Heagerty & Sharma, 2018; Robinson et al., 2016; van Mechelen et al., 1992). Future research that uses both quantitative and qualitative approaches to describe context, aetiology and mechanism of injury information will provide a more comprehensive understanding of the recruit injury problem (Bittencourt et al., 2016; Bolling et al., 2018; van Mechelen et al., 1992). Capturing the timing of recruit injury will also help identify the weeks with greatest injury risk (usually the first six weeks), which could be targeted by prevention interventions (Robinson et al., 2016). Finally, calculation of injury per 1000 person-days (or hours) assumes exposure remains constant per unit of time (International Olympic Committee et al., 2020). Varying levels of injury exposure will exist across basic training; however, the standardised nature of the recruit living and training environment would mean exposure may be considered more controlled than civilian sports populations.

4.6 CONCLUSION

Four years of physiotherapy presentations have identified that the lower limb is the most common region injured for New Zealand Army recruits undertaking basic training. More specifically, injuries to the knee and below were the most common sites of recruit injury. Identification of common injury sites will help guide development of targeted injury prevention interventions aimed at reducing burdens associated with recruit injury. Future recruit injury surveillance research would benefit from clear injury and severity definitions, identification of aetiology and mechanisms of injury using quantitative and qualitative approaches, established injury classification systems and use of consistent incidence and training exposure calculations to improve the comparability of research findings.

5. Study 2: Profiles of recruits entering army basic training in New Zealand

Study 2 was accepted by the journal of Military Medicine and has been published 14th Apr 2022.

Hall, N., Constantinou, M., Brown, M., Beck, B., Steele, M., Rousseau, J., & Kuys, S. (2022). Profiles of recruits entering army basic training in New Zealand. Military Medicine, 188(7-8), 1895-1902. http://doi 10.1093/milmed/usac090

A summary of Study 2 findings was presented at the International Physical Employment Standards (IPES) Conference in February 2023 (Abstract and presentation).

Hall, N., Constantinou, M., Brown, M., Beck, B., Steele, M., Rousseau, J., & Kuys, S. (24-26th Feb 2022). What are the physical performance characteristics of New Zealand Army recruits entering basic training. The International Physical Employment Standards Conference, Bond University, Gold Coast QLD, Australia.

5.1 ABSTRACT

Introduction: A high incidence of musculoskeletal injuries is sustained by army recruits during basic training. Describing recruits' personal, lifestyle and physical performance characteristics at entry to training can help identify existing intrinsic risk factors that may predispose some recruits to injury. Identifying modifiable and preventable intrinsic risk factors may contribute to lower recruit injury and associated burdens during the course of basic training.

Aims: The aim of this study was to therefore describe the profile of New Zealand Army recruits upon entry to basic training using personal, lifestyle and physical performance characteristics.

Methods: New Zealand Army male and female recruits from two intakes in the same year were invited to participate. Recruits' data on personal (sex, age, height, and weight), lifestyle (self-reported responses to the Military Pre-training Questionnaire comprising physical and injury history, diet, alcohol and smoking status) and physical performance characteristics (2.4 km timed run, weight-bearing dorsiflexion lunge test and the Y Balance Test™ for lower limb dynamic stability) were collected and analysed.

Results: Participants included 248 New Zealand Army recruits; 228 male (91.9%), 20 female (8.1%), average age of 20.3 ± 2.8 years. Findings indicated 30.9% of recruits reported injury in the 12 months prior to training commencing, with 44.8% of those injuries in the lower limbs. Pre-entry alcohol consumption was higher than recommended and 20.1% of recruits identified as current smokers. Recruits who passed the 2.4-km timed run included 53.8% of males and 28.6% of females. Weight-bearing dorsiflexion lunge test performance was within a normal range (right = 10.3 ± 3.3 cm); however, limb asymmetry (>1.5 cm) was present with 30.9% of recruits. For the Y Balance Test™ for dynamic lower limb stability, 70% of female recruits

had high posterolateral reach asymmetry (8.1 ± 6.0 cm), while normalised composite reach scores were low (right) for male (92.2 ± 8.1%) and female recruits (89.0 ± 7.5%).

Conclusions: New Zealand Army recruits entering basic training were predominantly active young males, reported few injuries in the previous year, had higher than recommended alcohol consumption and a minority were smokers. The majority of recruits had low aerobic fitness, average ankle dorsiflexion range and low dynamic lower limb stability. While a number of adverse characteristics identified are potentially modifiable, more research is required to identify an association to musculoskeletal injury risk in New Zealand Army recruits. Describing the profile of recruits entering training, particularly recruits at risk of injury is one of the first steps in injury prevention.

5.2 BACKGROUND

The incidence of musculoskeletal injuries sustained by military recruits during basic training from western countries is high (Hall et al., 2022; Molloy, Pendergrass, Lee, Chervak, et al., 2020; Robinson et al., 2016; Schram et al., 2019). Overall musculoskeletal injury incidence may be as high as 86% during infantry basic training (Sharma et al., 2017) and up to 80% of all injuries occur in the lower limbs (Heller & Stammers, 2020; Robinson et al., 2016). Overuse injury (≥ 65%) is more common than acute (35%) (Robinson et al., 2016; Rosendal et al., 2003), and female military recruits are at two times greater risk of injury than males during army full-time (Hauret et al., 2018) and reserve basic training (Orr et al., 2020).

Detrimental consequences of recruit lower limb musculoskeletal injuries can include lengthy injury rehabilitation (Sharma et al., 2015), subsequent and/or chronic injury (Cameron et al., 2016; Molloy, Pendergrass, Lee, Chervak, et al., 2020; Williams et al., 2018), injury time loss (Robinson et al., 2016), and backsquad (recycled) or discharge from military service (Orr et al., 2020; Rudzki & Cunningham, 1999). For the military, recruit musculoskeletal injury consequences include work and training time loss, increased demand and cost on health resources (Molloy, Pendergrass, Lee, Chervak, et al., 2020; Rudzki & Cunningham, 1999; Sharma et al., 2015), rising recruitment and retention costs, and service attrition. (Molloy, Pendergrass, Lee, Chervak, et al., 2020; Rudzki & Cunningham, 1999; Sharma et al., 2015). In the long term these burdens potentially impact organisation effectiveness and operational capability (Molloy, Pendergrass, Lee, Chervak, et al., 2020; Rudzki & Cunningham, 1999).

Specific personal, lifestyle and physical performance characteristics have been identified as intrinsic (person-related) risk factors which may predispose some recruits to musculoskeletal injury during training. Established recruit personal and lifestyle intrinsic injury risk factors include older age (Knapik et al., 2013a, 2013b), female sex (Molloy, Pendergrass, Lee, Chervak, et al., 2020; Orr et al., 2020), pre-existing injury (Robinson et al., 2016), and smoking history (Knapik et al., 2013a, 2013b). Physical performance characteristics such as low pre-entry aerobic fitness (Hall, 2017; Heller & Stammers, 2020; Robinson et al., 2016) have also been identified.

Other physical performance characteristics such as low (or high) ankle dorsiflexion range of motion (flexibility) and dynamic lower limb stability (balance) have been associated with musculoskeletal injury risk in sports and trained military populations (de la Motte, Lisman, et al., 2019; Plisky et al., 2021; Teyhen et al., 2015). However, research with military recruit populations is limited. For example, a study of Australian Army recruits (n = 1093) reported males with restricted ankle dorsiflexion range of motion were 2.5 times more likely to incur lower limb injury, while recruits with higher flexibility (high ankle dorsiflexion range of motion) were up to eight times more likely to incur lower limb injury during training (Pope et al., 1998). Measurement of ankle dorsiflexion range however, required technical proficiency, additional equipment (T square and fixed metre ruler) and trigonometry calculation (Pope et al., 1998). Investigation of simpler, field and resource-friendly measurement methods is important for clinicians and researchers establishing baseline dorsiflexion range of motion values in recruit populations.

Poor lower limb dynamic stability (balance) in relation to injury has also been investigated in sports populations. For example, male and female high school basketball players with a Star Excursion Balance Test anterior reach asymmetry greater than 4 cm were 2.5 times more likely to sustain a lower limb injury ($P < 0.05$). The same study found female basketballers with a normalised composite reach distance less than 94%, were 6.5 times more likely to sustain a lower limb injury ($P < 0.05$) (Plisky et al., 2006). Lower limb dynamic stability baseline values and/or risk of injury in military recruits have been assessed in a limited number of studies. Male Brazilian military recruits ($n = 135$) with high Y Balance Test™ (modified Star Excursion Balance Test) posterolateral reach direction asymmetry (≥ 4.08 cm) were more likely to develop patellofemoral pain over six weeks basic training (Nakagawa et al., 2020). Alternatively, no relationship was identified between Y Balance Test™ performance and injury risk in US Army, Air Force, Navy and Marine Corps recruits (de la Motte, Clifton, et al., 2019). Establishing clear baseline values of dynamic lower limb stability is warranted in different recruit populations and countries (Plisky et al., 2021).

Describing recruit personal, lifestyle, and physical performance characteristics at entry to training is important in establishing baseline values and to identify potential intrinsic injury risk factors. Modification of preventable factors may contribute to lower recruit injury and associated burdens.

5.2.1 Aims

The aim of this cross-sectional study was to describe the profile of male and female New Zealand Army recruits entering basic training across two recruit intakes including personal, lifestyle and physical performance characteristics.

5.3 METHODS

5.3.1 Design

Prospective cross-sectional study.

5.3.2 Participants

Participants were drawn from the general New Zealand population coming into the New Zealand Army. Prospective recruits volunteer to join the New Zealand Army, pass the NZDF aptitude test (basic reading and writing test), and attested (sworn in) to the army to commence basic training. Prospective recruits enter the service with varying levels of physical fitness and experience. Two intakes (approximately 140 per intake) of male and female regular force army recruits ($\geq$ 17 years) were eligible to commence basic training in 2012 at the participating training site. Recruits were provided with study information and an opportunity to ask questions before providing voluntary written informed consent to take part in this study. Included in the study were recruits who attested to the army and provided consent to participate. Recruits who declined consent to participate in the study, declined attestation to the army, or who were returning to training (after week one) due to being backsquadded (recycled) from previous recruit intakes, were excluded.

5.3.3 Measures

5.3.3.1 **Personal characteristics**

Sex and age were recorded by army physical training instructors. Height (cm) and weight (kg) were obtained from The Army Depot (TAD) personnel list and the local medical database. At entry medicals, height and weight is measured with recruits dressed in training uniform and without footwear.

5.3.3.2 **Lifestyle characteristics**

Lifestyle characteristics were recorded using the Military Pre-training Questionnaire (Robinson et al., 2010). The Military Pre-training Questionnaire is a low-cost, reliable self-reported, and descriptive questionnaire comprising five domains to assess multiple injury-related risk factors for military basic training recruits (Robinson et al., 2010). The five domains are physical activity, injury history, diet, alcohol, and smoking status; each scored separately. The Military Pre-training Questionnaire includes previously validated tools (Leisure-Time Exercise Questionnaire (Godin & Shepherd, 1985), the modified Rapid Eating and Activity Assessment of Patients (Gans et al., 2006), Alcohol Use Disorders Identification Test and Consumption questions (Bush et al., 1998), and the Cigarette Dependence Scale-5 (Etter et al., 2003)) with additional items relating to military recruit injury risk (Robinson et al., 2010). Sections of the questionnaire have identified British Army Infantry recruits at high risk of musculoskeletal injuries undertaking basic training (Robinson et al., 2016). The 15-minute questionnaire was issued to recruits by medical administrative staff during week one of basic training with sealed responses placed into a secure box for collection.

Within the Military Pre-Training Questionnaire, the Leisure-Time Exercise Questionnaire reports (Godin & Shepherd, 1985) reports pre-entry physical activity level. Expressed in units, the weekly frequency of activity based on metabolic equivalent values for listed exercise categories are summed to provide a total weekly activity score (Godin, 2011; Godin & Shepherd, 1985). A total score of ≥ 24 units indicates active, 14 to 23 units indicates moderately active and <14 units indicates insufficiently active (Godin, 2011). Only the responses to the first question of the Leisure-Time Exercise Questionnaire are presented in this study. A modified version of the Rapid Eating and Activity Assessment for Patients (Gans et al., 2006) comprised 24 questions to assess recruits' pre-entry self-reported dietary behaviours (Robinson et al., 2010). Questions (scored one to three) were summed out of a total of 72 to provide an estimation of diet quality, with higher scores indicating higher diet quality (Johnston et al., 2018). The Alcohol Use Disorders Identification Test and Consumption questions (AUDIT-C) (Bush et al., 1998) are a modified version of the 10-item AUDIT (Saunders et al., 1993). This three-item questionnaire was used to ascertain recruits' pre-entry alcohol consumption (Robinson et al., 2010). Questions are summed with scores ranging from 0 to 12; a score of 0 indicates no drinking (Bush et al., 1998) while higher scores (>5) suggest a risk of hazardous drinking (Reinert & Allen, 2007). Scores of four or more for males and three or more for females are considered positive (Reinert & Allen, 2007). Smoking status, established from the smoking section of the Military Pre-Training Questionnaire (Robinson et al., 2010), was reported as the number and percentage of recruits who identified as current smokers, ex-smokers, and non-smokers at entry to training.

5.3.3.3 **Physical characteristics**

Physical performance characteristics were recorded using the Regular Fitness Level 2.4-km timed run, the weight-bearing dorsiflexion lunge test (Bennell et al., 1998) and the lower quadrant Y Balance Test™ (Plisky et al., 2006). All tests were completed in week one of recruit basic training. The 2.4-km timed run was administered by army physical training instructors and both the weight-bearing dorsiflexion lunge test and the Y Balance Test™ were performed by two trained examiners (physiotherapists and/or one remedial instructor) during the initial medical review periods.

5.3.3.3.1 Regular fitness level

The 2.4-km timed run is a cost-efficient, field-based test of aerobic fitness used with military personnel with slow run times associated with higher musculoskeletal injury risk in male and female recruits (Hall, 2017; Heller & Stammers, 2020; Robinson et al., 2016). The 2.4-km run course is set over tarmac roads inside the military camp and recruits must run the course in the fastest time possible. Recruits are required to pass the 2.4-km timed run at least once during basic training in order to march out (complete training). Results were recorded in minutes and allocated either as a pass or fail dependent on age and sex adjusted grades. A pass grade for New Zealand Army recruits aged 25 years or less for males is 10.5 minutes and females is 12.3 minutes.

5.3.3.3.2 Ankle dorsiflexion range

The weight-bearing dorsiflexion lunge test (Bennell et al., 1998) measures ankle dorsiflexion range of motion with high or low range (flexibility) associated with greater risk of lower limb musculoskeletal injuries in army recruits (Pope et al., 1998). The test involves standing facing a wall and lunging forward so that the knee touches a vertical line drawn on the wall in front of the recruit (Figure 5.1). The foot is progressively moved backward until a maximum lunge is reached while the knee contacts the wall. During the standing lunge, the recruit's heel was held by the tester to prevent lifting from the floor and the recruit was advised to align their knee with their second toe. The untested back foot was placed on the floor. Up to five tests were allowed and at the maximum lunge point, the tester measures the distance to the wall from the tip of the recruit's big toe in centimetres (to the nearest 0.1 cm) (Bennell et al., 1998, p. 176).

Figure 5.1

The Weight-Bearing Dorsiflexion Lunge Test for Ankle Range of Motion

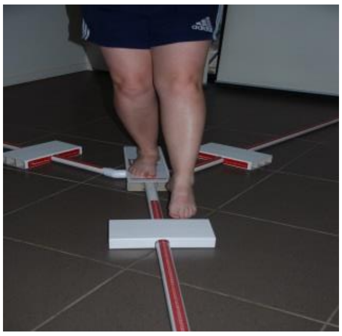
Recruits scoring further than 16.1 cm (58º) were classified as high dorsiflexion range of motion and those scoring less than 9.4 cm (34º) were classified as low dorsiflexion range of motion (Pope et al., 1998) with a relationship of 1 cm to 3.6º applied (Bennell et al., 1998; Hoch & McKeon, 2011). Asymmetry was the difference between right and left lower limb scores (cm). The percentage of recruits with a weight-bearing dorsiflexion lunge asymmetry greater than 1.5 cm (impaired dorsiflexion range) was recorded (Hoch & McKeon, 2011). The standing weight-bearing dorsiflexion lunge test for distance is considered time-, cost-, and resource-efficient (Bennell et al., 1998) and requires low technical proficiency (Konor et al., 2012). The distance method has good intra-rater reliability (ICC 0.98) and low measurement error for novice raters (Konor et al., 2012).

5.3.3.3.3 Lower limb dynamic stability (Y Balance Test ™)

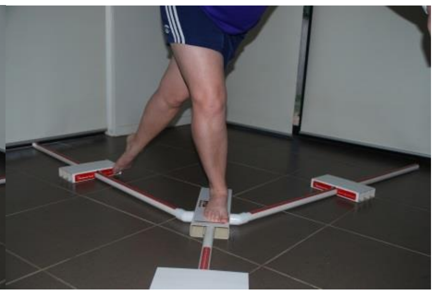
The Y Balance Test™ is a modified version of the Star Excursion Balance Test for dynamic lower limb stability (balance) which can predict musculoskeletal injury risk in sports (Gonell et al., 2015; Plisky et al., 2006) and training military populations (Teyhen et al., 2020). The Y Balance Test™ is performed standing barefoot on one leg while simultaneously reaching as far as possible with the non-weight-bearing leg over three directions: anterior, posteromedial, and posterolateral (Plisky et al., 2009) (Figure 5.2). Up to six practice trials were allowed, followed by three formal trials (Plisky et al., 2009). Testing was set up in accordance with recommendations for standardisation using the Y Balance Test™ kit equipment (YBT Kit, Move2Perform Evansville, Indiana, US) (Plisky et al., 2009).

Figure 5.2

Anterior, Posteromedial and Posterolateral Directions of the Y Balance Test™ Right Foot



i) Anterior



ii) Posteromedial iii) Posterolateral

The Y Balance Test™ performance was scored as the maximum individual reach right and left for anterior, posteromedial and posterolateral (to the nearest 0.5 cm) directions. Individual reach asymmetry was calculated as the difference between right and left lower limb scores (cm). Asymmetry scores greater than 4 cm were identified in each direction (>4.0 cm anterior (Plisky et al., 2006), ≥ 4.0 cm posteromedial (Gonell et al., 2015), and ≥ 4.08 cm posterolateral (Nakagawa et al., 2020)) because of their ability to predict musculoskeletal injuries in sports and recruit populations (Gonell et al., 2015; Nakagawa et al., 2020; Plisky et al., 2006). Composite reach score (normalised to leg length) was calculated as the summation of the three reach directions (anterior, posteromedial, and posterolateral), divided by three times the lower limb length (measured from anterior superior iliac spine to the distal portion of the medial malleolus (cm)) and multiplied by 100 (%) (Plisky et al., 2009). The number and percent of recruits scoring below the normalised composite reach cut-off score of 94% (Plisky et al., 2006) is reported. The Y Balance Test™ has good to excellent intra-rater (ICC 0.85-0.91) and inter-rater reliability (ICC 0.99-1.00) (Plisky et al., 2009).

5.3.4 Analysis

Descriptive statistics were presented as mean (± standard deviation) and frequencies (%) for combined recruit scores, males and females. Analyses were conducted using IBM SPSS Statistics for Windows (Version 27.0) (IBM Corp. Armonk, New York, USA).

5.3.5 Ethical approvals

Information of ethical approvals is presented in section 3.3.2

5.4 Results

Participants initially included 281 recruits from two intakes (four platoons per intake). Thirty-three were excluded; including five who did not consent to participate in the study. The final analysis, therefore, included 248 regular force New Zealand Army recruits (228 male, 20 female) with an average age of 20.3 ±2.81 years. Participants' characteristics are described in Table 5.1.

Table 5.1

Recruit Personal Demographics

Variable	Total (n=248)	Males (n=228, 91.9%)	Female (n=20, 8.1%)
Age (years)	20.3 (2.8)	20.3 (2.8)	20.7 (3.4)
Under 25	233 (94%)	216 (95%)	17 (85%)
Height (cm)	178.5 (7.3)	179.5 (6.6)	167.6 (5.9)
Weight (kg)	77.9 (11.4)	78.3 (11.3)	73.3 (11.2)
BMI (kg/m^2)	24.4 (3.1)	24.3 (3.0)	26.0 (3.1)

Note. BMI is Body Mass Index. Data presented as mean (standard deviation) or frequency (%).

Responses of the Military Pre-training Questionnaire for physical, injury, diet, alcohol and smoking history are presented in Table 5.2. The average recruit pre-entry Leisure Time Exercise Questionnaire score was 62.5 ± 27.0 units (62.7 ± 27.4 male, 60.0 ± 23.3 female). Seventy-one (30.9%) recruits reported an injury in the previous 12 months (MPQ Q2-4) with

30 (44.8%) of those in the lower limbs. The average score from the modified Rapid Eating and Activity Assessment for Patients reporting recruit pre-entry diet status was 47.7 ± 6.0 out of a total score of 72 (47.6 ± 6.1 males, 48.9 ± 4.6 females). Recruits average score from the Alcohol Use Disorders Identification Test-Consumption questions was 5.3 ± 3.0 units (5.4 ± 3.0 males, 3.5 ± 2.4 females). Approximately 57% of recruits commencing basic training reported being non-smokers, with 23% reported being ex-smokers and 20% current smokers.

Table 5.2

Recruit Lifestyle Characteristics (Military Pre-training Questionnaire)

Military Pre-training Questionnaire	Total (n=248)	Male (n=228)	Female (n=20)
[a]Physical history (units)	62.5 (27.0)	62.7 (27.4)	60 (23.3)
Injury in the last year	71 (30.9%)	62 (29.4%)	9 (47.4%)
Previous lower limb injury last year	30 (44.8%)	24 (40.7%)	6 (75.0%)
[b]Diet history (score)	47.7 (6.0)	47.6 (6.1)	48.9 (4.6)
[c]Alcohol Status (units)	5.3 (3.0)	5.4 (3.0)	3.5 (2.4)
[d]Smoking Status			
Non-smoker	130 (56.8%)	119 (56.7%)	11 (57.9%)
Ex-smoker	53 (23.1%)	48 (22.9%)	5 (26.3%)
Smoker	46 (20.1%)	43 (20.5%)	3 (15.8%)

Note: Data presented as mean (standard deviation) or frequency (%).

[a]Leisure-Time Exercise Questionnaire (LTEQ) (n=229).

[b]The modified Rapid Eating and Activity Assessment for Patients (REAP) (n=230).

[c]Alcohol Use Disorders Identification Test-Consumption (AUDIT-C) (n=230).

[d]Smoking status (n=229).

Results of physical performance measures for all, male and female recruits for the 2.4-km timed run, weight-bearing dorsiflexion lunge test, and the Y Balance Test™ are presented in Table 5.3. On average, recruit 2.4-km run time was 10.7 ± 1.4 minutes (10.6 min, ± 1.2 male, 13.5 min, ± 1.7 female) (Table 5.3). There were 53.8% male and 28.6% of female recruits who met the 2.4-km timed run requirement (passed).

Table 5.3

Recruit Physical Performance Characteristics

Physical measure	Total (n=248)	Male (n=228)	Female (n=20)
2.4 km timed run (seconds)	644.3 (83.6)	633.2 (69.5)	808.5 (104.9)
2.4 km timed run (minutes) (208 M, 14 F)	10.7 (1.4)	10.6 (1.2)	13.5 (1.7)
WBDFLT (cm) (223 M, 20 F)			
Right	10.3 (3.3)	10.4 (3.4)	9.5 (2.7)
Recruits < 9.44 cm (34°) (low)	106 (43.6%)	97 (43.5%)	9 (45.0%)
Recruits > 16.1 cm (58°) (high)	12 (4.9%)	12 (5.4%)	0 (0.0%)
Left	10.2 (3.2)	10.2 (3.3)	9.4 (2.8)
Recruits < 9.44 cm (34°) (low)	108 (44.4%)	99 (44.4%)	9 (45.0%)
Recruits > 16.1 cm (58°) (high)	8 (3.3%)	8 (3.6%)	0 (0.0%)
[a]Asymmetry	1.3 (1.4)	1.3 (1.4)	1.4 (1.4)
Asymmetry > 1.5 cm	75 (30.9%)	69 (30.9%)	6 (30.0%)
YBT-LQ absolute reach (cm) (225 M, 20 F)			
Anterior			
Right	61.5 (7.0)	62.0 (6.8)	55.2 (6.7)
Left	62.0 (7.5)	62.5 (7.4)	56.3 (6.6)
[a]Asymmetry	3.1 (2.7)	3.1 (2.6)	3.6 (3.4)
Recruits with asymmetry > 4 cm	63 (25.7%)	56 (24.9%)	7 (35.0%)
Posteromedial			
Right	99.0 (9.4)	99.8 (9.2)	90.4 (6.8)

Left	100.3 (9.5)	101.1 (9.2)	91.8 (8.3)
[a]Asymmetry	4.0 (3.5)	4.0 (3.4)	4.4 (5.3)
Recruits with asymmetry ≥ 4 cm	106 (43.3%)	98 (43.6%)	8 (40.0%)
Posterolateral			
Right	92.1 (10.9)	93.0 (10.7)	82.5 (7.3)
Left	92.6 (11.2)	93.3 (11.1)	85.1 (9.6)
[a]Asymmetry	5.1 (4.0)	4.8 (3.7)	8.1 (6.0)
Recruits with asymmetry ≥ 4.08 cm	126 (51.4%)	112 (49.8%)	14 (70.0%)
YBT-LQ Composite (normalised) (%)			
Right	92.0 (8.1)	92.2 (8.1)	89.0 (7.5)
Recruits < 94% cut-off	149 (60.8%)	133 (59.1%)	16 (80.0%)
Left	92.4 (8.6)	92.6 (8.5)	90.3 (9.7)
Recruits < 94% cut-off	150 (61.2%)	137 (60.9%)	13 (65.0%)

Note: Data presented as mean (standard deviation) or frequency (%).

cm, centimetres, F, Female, km, kilometre, M, Males, n, No., Number, WBDFLT, Weight-bearing dorsiflexion lunge test, YBT-LQ, Y Balance Test™ Lower Quadrant.

[a]Asymmetry is the absolute difference (cm) between right and left.

5.5 DISCUSSION

This study provided a profile of New Zealand Army recruits entering basic training. Recruits were predominantly male (91.9%), approximately 20 years old (< 25 years, 94%) with a normal (healthy) BMI of 24.4 kg/m^2. A similar proportion of males and females (91.8% and 8.2% respectively) has been reported in Australian Army full-time recruits (n = 12, 077) (Orr et al., 2020), and similar (comparable) personal characteristics for age, height, weight, and BMI of male army recruits are reported across militaries in different countries (Knapik et al., 2013a; Orr et al., 2020).

The majority of New Zealand Army recruits in the current study were active, few reported injuries in the previous year, diet quality was mid-range, and most recruits were non-smokers (57%). Of concern is the number of recruits with pre-existing injury, high pre-entry alcohol consumption and current smokers as these characteristics have shown a higher association to musculoskeletal injury risk during basic training (Robinson et al., 2016; Robinson et al., 2010).

Pre-existing injury has been reported to increase the risk of subsequent or recurrent injury (Robinson et al., 2016) and possible chronic injury (Cameron et al., 2016; Molloy, Pendergrass, Lee, Chervak, et al., 2020; Williams et al., 2018) for recruits undertaking basic training. In this study, 30.9% of New Zealand Army recruits presented with pre-existing injuries. Similar proportions are found with US Army military police recruits (n = 2391, 27.5%) (Knapik et al., 2013a), however a lower percentage of pre-existing injuries are reported by British Army Infantry recruits (n = 1810, 22.0%) (Robinson et al., 2016). While pre-existing lower limb injury is a well-established recruit intrinsic injury risk factor (Knapik et al., 2013a, 2013b; Robinson et al., 2016), it remains unclear if recruits with pre-existing injury had adequate injury rehabilitation and fully recovered prior to training commencement (Knapik et al., 2013a). Pre-entry injury outcome status (fully recovered or not) is therefore important to include in future questionnaires to better determine recruit injury risk (Knapik et al., 2013a; Robinson et al., 2016; Robinson et al., 2010) and identify recruits who could benefit from injury rehabilitation prior to training.

Alcohol and smoking consumption have been associated with physiological and psychosocial injury risk in recruit training populations. Entry-level alcohol consumption in the current study sample was above recommended cut points of four or more for males and three or more for females (Reinert & Allen, 2007), while one fifth of recruits (20%) identified as current smokers. Both these lifestyle characteristics have been associated with development of stress fracture and other health-related factors (Lappe et al., 2001) including increased social risk-taking behaviour (Knapik et al., 2013a). On the other hand, a recent systematic review of United States studies suggests evidence of an association between alcohol consumption and recruit injury is insufficient (Bulzacchelli et al., 2014). By contrast, smoking is a well-established recruit injury risk factor (Knapik et al., 2013a, 2013b). Identification of adverse lifestyle factors in recruits is important as they may be modifiable with intervention pre-entry. Additionally, some factors (alcohol, diet and smoking) could be standardised upon entry as part of the controlled military living and training environment, potentially contributing to a lower risk of recruit injury.

Physical performance characteristics describe New Zealand Army recruits as having slow run times, normal dorsiflexion range of motion (flexibility) and low dynamic lower limb stability. Just over half of male recruits and less than a third of female recruits passed the 2.4 km timed run, providing evidence there is low fitness on entry. Low pre-entry fitness is a significant risk factor for recruit musculoskeletal injury (Hall, 2017; Heller & Stammers, 2020; Robinson et al., 2016) and attrition (Hall, 2017) across multiple basic training populations. For example, in a population of British Army female recruits, the average 2.4 km run time for non-injured recruits was faster than injured recruits (12 minutes 13 seconds compared with 12 minutes 43 seconds) and for every 10 seconds increase in time, there was an 8.3% increased risk of musculoskeletal injury (Heller & Stammers, 2020). Adherence to 2.4 km timed run-pass requirements or more stringent times is likely to lower musculoskeletal injury rates and associated burdens; the challenge for armies is finding a balance between recruits meeting entry fitness requirements and achieving military entry quotas.

While the majority of New Zealand Army recruits exhibited normal or optimal ankle dorsiflexion range of motion (flexibility), more than 45% of recruits had low (<9.4 cm) or high (>16.1 cm) dorsiflexion range of motion, and approximately 30% of recruits displayed asymmetry range greater than 1.5 cm indicating impaired ankle dorsiflexion (Hoch & McKeon, 2011). Both low and high ankle dorsiflexion range of motion (Pope et al., 1998) and asymmetry ≥ 6.5° (approximately 1.8 cm) (Teyhen et al., 2015) have previously identified recruits or trained military personnel at heightened risk of lower leg (knee and below) and/or musculoskeletal injuries. New Zealand Army recruits commencing training with high and low or asymmetry in dorsiflexion range of motion may therefore be at greater risk of musculoskeletal lower limb injury (2.5 to 8 times respectively (Pope et al., 1998)), however more research is required to directly confirm this relationship. While previous data has been based on male populations, the current study is one of the first to provide weight-bearing dorsiflexion lunge test values (ranges) for distance (cm) for both male and female army recruits upon entry to training.

Dynamic lower limb stability testing to identify baseline values and musculoskeletal injury risk is gaining popularity across sports and military populations. To our knowledge, this is one of few studies to investigate dynamic lower limb stability in male and female recruits. Our study found that although results from the Y Balance Test™ (Lower Quadrant) for anterior and posteromedial direction asymmetry were within normal limits (< 4 cm and ≤ 4 cm respectively), New Zealand Army recruits exhibited high posterolateral reach asymmetry and low normalised composite reach scores, particularly female recruits. High posterolateral Y Balance Test™

asymmetry (≥ 4.08 cm) has previously been associated with approximately 5.5 times the risk of developing patellofemoral pain over six weeks of basic training (Nakagawa et al., 2020). Approximately 51% of recruits in the current study, including 70% of the female recruits, displayed asymmetry greater than or equal to 4.08 cm.

The association between low baseline composite (normalised) reach score and injury risk in recruits has had limited previous investigation. No association was found between composite reach (measured using the Y Balance Test™) and injury prediction in United States military recruits (de la Motte, Clifton, et al., 2019) although injury was reported as an incidence of pain and actual injuries were not reported. However, low normalised composite reach score (<94%; measured using the Star Excursion Balance Test) has been associated with 6.5 times greater risk of lower limb musculoskeletal injury in female basketballers (Plisky et al., 2006). Approximately 60% of the recruits in the current study scored below this injury risk cut point, although interestingly, higher scores were reported for male and female New Zealand Army Officer trainees (96% male, 98% female) at entry to training (Edgar et al., 2020). Due to the high prevalence of knee injury in New Zealand Army recruits (Hall et al., 2022), further research is required to identify if recruits, particularly females, may be at high risk of developing lower limb injury, such as patellofemoral pain, during the early weeks of basic training.

Slow 2.4-km run time, altered ankle dorsiflexion range of motion, and low lower limb dynamic stability have potential to be modifiable injury risk factors. If deficits are identified prior to training, mitigation measures could be taken where possible to reduce likelihood of recruit musculoskeletal injuries during basic training.

5.5.1 Strengths

To our knowledge, this is the first study to describe gender-specific profiles for personal, lifestyle and physical performance characteristics of New Zealand Army recruits entering basic training and the sample size was robust. A combination of a self-reported questionnaire, simple field-friendly, cost and resource effective objective measures were used, which are ideal for mass screening and are repeatable throughout a military career. This study is one of few to describe results of the weight-bearing dorsiflexion lunge test using a simple validated distance method and potentially one of the first to report results for dynamic lower limb stability (balance) for male and female New Zealand Army recruits using the Y Balance Test™. Recruits participating with minor injuries were also included providing a real-world sample for physical performance testing. These findings are generalisable to recruit populations from other militaries who display similar personal characteristics. Additionally, interoperability is enhanced by the sharing of military health information across different military populations and countries. Results of this study provide important baseline values which can be used for future studies of injury risk in army recruits.

5.5.2 Limitations

Ethnic diversity information was not captured; therefore, the personal, lifestyle, and physical performance characteristics of different Māori, Pacific Island, European and other populations applying to New Zealand Army basic training is not available. Female recruits were included; however numbers were small. Cut off points for the Y Balance Test™ were based predominantly on research of musculoskeletal injury risk in sports populations as limited or no data is available for cut-off points for army recruits.

5.6 CONCLUSION

Describing the profile of New Zealand Army male and female recruits at entry to basic training has provided baseline personal, lifestyle and physical performance characteristic data. New Zealand Army recruits are predominantly young active males, few had pre-existing injury in the previous year, pre-entry alcohol consumption was higher than recommended, and a minority are current smokers. The majority of recruits had low aerobic fitness, average ankle dorsiflexion range and low dynamic lower limb stability. A number of these baseline values are associated with higher musculoskeletal injury risk and are potentially modifiable. Identified risk factors could be mitigated leading to lower recruit musculoskeletal injury and associated burdens during basic training. Describing the profile of recruits entering training is the first step in injury prevention and future research should investigate the association of baseline personal, lifestyle and physical performance measures to actual injuries sustained by recruits during training.

6. Study 3: Does a six-week structured neuromuscular training program lead to fewer lower limb injuries for New Zealand army recruits undertaking basic training? A cluster randomised controlled trial

Prepared as per publication for Clinical Orthopaedic Related Research journal for submission in December 2023.

6.1 Abstract

Introduction: Prevention of musculoskeletal injury during basic recruit training is challenging. Neuromuscular injury prevention training has been beneficial in sports populations and a small number of military studies.

Aims: To investigate if a six-week structured neuromuscular training program would lead to fewer lower limb injuries in New Zealand Army recruits undertaking 17 weeks of military basic training compared to usual training.

Methods: This double-blind cluster randomised control trial included army recruits from two consecutive intakes in the central North Island of New Zealand. Recruits received six weeks of either Neuromuscular or Usual Training warm up two to five times per week. The primary outcome was incidence of lower limb injuries during basic training. Secondary outcome measures included number of total health care encounters for injury, occupational endpoint achieved and accumulative light duties days due to injury. Injury outcomes were assessed after completion of basic training.

Results: A total of 248 recruits (228 male, 20 female, age 20.28 ± 2.81 years) were enrolled. Cumulative injury incidence was 63.2% for control and 52.8% for neuromuscular intervention groups, with no between group difference ($p = 0.098$). There was no between group difference in average new injury per recruit (control 1.31, intervention 1.10, $p = 0.224$). The difference in average lower limb total health care encounters for injury per recruit was significantly higher in the control group (control 4.83 ±7.58, intervention 3.45 ± 5.79, $p = 0.041$), and average number of health care encounters per recruit for knee was significantly higher for control group (control 262, intervention 120, $p < 0.001$). More intervention recruits completed training on time (control 84, intervention 98, $p = 0.026$). Neuromuscular injury reduction effectiveness appeared to be confined to the weeks during which the neuromuscular intervention was applied.

Conclusion: Simple, low-cost neuromuscular exercises targeting the lower limbs did not change injury incidence but did lower health care encounters for injury sustained by New Zealand Army recruits during basic training. Future research should investigate the effectiveness of implementing neuromuscular training earlier, prior to training, and possibly for the duration of basic training.

6.2 BACKGROUND

The high incidence of musculoskeletal lower limb injuries sustained by recruits on basic training remains a problem for western military forces (Molloy, Pendergrass, Lee, Chervak, et al., 2020). Despite research efforts, prevention of recruit musculoskeletal injury and associated burdens during basic training remains elusive.

Implementation of neuromuscular, multiaxial, proprioceptive and agility training has been recommended for injury prevention in US military populations (Bullock et al., 2010) with similar recommendations made for the New Zealand military (Davidson et al., 2009). Neuromuscular training is defined as supplemental training that includes both general fundamental running warm up drills and specific exercises that target motor control deficits and enhance skill-based elements of physical fitness (Myer et al., 2011, p. 3). The benefits of neuromuscular training for injury prevention are well documented in sporting populations (Hubscher et al., 2010; Marshall et al., 2016; Thorborg et al., 2017); however, only a small amount of evidence exists for military recruits and conscript training populations (Brushoj et al., 2008; Coppack et al., 2011; Goodall et al., 2013; Parkkari et al., 2011). For example, a 75% reduction in the incidence of overuse anterior knee pain was reported in UK military recruits using body control exercises (Coppack et al., 2011), while a combined neuromuscular training program with injury prevention counselling significantly reduced acute ankle and upper extremity injuries in young male Finnish Army conscripts (Parkkari et al., 2011). Other potential benefits of injury reduction using neuromuscular training for military recruits are improved health status, lower health care encounters and cost (Marshall et al., 2016; Sharma et al., 2015), improved military occupational endpoint achieved (Coppack et al., 2011) and less injury time loss (Parkkari et al., 2011).

While high incidences of lower limb injuries have previously been reported in New Zealand Army recruits (Davidson et al., 2008) and in Study 1, it was unknown if neuromuscular injury prevention programs would lower these injury rates. Additionally, research of neuromuscular training that report comprehensive lower limb injury data, designed to minimise recruit overtraining or training errors (Bullock et al., 2010; Goodall et al., 2013), and undertaken in a geographical environment representative of the arduous nature of New Zealand Army recruit training, was lacking.

6.2.1 Aims

The aim of this study was to investigate if a six-week structured neuromuscular training program would lead to fewer lower limb injuries in New Zealand Army recruits undertaking 17 weeks of military basic training compared to usual training. Secondary aims included the evaluation of the effects of a neuromuscular training program on total health care encounters for injury sustained, occupational endpoint achieved and training time lost due to injuries.

6.3 METHODS

6.3.1 Design

This study was a double-blind cluster-randomised controlled trial involving a Neuromuscular Training intervention group and a Usual Training control group per intake. Participants within the same cluster received physical training consisting of the intervention Neuromuscular Training or control Usual Training programs, delivered by the designated physical training instructors. Physical training instructors leading the Usual Training were blinded to the exercise prescription undertaken by the Neuromuscular Training group. Recruits were blinded to group allocation and delivery, and the gymnasium environment was concealed during basic training.

Medical practitioners such as medics, doctors, and nurses involved in the initial medical diagnosis and treatment of musculoskeletal lower limb injury, skin or nail and cramp presentations, were blinded to group allocation and training program details. This reflected the usual medical triage process for this military site.

6.3.2 Participants

Participants were recruited from four platoons from each of two consecutive intakes of approximately 140 regular force army recruits. Recruits included both males and females 17 years or older who commenced basic training in the central New Zealand North Island in 2012. Recruits who provided informed consent were included, those who did not consent, declined attestation or who re-joined basic training (after Week 1) due to being backsquadded from a previous intake, were excluded from the study. Recruits who did not seek medical attention for an injury were not recorded and excluded from the study.

Age, height (cm), weight (kg), body mass index (BMI), aerobic fitness from the 2.4 km timed run test and injuries in the previous year reported from the self-reported Military Pre-Training Questionnaire (Robinson et al., 2010) were recorded in Week 1 of basic training for all participants, as previously described Section 5.4.

6.3.3 Procedures

6.3.3.2 Random allocation

Computer generated randomisation (free-online randomiser) was used by an independent civilian unrelated to the study, to allocate participants. Neuromuscular Training and Usual Training groups were made up of two platoons per intake and were allocated in these clusters to either morning or afternoon physical training sessions. Randomisation results were concealed in an envelope and handed to the head physical training instructor for dissemination to physical training instructors leading the Neuromuscular and Usual Training groups.

6.3.3.3 **Intervention**

All participants underwent a 17-week basic training program with Weeks 1–7 comprising drill, classroom-based activities involving basic soldier skills and physical training sessions with recruits included in either the Neuromuscular Training or Usual Training groups. During Weeks 8–17 recruits engaged in field exercise, range-based activities, fewer physical training sessions and drill practice leading up to Week 17 march out.

During Week 1 of basic training, recruits participated in logistical and administrative activities. From Weeks 2–7, both the Neuromuscular Training and Usual Training groups performed warm up exercises two to five times per week for 18-20 minutes within the scheduled physical training program. Total physical training duration was typically 90 minutes, with supervision and feedback on exercise technique provided by qualified Army Physical Training Instructors for all sessions.

The Neuromuscular Training program included five-minutes of running drills, followed by 13-15 minutes of circuit-based exercises targeting lower limb strength, technique, neuromuscular control, core or trunk stability and plyometric dynamic exercises (Myer et al., 2011) summarised in Table 6.1.

The neuromuscular training program exercises in the current study were purposively developed to target lower limb injuries effecting New Zealand Army recruits, specifically the knee, shin/calf, and the ankle identified in Study 1. The program was based on existing neuromuscular warm up programs and recommendations from a systematic review, randomised-controlled trials (Hubscher et al., 2010; Olsen et al., 2005; Pasanen et al., 2008) and programs that target specific injury presentations such as anterior knee pain (Coppack et al., 2011), ankle sprain (Parkkari et al., 2011) or other lower limb musculoskeletal injuries effecting military recruit populations (Brushoj et al., 2008). The training program was also targeting the first five to seven weeks of recruit basic training. This is important because this is when the majority of recruit injuries occur (Coppack et al., 2011; Hall, 2017; Heller & Stammers, 2020; Robinson et al., 2016).

Prior to the commencement of the intervention program, Neuromuscular Training group physical training instructors received information booklets, display posters (correct/incorrect technique photographs) and one-hour training-of-the-trainer by the candidate (NH) detailing Neuromuscular Training exercise prescription and delivery. Neuromuscular training was delivered within the existing physical training warm up and was not additive. Circuit exercises were progressed fortnightly by the physical training instructors to further challenge strength, technique, neuromuscular control, core and trunk stability and plyometric ability (10.3 Appendix C). Weeks 4-5 and Weeks 6-7 included the addition of firstly assisted and then unassisted Nordic hamstring strengthening exercises, undertaken in pairs (Brockett et al., 2001; Matthews et al., 2015).

The Usual Training group undertook the scheduled training program at a separate time, with alternating morning or afternoon sessions to the Neuromuscular Training group. Usual Training was led by different physical training instructors. The Usual Training group exercises consisted of running drills, muscular strength, and endurance, and stretches of large muscle groups as part of the warm-up period. Recruit compliance (attendance) at physical training sessions was recorded by physical training instructors. Average compliance percentage was calculated based on available records. Both groups participated in 21-23 scheduled physical training days (10.4 Appendix D).

Table 6.1

Neuromuscular Training Intervention Program Summary Weeks 2 to 7

Exercise number	Exercise type	Description	Time
Initial run warm up			
1	Slow speed run	Light jog forwards, backwards, heel flick, knees up and carioca	3 min
2	Medium speed run	Shuttle runs	2 min
Circuit exercises			
3	Strength	Walking lunges	1 min
4		Gluteal isometric	1 min
5		Adductor squeezes	1 min
6		Nordic hamstrings (Week 4-5, Week 6-7)	1-2 min
7	Technique	¼ squat single leg	1 min
8		Step forward/hold	1 min
9	Neuromuscular	Star excursion pattern	1 min
10		Wobble board (round)	1 min
11		Single leg standing, running motion opposite leg (Balancing disc Week 4-5, Week 6-7)	1 min
12	Core/trunk stability	Prone plank	1 min
13		Side planks	1 min
14	Plyometric	Lateral jump	1 min
15		Box jump	1 min
16		Horizontal/Vertical jump	1 min

Note. Detailed description is provided in 10.3 Appendix C, Neuromuscular programs Week 2-3, Week 4-5, and Week 6-7.

6.3.4 Measures

The primary outcome measure was the incidence of injuries sustained by recruits during basic training. Secondary outcome measures included total health care encounters, occupational endpoint achieved by recruits and time on light duties for injury sustained during basic training.

Information pertaining to injury incidence, health care encounters and light duties days were retrieved retrospectively from the local electronic medical database after completion of basic training by the candidate with assistance of the database manager.

6.3.4.2 **Primary outcomes**

The primary outcome of injury incidence is reported according to the number of recruits who have sustained injuries and also reported according to the number of injuries sustained across all recruits.

Injury incidence

A lower limb injury was defined as presentation of any symptom/s of pain, inflammation, or functional disorder that involved musculoskeletal or soft tissues; resulted in the recruit obtaining a medical/health care consultation; could occur entirely or in part as a consequence of an external trauma or strain incurred during basic training (Heir & Glomsaker, 1996); and could include aggravation (or subsequent injury) of a pre-existing injury during basic training (Hamilton et al., 2011; International Olympic Committee et al., 2020). Health care encounters for lower limb conditions for skin such as blisters or cellulitis, nail such as an ingrown toenail and muscle cramp were also included, and for simplicity, will be described as an injury for the rest of this paper.

New (index) injuries were defined as any new (first) health care encounter for a lower limb injury reported during basic training (Finch & Cook, 2014; Hamilton et al., 2011). New injuries were reported per week of training as injury incidence from weeks one to 17. Multiple new lower limb injuries occurring to the same participant were included separately and simultaneous bilateral presentations were counted as two new injuries.

Lower limb injury reported by recruits to the medical centre, or the field medic, were recorded on the local medical database. Health care encounters for lower limb injury were categorised according to anatomical body regions which included: the foot, ankle/Achilles, shin/calf, knee, thigh, hip/groin/pelvis, skin/nail, and cramps, for tabulation and analysis in Microsoft Excel (Version 2010) tables after completion of basic training.

Injury incidence according to individual recruits is reported as:

- Number of recruits sustaining one or more injuries for the lower limb overall.
- Cumulative injury incidence (%) was calculated as the number of recruits with one or more injuries/total number of recruits x 100% (Knapik et al., 2013a).
- Injury incidence rate (Exposure time) was calculated as recruits with one or more injuries/total time in company for all recruits x 1000 (injuries/1000 person-days) (Knapik et al., 2011).

Injury incidence according to new overall lower limb injuries is reported as:

- Number of overall lower limb injuries
- Average number of lower limb injuries per recruit
- Number of new injuries for lower limb overall and per individual anatomical region.

6.3.4.3 **Secondary outcomes**

Secondary outcome measures included total health care encounters, occupational endpoint achieved by recruits and time on light duties for injury sustained during basic training.

Health care encounters

Health care encounters were defined as recruits' medical attention burden and included new and follow up health care encounters. The number of visits to internal camp-based services and external health care appointments were recorded. Internal practitioners included military and civilian doctors, nurses, medics, physiotherapist, and remedial instructor. External appointments included visits to radiology, podiatry, pathology, and medical specialists.

Health care encounters are reported as:

- Total number of health care encounters for lower limb injuries
- Average number of health care encounters per recruit for overall lower limb injury and individual anatomical regions
- Number of health care encounters for lower limb injuries overall and for individual anatomical region for lower limb injuries

Occupational endpoint achieved and light duties days.

At the completion of training, recruit occupational endpoint outcomes were provided to the Candidate by the recruit training unit, The Army Depot. Occupational endpoint categories included: completed training, backsquad, discharge including medical, administrative, or other, and voluntary release.

Light duties issued by medical staff for lower limb injury was recorded using data from the medical database by the candidate (NH) and presented as number of recruits with light duties and accumulative time loss in days.

6.3.5 Analysis

Descriptive statistics were presented as means (standard deviation) for continuous variables, and frequencies (%) for categorical variables. Differences between control and intervention groups for continuous data were calculated with independent samples T-tests. When assumptions for this test were not satisfied, a Mann-Whitney test was used. Fishers exact test and chi-square tests were used to determine differences between control and intervention groups for categorical data. When testing the difference between two proportions, the Z test for comparing two proportions was used. A p-value less than or equal to 0.05 was deemed statistically significant. Data analysis was conducted using IBM SPSS Statistics for Windows (Version 28) (IBM Corp. Armonk, New York, USA).

6.3.6 Ethical approvals

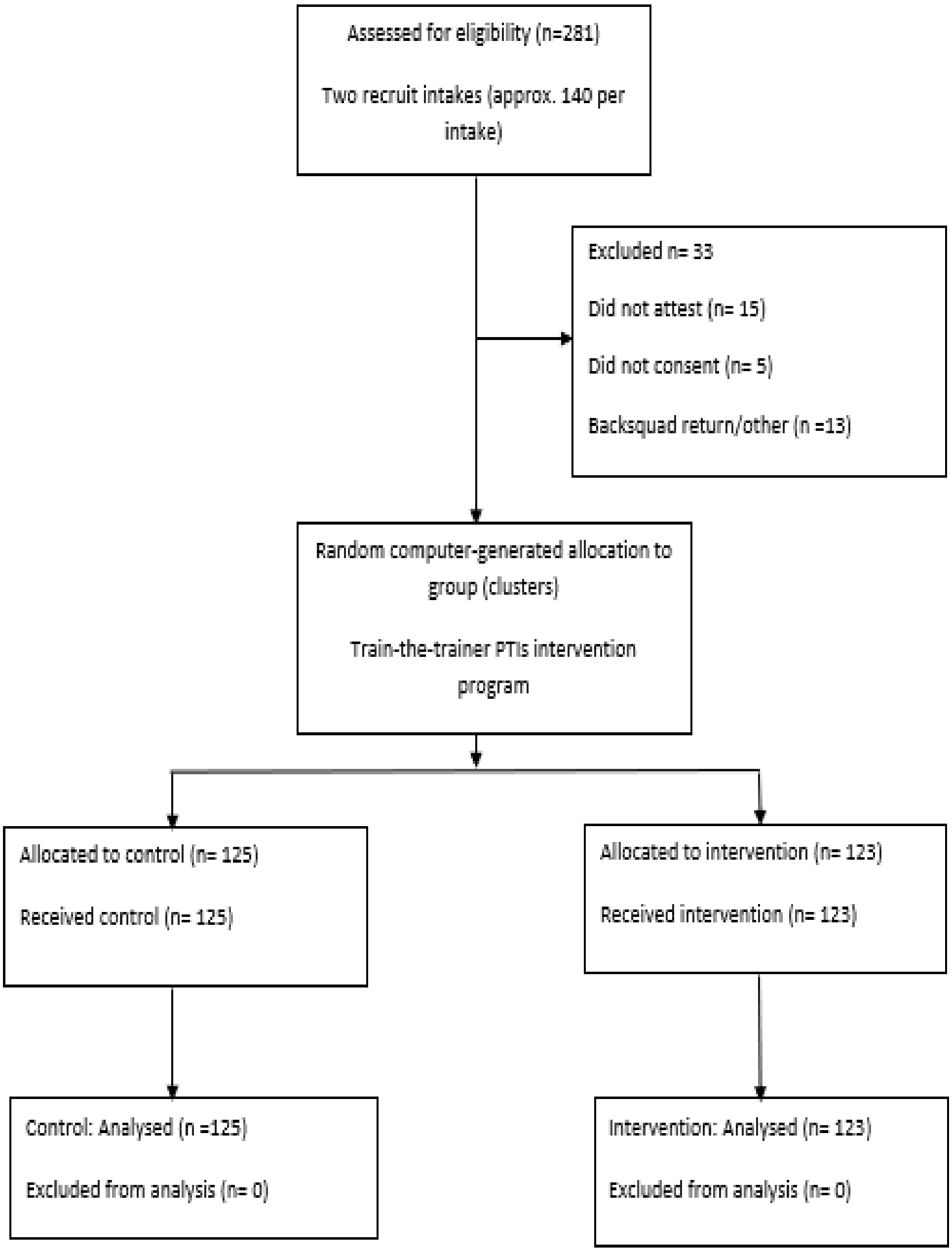
Ethical approvals are presented in section 3.3.2.

6.4 RESULTS

The flow of participants through the trial is detailed in Figure 6.1. Potential participants included 281 army recruits from two consecutive intakes (eight platoons). Thirty-three were excluded from the study; five did not consent and 13 returned after Week 1, either from a period of leave or were backsquadded and were returning from a previous intake. In total 248 recruits, 228 males and 20 females, participated in the study. Randomisation resulted in 115 males and 10 females in the control group and 113 males and 10 females in the intervention group. On average, exercise compliance (attendance/participation) was approximately 90% from both the control and intervention physical training sessions. Participants demographics are described in Table 6.2.

Figure 6.1

Flowchart



Note. attest means sworn in, N= Number, PTIs= Physical Training Instructors.

Table 6.2

Recruit Personal Demographics

	Control			Intervention			p-value
	Male n= 115	Female n= 10	Total n= 125	Male n=113	Female n= 10	Total n= 123	
Demographics							
Age (yrs)	20.20 (2.88)	20.40 (3.27)	20.22 (2.90)	20.31 (2.66)	21.00 (3.59)	20.37(2.74)	0.706
Height (cm)	179.40 (6.53)	168.45 (5.86)	178.52 (7.12)	179.57 (6.66)	166.66 (6.16)	178.50 (7.50)	0.986
Weight (kgs)	77.96 (10.91)	74.38 (10.41)	77.68 (10.87)	78.72 (11.77)	72.12 (12.43)	78.17 (11.91)	0.737
BMI (kg/m2)	24.20 (2.99)	26.18 (3.21)	24.36 (3.05)	24.36 (3.09)	25.81 (3.10)	24.48 (3.10)	0.769
2.4-km timed run (min)	10.72 (1.22)	13.14 (1.20)	10.87 (1.35)	10.39 (1.07)	13.81 (2.22)	10.61 (1.43)	0.164
Previous injury (MPQ 2-4)	29 (24.2%)	3 (2.5%)	32 (26.7%)	30 (27.3%)	5 (4.5%)	35 (31.8%)	0.468[a]

Note. BMI is Body Mass Index, cm is centimetres, kgs is kilograms, km is kilometres, m is metres, MPQ is military pre-training questionnaire, min is minutes, n is number and yrs is years.

Note. All statistical tests were presented as mean (standard deviation) or frequency (%), except [a] = Fishers exact (two-tailed).

6.4.1 Primary outcomes

Recruit injury

The total number of recruits sustaining one or more injuries across the lower limbs during basic training was 79 in the control and 65 in the intervention group. There was no between group difference in recruit cumulative injury incidence between the control (63.2%) and the intervention (52.8%) groups (p = 0.098). Injury incidence rate (injuries/1000 person-days) (Knapik et al., 2011) was 1378.15 in the control group and 1134.45 in the intervention group.

New injury

There was a total of 164 new lower limb injuries for control and 135 injuries for the intervention group (Table 6.3). Average new injury per recruit was 1.31 in the control and 1.10 in the intervention group. There was no difference between groups (p = 0.224). The three most common new injury anatomical regions were reported at the knee, shin/calf and ankle/Achilles. Injuries occurring at the knee were 54 (18.1%) in the control, 33 (11.0%) in the intervention group (p = 0.107). Injuries occurring at the shin/calf, with 54 (18.1%) in the control, 28 (9.4%) in the intervention group (p = 0.019). Injuries were sustained at ankle/Achilles and included 18 (6.0%) in the control and 27 (9.0%) in the intervention group (p = 0.030).

Table 6.3

Number (Percentage) of New Recruit Lower Limb Injuries by Body Region for Control and Intervention Group

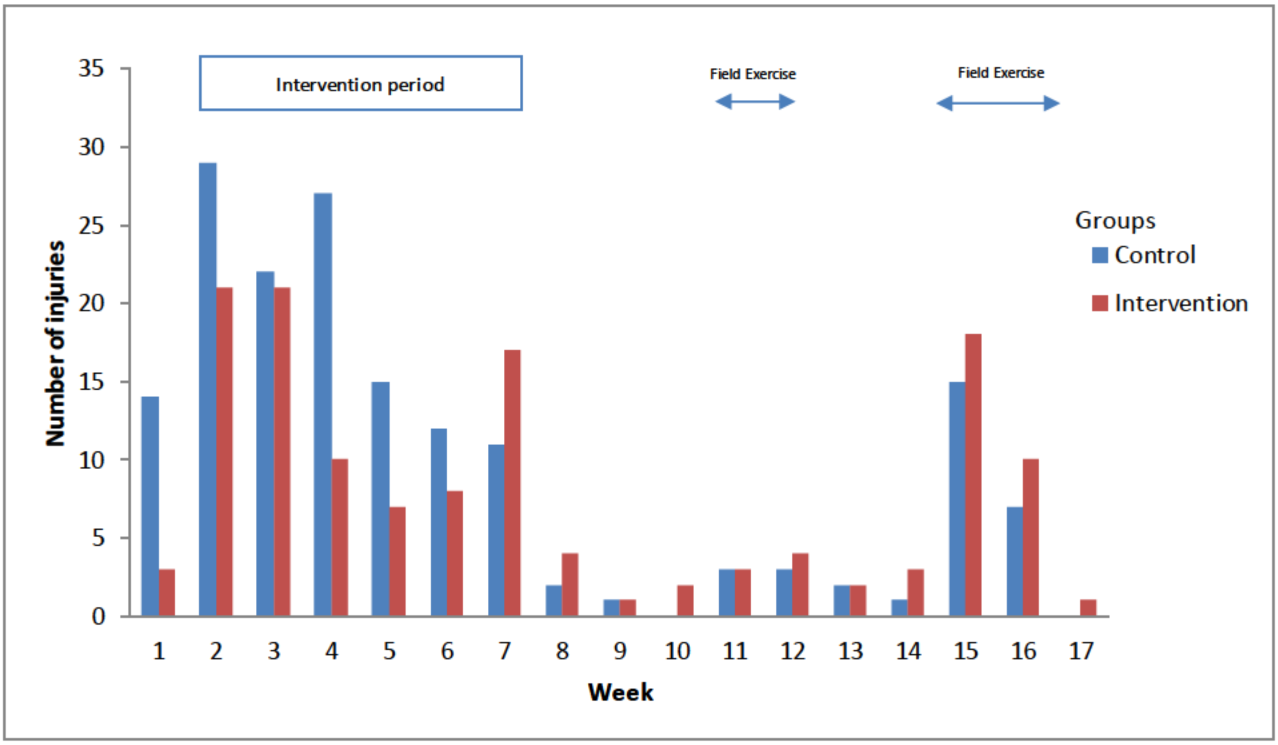
New injury Body region	Control n (%)	Intervention n (%)	p value
Foot /Toes	7 (4.3)	11 (8.1)	0.162
Ankle/Achilles	18 (11.0)	27 (20.0)	0.030
Shin/Calf	54 (32.9)	28 (20.7)	0.019
Knee	54 (32.9)	33 (24.4)	0.107
Thigh	4 (2.4)	7 (5.2)	0.208
Hip/Groin/Pelvis	6 (3.7)	10 (7.4)	0.153
Skin/Nails	20 (12.2)	18 (13.3)	0.772
Cramp	1 (0.6)	1 (0.7)	0.889
Total	164 (100.0)	135 (100.0)	

Note: One recruit could present with bilateral and/or injuries to multiple body regions.

Figure 6.2 outlines the number of new injuries sustained requiring healthcare encounters across the 17 weeks of basic training. The majority of these injuries (73%) were reported over the first seven weeks of training for both groups.

Figure 6.2

Number of New Injuries Sustained Each Week During 17 Weeks of Basic Training



6.4.2 Secondary outcomes

<u>Health care encounters (new and follow up)</u>

There were 605 control and 423 intervention group health care encounters for lower limb injury (Table 6.4).

Average number of health care encounters per recruit for lower limb injury was 4.83 (SD 7.58) in the control and 3.45 (SD 5.79) in the intervention group ($p = 0.041$). There was no between group difference for the average number of health care encounters per recruit across all individual anatomical regions ($p > 0.128$), except for the knee. Average number of knee injury health care encounters per recruit was significantly higher in the control group than the intervention group ($p = 0.010$).

Table 6.4

Number (Percentage) of Total Health Care Encounters for Recruit Lower Limb Injuries by Body Region for Control and Intervention Groups

Health care encounters Body region	Control n (%)	Intervention n (%)	p value
Foot /Toes	29 (4.8)	42 (9.9)	0.001
Ankle/Achilles	61 (10.1)	76 (18.0)	<0.001
Shin/Calf	164 (27.1)	95 (22.5)	0.091
Knee	262 (43.3)	120 (28.4)	<0.001
Thigh	5 (0.8)	15 (3.5)	0.002
Hip/Groin/Pelvis	30 (5.0)	29 (6.9)	0.197
Skin/Nails	51 (8.4)	39 (9.2)	0.066
Cramp	3 (0.5)	7 (1.7)	0.063
Total	605 (100.0)	423 (100.0)	

Note: One recruit could present with bilateral and/or injuries to multiple body regions.

The three most common individual anatomical regions requiring health care encounters for injury were sustained at the knee, shin/calf and ankle/Achilles. Health care encounters required for injuries sustained at the knee were 262 (25.5%) in the control and 120 (11.7%) in the intervention group ($p < 0.001$). Health care encounters required for injuries sustained at the shin/calf were 164 (16.0%) in the control and 95 (9.2%) in the intervention group ($p < 0.091$). Health care encounters were required for injuries sustained at the ankle/Achilles with 61 (5.9%) in the control and 76 (7.4%) in the intervention group ($p = <0.001$).

<u>Occupational endpoint achieved and light duties days.</u>

The number of recruits completing training on time were 84 in the control and 98 in the intervention group (p = 0.026). Of the recruits that did not complete training on time, 11 were backsquadded in the control and nine in the intervention group (p = 0.667), seven were discharged in the control and four in the intervention group (p = 0.368), and voluntary releases included 23 in the control and 12 in the intervention group (p = 0.051). There was no overall between group difference in secondary outcome for occupational endpoint achieved (p = 0.210).

The number of recruits requiring light duties for injury were 61 in the control group and 49 in the intervention group, with no statistical significant between group difference found (p = 0.155). There was a total of 964 and 725 accumulative light duties days for the control and intervention group recruits, respectively (p = 0.099).

6.5 DISCUSSION

This double-blind cluster randomised controlled trial is the first to examine the effectiveness of six weeks of neuromuscular training program compared with usual training to lower incidence of lower limb injury among New Zealand Army recruits undertaking 17 Weeks of basic training. Additionally, this study provides comprehensive audit of lower limb injury incidence and associated burdens of recruits undertaking training.

No difference was found in the number of recruits presenting with lower limb injuries or the total number of new lower limb injuries occurring following a neuromuscular training program applied over the first seven weeks of basic training. The most common new injuries occurred at the knee, shin/calf and ankle/Achilles for both groups, with the majority of these injuries reported within the first seven weeks of training. There were no differences in the number of new injuries sustained at specific body regions, apart from injuries sustained at the shin/calf and ankle/Achilles. The neuromuscular training program resulted in fewer total health care encounters (new and follow up) for lower limb injuries. More specifically, people who underwent the neuromuscular training program required fewer total injury health care encounters for knee and shin/calf injuries compared to the usual training recruits, though more health care encounters were required for ankle/Achilles injuries. Additionally, more recruits successfully completed training on time.

This study used point of care (Pope & Orr, 2017) and comprehensive reporting of recruit lower limb injury. This meant new and follow up health care encounters for injury were reported. This method of analysis assists reporting injury incidence rates and injury severity based on injury clinical demand (International Olympic Committee et al., 2020; Sharma et al., 2015), and this may be one of few military recruit studies to do so. All injury types such as acute/traumatic, repetitive/overuse, contact/non-contact, direct/indirect mechanisms, and multiple injuries to the same recruit were included, while common conditions effecting soldiers such as skin blisters, in-grown toenail and muscular cramps were also reported. Collectively, these factors provide a real-world picture of the actual recruit injury problem and injury lowering effectiveness of the intervention in comparison with usual training.

The neuromuscular intervention appeared to have little impact on the number of recruits injured or average overall new injury diagnosis rates for lower limb. This was unexpected. Despite supervision by qualified physical training instructors and exercise sets, repetitions and session time are similar to those currently proposed to optimise neuromuscular training outcomes from a meta-analysis of young athletes (Steib et al., 2017); potentially the intervention period of 6 weeks was not long enough. Six weeks was chosen because the intervention needed to fit within army recruit physical training schedules. A neuromuscular session period of 1.5 to 6 months (6.5 to 26 weeks) is recommended to optimised neuromuscular training (Steib et al., 2017). Results are still encouraging for neuromuscular training and potentially starting neuromuscular training earlier as part of a preconditioning program or applying neuromuscular training throughout basic training could also be considered. Accessing recruits prior to training and throughout outdoor field exercise and range weeks may be an issue, although exercises were designed to be applicable in civilian setting and in the field.

Despite this lack of difference in injuries sustained, fewer overall lower limb injury health care encounters and fewer knee and shin/calf injury encounters per recruit were observed following the neuromuscular training intervention. As no other military studies using neuromuscular training report incidence of all injury health care encounters which can describe injury severity from clinical context, comparison of our study results is difficult. However, knee injuries are common making up approximately 30% of all new injuries and are responsible for approximately 37% of all health care encounter burden, so the current study's findings of less medical burden of knee injuries should be positively regarded.

Most injuries were sustained across the first seven weeks of training, and similar findings are reported in UK recruit populations (Coppack et al., 2011; Hall, 2017; Heller & Stammers, 2020; Robinson et al., 2016). A surge in injuries was also observed for both groups in Week 15-16. This period of basic training corresponds to recruit's final military field exercise. During field exercise activities, recruits experience an increase in vigorous physical training, sustained high loads pack walking, challenging environmental conditions and sleep restriction (Almeida et al., 1999; Heller & Stammers, 2020; Orr et al., 2014). Sustained load carriage has been associated with increased incidence of knee and foot pain, foot blisters (Orr et al., 2014), and fatigue-related subsequent ankle sprain, particularly for recruits with previous ankle sprain history (Janssen et al., 2016) and functional instability (Mohammadi et al., 2013). Neuromuscular training did not appear to influence injury occurrence during the vigorous and challenging final field exercise weeks occurring towards the end of basic training.

In sports studies, similar neuromuscular training programs have also reported favourable reductions in lower limb injury rates. Olsen et al. (2005) reported 50% fewer acute knee and ankle injuries following 15 to 20 minutes of neuromuscular training one to five times weekly across 15 consecutive sessions in adolescent handball players, while a 20–30-minute neuromuscular warm up program delivered up to two to three times weekly for 16 weeks resulted in a 66% fewer acute non-contact leg injuries in female floorball players (Pasanen et al., 2008). Interestingly, military and sports studies reporting positive injury outcomes using neuromuscular training emphasised movement quality, and alignment specifically of the hip and knee over the ankle. Programs were also supervised by qualified staff including military and civilian instructors or coaches (Coppack et al., 2011; Olsen et al., 2005; Parkkari et al., 2011), and physiotherapists (Pasanen et al., 2008). In the current study, alignment of the hip, knee and ankle was emphasised in this cohort and all sessions were supervised by qualified and experienced army physical training instructors. These factors may have also contributed to the positive findings.

Other additional benefits of neuromuscular training compared to usual training included improved occupational endpoint achieved, fewer recruits requiring light duties for injury and fewer accumulative light duties days. Improved completion rates and more recruits able to engage in more required military training activities is of potential benefit. In fact, results from this cohort mean that 14 more intervention group recruits completed training on time. Given the cost of recruitment and retention is high and increases over time (USD $57, 500 to USD $75, 000 per recruit over 10 years in the USA) (Molloy et al., 2012; Molloy, Pendergrass, Lee, Chervak, et al., 2020) the improvement in military occupational recruitment and retention capability and associated costs saving, should not be underestimated.

6.5.1 Strengths

This study has several strengths. This study was a double-blinded cluster randomised controlled trial and the sample size was representative of regular force New Zealand Army recruit intakes entering training across six months. A combination of point of care and self-reported injury information was used. Point of care medical information is understood to be more accurate than work, health, and safety reporting in military populations (Pope & Orr, 2017). Injury data was collected by a one masters qualified physiotherapist (the Candidate) with a decade of experience working in military health care, which enhances intra-rater reliability (Phillips, 2000) and improves accuracy and consistency with medical injury diagnosis (Finch et al., 2014).

Neuromuscular intervention exercises were chosen for their ease-of-use training large groups, were provided within the existing physical training schedule, were not additive to avoid overtraining, required no additional staffing, and low equipment. High compliance was achieved, likely due to the supervision by qualified staff (Coppack et al., 2011; Myer et al., 2011; Parkkari et al., 2011). Intervention exercise equipment was low cost, could be used in a variety of military settings, in camp and in the field, and had usefulness beyond this study's completion.

Findings of this research may be generalisable to other military recruit, tactical and service populations with similar baseline characteristics who share standardised training and living conditions. Sharing of military recruit injury prevention initiatives across different military populations and countries enhances interoperability. The neuromuscular intervention exercises investigated in this study were subsequently rolled out for New Zealand Army recruits, delivered within the existing physical training syllabus after completion of the study.

6.5.2 Limitations

Some limitations are also acknowledged of this study. Use of agreed and standardised injury definitions (i.e., medial tibial stress syndrome versus shin splints versus leg pain) was not possible due to rotating medical staff. While injury diagnosis described by anatomical body region is broad, it is possibly the most ideal way to explain recruit injury data. This injury data set may have therefore included subsequent, recurrent and exacerbation injuries (Finch & Cook, 2014; Hamilton et al., 2011) which could lead to overestimation of reoccurring injuries such as ankle sprain. Additionally, injuries sustained by recruits that were not reported to the medical centre were not recorded; this could underestimate recruit injury. While neuromuscular training exercise sets and repetitions were suggested, recruits could self-pace, therefore unit of time more accurately describes the intervention prescription. Blinding of recruits, although attempted, was not successful as study groups shared living and eating conditions and exercise details shared. Furthermore, no follow-up occurred beyond 17 weeks; therefore, no conclusions can be made about the long-term benefits of the intervention.

The Candidate was the sole physiotherapist on site during the study which could create contamination/ascertainment bias (Armijo-Olivo et al., 2022). However, injury presentations were triaged initially via medics, doctors and nurses and injury incidence, occupational endpoint, and light duties days data were not recorded or analysed until after completion of basic training to limit potential bias.

6.6 CONCLUSION

A low cost, simple set of neuromuscular exercises targeting lower limb strength, technique, neuromuscular control, core or trunk stability and plyometric ability applied over the first seven weeks of basic training, did not produce a difference for recruits presenting for injury or average new injury, however were effective in producing fewer overall lower limb injury, and total knee injury health care encounters. Additionally, greater numbers of recruits successfully completed training on time. More research is required to identify if starting a neuromuscular training program prior to basic training or extending throughout the intake leads to even fewer lower limb injuries and associated burdens during basic military training.

7. Study 4: Can baseline recruit characteristics predict actual injuries sustained during New Zealand army basic training?

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7.1 Abstract

Introduction: Army recruits entering basic training with suboptimal physical fitness and adverse personal and lifestyle characteristics may be at heightened risk of injury. It is unknown if risk factors for lower limb injuries could be identified upon entry to basic training for New Zealand Army recruits.

Aims: To investigate if personal, lifestyle and physical performance characteristics reported at entry to training could identify recruits who sustain a lower limb injury during New Zealand Army basic training.

Methods: Logistic regression analyses were undertaken of recruits' baseline personal (age, sex, BMI), lifestyle (history of smoking and previous injury) and physical performance characteristics (2.4 km timed run outcome, ankle range of motion using the weight-bearing dorsiflexion lunge test and lower limb dynamic stability using the Y Balance Test™) to determine how well variables predicted the occurrence of an injury. Backwards stepwise logistic regression determined the optimal model to predict the occurrence of an injury in this dataset. Significance was set to the default 0.1.

Results: In total 248 recruits, 228 males and 20 females, were eligible to participated in the study. Forty-six (18.5%) recruits had missing data which resulted in 202 (81.5%) remaining for the analysis. Backwards stepwise logistic regression had two variables associated with injury risk in the final model: passing the 2.4 km timed run and Y Balance Test^{TM} average normalised posterolateral reach for the right limb. This model accurately predicted 60.9% of recruits, with 36 correctly assigned as not injured and 87 correctly assigned as injured.

Conclusion: Two physical performance characteristics could identify lower limb injury risk in New Zealand Army recruits during basic training. Recruits who did not pass entry 2.4 km timed run and recruits who had low right posterolateral Y Balance Test^{TM} score for lower limb dynamic stability were associated with injury during basic training. These findings support the use of entry physical performance injury screening to identify recruits at high risk of injury entering training.

7.2 BACKGROUND

High incidences of injuries are sustained by recruits during basic training leading to substantial training time loss, career alteration and economic and operational readiness consequences (Davidson et al., 2008; Kaufman et al., 2000; Molloy, Pendergrass, Lee, Chervak, et al., 2020; Schram et al., 2019). Recruits entering army basic training with suboptimal physical fitness and adverse lifestyle characteristics such as previous injury and a history of smoking may be at heightened risk of injury (Knapik et al., 2013a; Robinson et al., 2016). By accurately identifying recruits at higher risk of injury entering basic training, mitigation measures could be taken, resulting in substantial reductions in injury incidence and associated injury burdens for both recruits and the military. The challenge is selecting injury risk measures suitable and effective for mass screening of recruit populations that are likely to be adopted by small and resource limited military training establishments.

Research which investigates injury screening or prediction tests to identify injury risk for military populations is emerging. Screening tests have included existing military fitness tests as standalone (Hall, 2017; Heller & Stammers, 2020; Orr et al., 2020; Sefton et al., 2016) or combined with surveys and physical performance tests such as the Functional Movement Screen™, Y Balance Test™ for dynamic lower limb stability and ankle dorsiflexion range of motion (Teyhen et al., 2016; Teyhen et al., 2015; Teyhen et al., 2020). Others have investigated screening tests that only include functional movement tests (Functional Movement Screen™, Y Balance Test™, Landing Error Score System, Overhead Squat) (de la Motte et al., 2016). Predictive risk algorithms for re-injury following an initial musculoskeletal injury have also been reported (Rhon et al., 2018).

Limitations exist with the application of some screening tests to recruit populations. For example, the Functional Movement Screen™ (Cook et al., 2006a, 2006b) while thorough, requires additional time, equipment and staff to conduct and may not be feasibly implemented due to constraints of a busy recruit training program (de la Motte et al., 2016). Additionally, injury screening research performed with trained military personnel (Teyhen et al., 2014; Teyhen et al., 2016; Teyhen et al., 2015; Teyhen et al., 2020) may not be representative of younger, inexperienced recruit basic training populations. Even when screening tests are performed with recruits, screening may be limited to a single test such as ankle dorsiflexion range of motion (Pope et al., 1998), a single injury type such as patellofemoral pain (Nakagawa et al., 2020) or report exclusively male (Hall, 2017; Nakagawa et al., 2020; Sefton et al., 2016; Taanila et al., 2015) or female recruit populations (Heller & Stammers, 2020; Shaffer et al., 2006).

Ideally, screening tests need to be cost, resource and time efficient (Sefton et al., 2016), use existing staff and be applicable in a range of military training environments (classroom, field-based) whilst also fitting around the existing training program and constraints of a regimented military recruit training establishment (Davidson et al., 2009; Sefton et al., 2016). Such screening tests should include data of recruit personal characteristics (sex, age, weight, height) (International Olympic Committee et al., 2020), military fitness test results (Hall, 2017; Heller & Stammers, 2020), and preferably use simple low cost physical performance tests with known ability to identify higher lower limb injury risk in military and sports populations such as ankle dorsiflexion range of motion (Bennell et al., 1998; Pope et al., 1998; Powden et al., 2015) and dynamic lower limb stability (Nakagawa et al., 2020; Plisky et al., 2009; Plisky et al., 2006; Shaffer et al., 2013; Teyhen et al., 2020). Additionally, responses from surveys like the Military Pre-training Questionnaire can give insight into self-reported pre-entry lifestyle characteristics of recruits including physical fitness, injury history, diet/nutrition status, alcohol consumption, and smoking history (Robinson et al., 2016; Robinson et al., 2010). Results of screening tests can then be compared to actual injuries sustained by recruits during basic training to ascertain their effectiveness.

It is currently unknown if risk factors to common New Zealand Army recruit musculoskeletal lower limb injuries could have been identified upon entry to basic training.

7.2.1 Aims

The aim of this study is to investigate if baseline personal, lifestyle and physical performance characteristics reported at entry to training could identify recruits who sustained lower limb injury during New Zealand Army basic training.

7.3 METHODS

7.3.1 Study design

This is a prospective cohort study.

7.3.2 Participants

Participants were male and female regular force army recruits (≥ 17 years old) across two consecutive intakes of approximately 140 recruits, with 4 platoons per intake. Recruits commenced basic training in the New Zealand central North Island in 2012. Recruits who provided informed consent were included, while those who did not consent, declined attestation or who re-joined basic training after Week 1 due to being backsquadded from previous intakes were excluded from the study. Additionally, recruits who did not seek medical attention for an injury were not recorded and excluded from the study.

7.3.3 Measures

7.3.3.1 **Personal, lifestyle and physical characteristics**

All personal, lifestyle and physical performance characteristics were recorded in Week 1 of basic training for all participants. Personal characteristics included sex, age, height (cm), weight (kg), and Body Mass Index (BMI). Lifestyle characteristics including pre-entry physical fitness, injury history, diet, alcohol, and smoking status were recorded using the self-reported Military Pre-training Questionnaire (Robinson et al., 2016; Robinson et al., 2010).

Physical performance characteristics including aerobic fitness test results using the 2.4 km timed run, ankle dorsiflexion range of motion using the weight-bearing dorsiflexion lunge test (Bennell et al., 1998), and dynamic lower limb stability using the Y Balance Test™ (Plisky et al., 2009; Plisky et al., 2006) were recorded. The timed 2.4 km run was administered by army physical training instructors, with results recorded using a stopwatch. The weight-bearing dorsiflexion lunge test and Y Balance Test™ were administered by two Army Reservist physiotherapists or an army remedial instructor. Further details regarding the tests have previously been described in Section 5.3.3.

7.3.3.2 **Injury incidence**

Injury incidence was defined as any new health care encounter for a lower limb injury sustained during basic training (Finch & Cook, 2014; Hamilton et al., 2011). A lower limb injury was defined as presentation of any symptoms of pain, inflammation, or functional disorder that involved musculoskeletal or soft tissues; resulted in the recruit obtaining a health care encounter; could occur entirely or in part as a consequence of an external trauma or strain incurred during basic training (Heir & Glomsaker, 1996); and could include aggravation of a pre-existing injury (Hamilton et al., 2011; International Olympic Committee et al., 2020). Multiple new lower limb injuries to the same recruit were included separately, and simultaneous bilateral presentations were counted as two individual new injuries.

Lower limb injury reported by recruits to the medical centre, or the field medic were recorded on the local medical database. Lower limb injuries were subdivided into anatomical body regions which included: the foot, ankle/Achilles, shin/calf, knee, thigh, hip/groin/pelvis, skin/nail, and cramps. Lower limb conditions for skin such as blisters or cellulitis, ingrown toenail and muscle cramp were also included as injuries. Injury data were tabulated and analysed in Microsoft Excel (Version 2010) tables after completion of basic training.

7.3.4 Analysis

Descriptive analyses were undertaken of recruits' baseline personal, lifestyle and physical performance characteristics in Section 5.4. Variables for inclusion into the predictive model were identified from previous research which had shown ability to identify lower limb injury risk in military recruits, sports, and healthy young adult populations. Personal characteristics included age, sex and BMI (Knapik et al., 2013a, 2013b). Lifestyle characteristics included previous injury in the last year and a history of smoking (Knapik et al., 2013a, 2013b; Robinson et al., 2016). Physical performance characteristics included; pass results of the 2.4 km timed run for aerobic fitness (Hall, 2017; Heller & Stammers, 2020; Robinson et al., 2016), the weight-bearing dorsiflexion lunge test (Bennell et al., 1998) and the lower quadrant Y Balance Test™ for dynamic lower limb stability (Plisky et al., 2009; Plisky et al., 2006). Ankle dorsiflexion range of motion was recorded as average maximum reach for distance in centimetres (converted from degrees) (Bennell et al., 1998; Pope et al., 1998), and asymmetry difference (>1.5 cm or equivalent degrees) (Hoch & McKeon, 2011; Teyhen et al., 2015). Lower quadrant Y Balance Test™ was normalised to leg length (%) and recorded as anterior (Plisky et al., 2009; Plisky et al., 2006), posteromedial (Gonell et al., 2015), and posterolateral reach direction (Nakagawa & Petersen, 2018) for right and left limbs, and average combined composite score (%) (Butler et al., 2013; Plisky et al., 2006).

For each variable, a logistic regression was performed to determine how well the variable predicted the occurrence of an injury in this dataset. All variables were then used in a backwards stepwise logistic regression to determine the optimal model to predict the occurrence of an injury in this dataset. Significance was set to the default 0.1 for a logistic regression. Analysis was performed using SPSS Version 29.

7.3.5 Ethical approvals

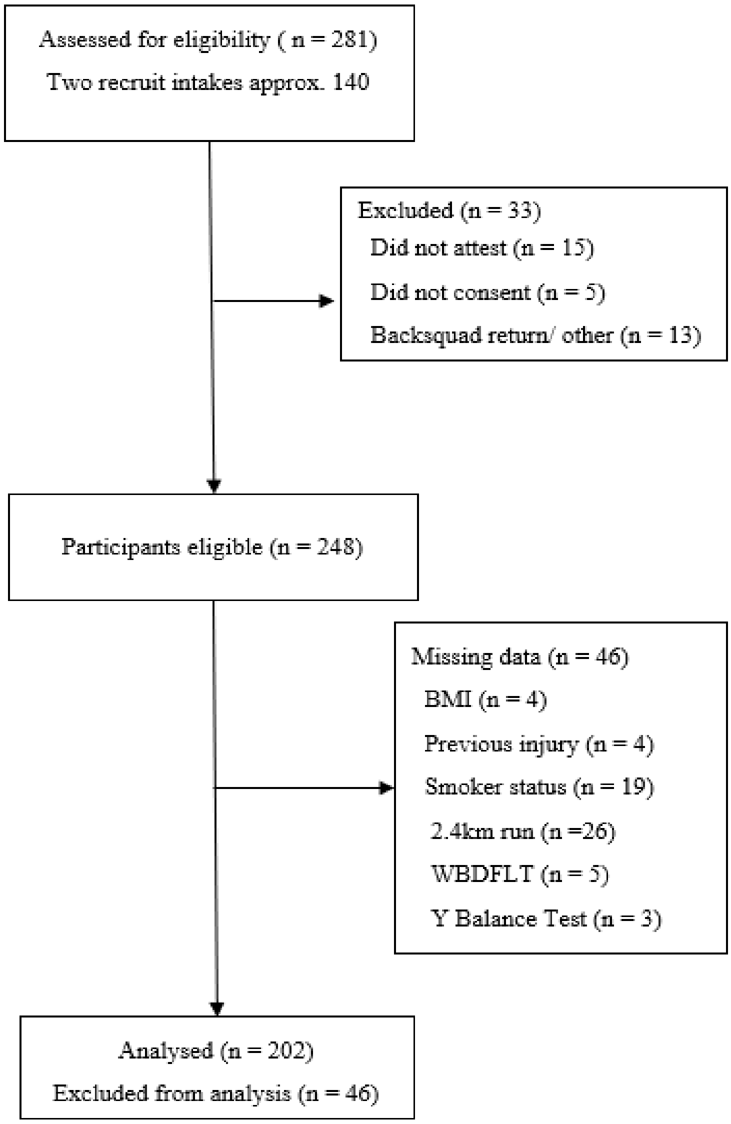
Ethical considerations are presented in Chapter 3.3.

7.4 RESULTS

The flow of recruits through the trial is detailed in Figure 7.1. Potential participants included 281 army recruits from two consecutive intakes, and eight platoons in 2012. Thirty-three were excluded from the study; including five who did not consent. In total 248 recruits, 228 males and 20 females, were eligible to participated in the study. Forty-six (18.5%) recruits had missing or incomplete data, which resulted in 202 (81.5%) complete sets of recruit data remaining for this analysis.

Figure 7.1

Flow Diagram of Recruits Through the Study



Note: Missing data tally (n = 46) does not equal the sum of all measures listed (n = 75) because some participants had incomplete data across multiple variables.

Variables not significant in the final model were the personal characteristics; sex (p = 0.152), age (p = 0.635), and BMI (p = 0.615), lifestyle characteristics of previous injury (p = 0.340) or history of smoking (p = 0.166) and physical performance characteristics for weight-bearing dorsiflexion lunge test average maximum distance (p = 0.257) or asymmetry in centimetres (p

= 0.591), and for Y Balance Test™ composite score (p = 0.677) or left-sided posterolateral reach normalised to leg length (p = 0.737).

Recruit baseline personal demographics, lifestyle and physical performance characteristic results from Week 1 have been previously reported in Section 5.4.

Of the 12 separate univariate logistic regressions, only two of the 12 variables identified in Section 7.3.3.1 were significant. Passing the 2.4 km timed run (p = 0.067, CI 95% 0.355 to 1.035) and Y Balance Test™ average normalised posterolateral reach for the right limb (p = 0.069, 95% CI 0.015 to 1.169) identified recruits at risk of sustaining a lower limb injury from Week 1 of basic training.

The backwards stepwise logistic regression had two significant variables associated with injury risk in the final model. The two variables were passing the 2.4 km timed run (p = 0.018) and Y Balance Test™ average normalised posterolateral reach for the right limb (p = 0.102) (see Table 7.1). The p-value reported in the final model for the Y Balance Test™ average normalised posterolateral reach for the right limb is slightly over 0.1, but it should be noted that the actual p-value used for inclusion in the model is determined in SPSS by the separate Model if Term Removed calculation which had a p-value of 0.098. For this reason, a decision was made to keep this borderline variable in the model. This model accurately predicted 60.9% of recruits (36 were correctly assigned as not injured and 87 were correctly assigned as injured).

Table 7.1

Results of Logistics Regression for Relationship Between Baseline Data and Injury Occurrence in Army Recruits

Variable	OR (95% CI)	p- value
Personal		
Sex	2.75 (0.69-10.97)	0.152
Age (yrs)	1.03 (0.91-1.16)	0.635
BMI (kg/m^2)	0.97 (0.88-1.08)	0.615
Lifestyle		
Previous injury	1.37 (0.72-2.64)	0.340
History of Smoking	1.51 (0.84-2.72)	0.166
Physical Characteristics		
2.4 km timed run pass (min)	0.50 (0.28-0.89)	0.018
Weight-bearing dorsiflexion lunge test		
Maximum reach (cm) average	1.06 (0.96-1.16)	0.257
Asymmetry (cm)	0.94 (0.76-1.17)	0.591
Y Balance Test normalised		
Posterolateral (%) right	0.13 (0.1-1.49)	0.102
Posterolateral (%) left	0.35 (0.00-165.89)	0.737
Posterolateral asymmetry (cm)	0.95 (0.88-1.02)	0.147
Composite score (%) average	1.02 (0.94-1.10)	0.677

Note: BMI is Body Mass Index, CI is confidence interval, cm is centimetres, kg is kilograms, km is kilometres, m is metres, min is minutes, OR is odds ratio, % is percentage.

7.5 DISCUSSION

Lowering musculoskeletal injury during basic training requires initially identifying recruits at high risk of injury at entry, and to see if modifiable factors could be addressed to mitigate that risk. Results from this study addresses the first concept by investigating the effectiveness of injury risk factors to identify an association to actual injuries sustained by recruits during basic training. It appears that recruits entering basic training with low aerobic fitness and reduced lower limb dynamic stability are at risk of sustaining a lower limb injury.

Recruits entering training with low physical fitness (slow 2.4 km run time) appear to be at greater risk of sustaining a lower limb injury. This finding is perhaps not surprising. Substantial research exists supporting a strong association of low entry physical fitness and a greater risk of injury during basic training across army (Hall, 2017; Heller & Stammers, 2020; Jones et al., 2017; Lisman et al., 2017; Robinson et al., 2016), marine corps, and air force recruit populations (Knapik et al., 2010; Kupferer et al., 2014; Rauh et al., 2006). In fact, the slower the run time, the greater the risk for injury has been demonstrated (Heller & Stammers, 2020; Jones et al., 2017). Low physical fitness at entry suggests recruits may not be conditioned appropriately to cope with the arduous challenges of basic training (Robinson et al., 2016) leading to greater overall fatigue and this may increase injury risk (Lisman et al., 2017). Additionally, perhaps too much time could have elapsed between the recruitment fitness test and Week 1 entry testing, resulting in aerobic fitness deconditioning of prospective recruits (Heller & Stammers, 2020).

Aerobic fitness as measured by 2.4 km timed run is a modifiable intrinsic recruit injury risk factor. Ideally, if prospective recruits train to exceed the minimum 2.4 km pass time requirements pre-entry, and if military recruitment adheres to run time cut-off standards, it is likely to result in fewer lower limb injuries occurring during New Zealand Army basic training. The challenge for militaries is finding a balance between achieving recruitment quotas and finding enough recruits meeting entry fitness requirements. Preconditioning programs for low fitness recruits delivered prior to formal basic training have demonstrated lower risk of injury (Dijksma, Zimmermann, et al., 2020; Knapik et al., 2006) and reduced attrition in male and female US Army recruits (Knapik et al., 2006). Preconditioning programs warrants further research investigation to address entry of low fitness recruits and risk of injury in the New Zealand Army.

Low dynamic stability is a risk factor for injury. Possible reasons for this could be related to hip strength and limb dominance. A significant association was found between low Y Balance Test™ posterolateral normalised score which reports limb dynamic stability, and injury risk for the right lower limb. Reduced hip girdle muscle strength required to maintain stability of the pelvis and trunk throughout the Y Balance Test™ may contribute to this finding (Wilson et al., 2018). Low isometric hip strength, particularly hip abduction, has been associated with low posterolateral dynamic stability performance using the Y Balance Test™ or modified Star Excursion Balance Test (Francis et al., 2018; Plisky et al., 2009; Wilson et al., 2018). New Zealand Army recruits with low dynamic stability scores for posterolateral reach, potentially may have low hip abduction strength and this appears to be isolated to the right limb.

Low right-sided lower limb dynamic stability as a risk factor for injury may be related to limb dominance. Low right-sided posterolateral dynamic stability suggests asymmetry exists in performance in this cohort of army recruits, although it is unclear if the dominant or non-dominant limb performs better on dynamic stability testing. Limb dominance was not reported in this cohort, and therefore it is unclear if limb dominance contributed to the difference in limb performance with posterolateral dynamic stability and recruit injury risk. Limb dominance, however, was not found to be significant for Y Balance TestTM dynamic stability performance in two studies, including one in a population of young adults (Fusco et al., 2020) and another of healthy participants (Wilson et al., 2018). Given the low cost and time for testing, findings support use of dynamic stability using the Y Balance TestTM to identify recruits at high risk of injury on entry to training.

Other physical performance tests of dynamic stability were not associated with lower limb injury in this cohort of New Zealand Army recruits. This finding was unexpected as previous research using the Y Balance Test™ (modified Star Excursion Balance Test) normalised composite score found higher injury risk using cut points below 89.6% and 94% in sports populations (Butler et al., 2013; Plisky et al., 2006). Previous research by de la Motte, Clifton, et al. (2019) also found no association of injury risk to Y Balance Test™ performance across four US military recruit populations (Army, Navy, Air Force and Marine Corps). However, injury in that study was defined as an incidence of pain and specific injury indices were not reported (de la Motte, Clifton, et al., 2019). The relationship between Y Balance Test™ performance and injury risk remains unclear. Potentially, the Y Balance Test™ may perform better as part of a multifactor risk model and investigation of sex, age, sport or military unit, and country specific cut points are required to better determine its association to recruit injury risk in future research (Plisky et al., 2021).

Results of this study support the use of physical performance injury screening consisting of aerobic fitness and lower limb dynamic stability testing in New Zealand Army recruits at entry to training. Other benefits of injury screening include providing an opportunity for initial health screening (Bahr, 2016; Bakken et al., 2016; Heagerty & Sharma, 2018), builds rapport between the medical team and incumbent recruits, is important for medicolegal duty-of-care requirements (Bahr, 2016; Bakken et al., 2016), and provides baseline measurement of personal, lifestyle and physical performance characteristics.

7.5.1 Strengths

This sample is representative of six months regular force New Zealand Army basic training recruits and includes males and females. All lower limb injury types, injury mechanisms, and conditions commonly effecting recruits such as skin, nail and cramps were included. Multiple and bilateral injuries were reported individually which potentially, is more thorough than studies limited to first time injury or time to first injury reporting (Finch & Cook, 2014). Collectively, this dataset more likely represents the actual extent of the recruit injury problem. Other strengths of the study include blinding of outcome assessors for injury presentations, the weight-bearing dorsiflexion lunge test, and the Y Balance Test™ outcome measures were chosen for their low cost, time and resource efficiency (2.4 km run test already exists) and proven association identifying recruits at risk of injury in military and sports populations.

7.5.2 Limitations

Forty-six recruits had incomplete or missing data, leaving 202 for inclusion in the logistic regression analysis. This limitation for the most part, reflects the logistical constraints of collecting research data during recruit basic training as regimental and army medicals took priority. Because few females entered basic training, data for the current study were reported combining results of both sexes, therefore sex-specific outcomes were not thoroughly investigated. Additionally, injuries sustained by recruits that were not reported to the medical centre were not recorded; this could underestimate recruit injury. Limb dominance was not collected, therefore data for some physical characteristics were averaged for right and left lower limbs. Investigation of previous injury recovery status such as fully recovered or not, and female menstrual history upon entry to training may also be useful to include in future injury risk research models.

7.6 CONCLUSION

This study investigated whether personal, lifestyle and physical performance characteristics could identify lower limb injury risk in New Zealand Army recruits during basic training. Recruits with a slow 2.4 km run time at entry to basic training were more likely to sustain a lower limb injury than recruits who passed. Recruits with low right posterolateral score for lower limb dynamic stability were identified as at greater risk of injury during basic training. These findings support the use of entry physical performance injury screening and adherence to 2.4 km run time cut points pre-entry to potentially lower recruit injury risk training. Research which investigates baseline characteristics and injury risk at entry to training is now required with larger numbers of New Zealand Army recruits, and over longer periods.

8. DISCUSSION

This program of research aimed to establish the extent of the recruit injury problem, the profile and aetiology of recruit injuries and the effect of six weeks neuromuscular training compared to usual training on incidence of lower limb injury of New Zealand Army recruits. Additionally, this program of research investigated if baseline personal, lifestyle and physical performance characteristics could predict actual injury sustained during training. Four studies inform this research and are aligned with the four-step 'sequence of injury prevention' model (van Mechelen et al., 1992).

This chapter presents a summary of the overall findings of the included studies, and explores clinical implications, and future directions. Strengths and limitations of the research program are also discussed.

8.1 SUMMARY OF RESEARCH FINDINGS

Study 1 established the extent of the New Zealand Army recruit injury problem using four-years of physiotherapy provisions. Findings from Study 1 indicated that recruits were likely to sustain injuries at the lower limb, with two-thirds of all injuries occurring at the knee, the shin/calf and the ankle/foot. By identifying common injury sites during basic training, injury prevention programs may be developed to target these at-risk regions.

Study 2 established aetiology of recruit injury by investigating baseline profiles of personal, lifestyle and physical performance characteristics and identified potential recruit intrinsic injury risk factors at entry to training. New Zealand Army recruits were mostly male, had normal BMI, slow run times, and some had altered ankle dorsiflexion range of motion, and low dynamic lower limb stability. The physical performance characteristics identified are potentially modifiable injury risk factors.

After understanding the recruit lower limb injury problem, the profile of recruits entering training and the presence of injury risk factors upon entry, a neuromuscular injury prevention program was developed and implemented to target injuries sustained at the knee and below. Findings from Studies 1 and 2 informed Study 3, addressing the third step in the ‘sequence of injury prevention’ model (van Mechelen et al., 1992).

Study 3, utilising a cluster randomised controlled trial found that a six-week neuromuscular training program led to fewer overall health care encounters for lower limb injuries and knee presentations despite no between group differences in recruits with lower limb injuries or average new injury per recruit.

Study 4 showed recruits with slow 2.4 km run time and low right-sided dynamic lower limb stability at baseline were at greater risk of injury during basic training. Potentially, these tests could be used as a screening tool to identify recruits at greater risk of injury entering training and mitigation measures could be taken to reduce risk.

8.2 Clinical implications and future recommendations

This program of research has identified several clinical implications. Firstly, knee injuries are common in army recruits. Recruits enter training with injury risk factors and therefore screening is important. Neuromuscular training is effective in reducing health care encounters and burdens for injuries sustained during basic training. Finally, injury consensus statements are required to better report military recruit injury in the future. Recommendations for future research investigating injuries in New Zealand Army recruits will be discussed.

8.2.1 Knee injuries are common in New Zealand Army recruits

The knee was the most common lower limb region injured and demanded the greatest amount of health care for New Zealand Army recruits undertaking basic training. The knee therefore represents the greatest region of burden describing the extent of the injury problem in New Zealand Army recruits.

High prevalence of knee injury was reported in two studies in this program of research. In Study 1, injuries reported at the knee and below accounted for two-thirds of overall injury presentations to physiotherapy and the knee accounted for more than 24% of injury presentations across the whole body. Similarly, Study 3 found that the knee region represented the greatest number of new injuries at 29% of the total and required the greatest number of health care encounters (37%) for lower limb injury sustained by army recruits across both the neuromuscular training and usual training groups. These studies provide a comprehensive audit of new injury incidence and follow up health care, which provides greater understanding of the scope of the knee injury problem and health care burden effecting New Zealand Army recruits. This program of research identified injury sustained at the knee remains a primary target for continued injury risk identification and prevention efforts.

Knee injury incidence in New Zealand Army recruits may be higher than other military recruit populations, however incidence rates vary. Knee injury incidence was reported at approximately 26% with UK Army Infantry recruits (Heagerty et al., 2018) and approximately 20% with US Army trainees (Hauschild et al., 2018). Interestingly, Australian Army full-time recruits report knee injury represent 13.3% of all minor personal injury and 16.3% of all serious personal injury (Schram et al., 2019). Lower injury incidence reported in other studies could be attributed to knee injury incidence being included across all musculoskeletal presentations. Furthermore, heterogeneous injury definitions and incidence reporting were used across studies, and one study divided injury presentations into minor and serious subgroups (Schram et al., 2019), making comparisons difficult between studies.

Reasons for the high number of knee injuries found in this program of research may be due to intense recruit training regime (Robinson et al., 2016), low fitness and pre-existing injury of recruits at entry to basic training. Furthermore, the New Zealand Army recruits train in arduous terrain in Waiouru in the central North Island and may be at greater exposure to risk as they spend more time in the field than Air Force and Navy recruit populations (Davidson et al., 2008). The high prevalence of knee injury may also be due to impairments proximal to the knee such as poor neuromuscular control of the hip, pelvis and trunk which have been reported to effect knee tibiofemoral and patellofemoral joint kinematics and kinetics (Powers, 2010).

Impairments at the hip, particularly weakness of hip abductors and altered neuromuscular control, may underpin common injuries such as iliotibial band syndrome and patellofemoral pain syndrome. These factors contribute to greater knee valgus moments and angles which may adversely affect the knee during training (Hewett, Myer, Ford, et al., 2005; Nakagawa et al., 2020; Powers, 2010), and females are potentially more affected by these proximal influences (Powers, 2010). As such, the intervention training program implemented in Study 3 incorporated exercises aiming to improve neuromuscular control of the lower limb together with control of the hip, pelvis and trunk.

This is one of few studies reporting knee injury health care burden in military recruits, adding to the body of literature. One study reported knee injury rehabilitation timeframes finding anterior knee pain required longer rehabilitation than iliotibial band syndrome in UK Army Infantry recruits (Sharma et al., 2015), however no other pathology or knee injury types were reported. In the current cohort of New Zealand Army recruits, nearly 400 health care encounters were required for injuries sustained at the knee over six months. Reporting health care demand that includes number of encounters for injury rehabilitation is important. Lengthy injury rehabilitation with increased health encounters can be costly for medical resources, can result in training time loss, extend training time, and can affect operational capability and deployment readiness longer term (Sharma et al., 2015; Teyhen et al., 2018). Limiting reporting to only include new knee injury incidence would potentially under-estimate the scope of the knee injury burden effecting recruits and opportunities for injury mitigation might be underestimated and underdelivered.

While knee injuries are common in basic training recruits, previous research reports mostly male recruit populations (Heagerty et al., 2017b; Sharma et al., 2015), mixed-sex results for recruits (Coppack et al., 2011) or reports knee injury incidence comparing trained male and female military personnel (Schram, Orr, et al., 2022). Due to low female recruit numbers, the current body of research did not separate outcomes of knee injury incidence based on sex (Study 1 and 3), so the incidence of knee injury sustained by the female recruits remains unclear. Future research should therefore report male and female injuries separately to better understand sex-specific differences in basic training recruits.

8.2.2 Recruits enter basic training with injury risk factors

The current program of research established that New Zealand Army recruits enter training with personal, lifestyle and physical performance injury risk factors, of which several are modifiable. Identifying recruit injury risk factors fulfills the second step in the 'sequence of injury prevention model', which is to establish injury aetiology (van Mechelen et al., 1992).

Personal risk factors for injury were not identified within this program of research. In other recruit populations, personal characteristics such as age (≥ 30 years) (Knapik et al., 2013a), female sex (Jones et al., 2017) and high or low BMI have been associated to a high injury risk in US recruit populations (Jones et al., 2017). Less than 10% of recruits included in this program of research met these previously identified risk factors for age and female sex, which perhaps could explain why personal factors were not associated with injury risk in this cohort of recruits. While age and sex are not modifiable at entry, recruits matching high risk age and sex characteristics could be accommodated by changes to training such as more graduated load introduction and allocation to ability based physical fitness training to lower injury risk. Further research with larger numbers of New Zealand Army recruits is required to better understand personal injury risk factors entering basic training.

Lifestyle risk factors identified in army recruits included pre-existing injury and current smoking history. More than 30% of New Zealand Army recruits in the current study entered training with pre-existing injury, and one fifth were current smokers. Similar numbers of UK Infantry recruits (Heagerty et al., 2018) and US Military Police recruits enter training with a prior injury (Knapik et al., 2013a), while evidence of higher rates of current smokers (67%) have been observed in UK Infantry recruits (Sharma, 2018). Presence of pre-existing injury and whether such injuries had fully recovered (Knapik et al., 2013a) is important for militaries to understand. Militaries may need to manage at-risk recruits and minimise the potential for subsequent and chronic injury, which can lead to detrimental occupation consequences such as backsquad or discharge. Similarly, smoking rates may need to be monitored as excessive smoking or even taking up smoking during training should be avoided due to poorer healing rates and known association to risk of injury during basic training (Knapik et al., 2013a, 2013b). Regardless, these lifestyle characteristics are potentially modifiable with prevention interventions such as injury rehabilitation and quit smoking programs, with intervention aimed to lower recruit injury during training.

Physical performance testing of aerobic fitness, ankle dorsiflexion range of motion and lower limb dynamic stability may identify recruits with injury risk factors at entry to training. Some of these characteristics are potentially modifiable. Approximately 54% of male and approximately 29% of female New Zealand Army recruits met pass time requirements, and non-passing recruits were more likely to injure during training (Study 4). Others have also reported a relationship between slow 2.4 km timed run and risk of injury (Hall, 2017; Heller &

Stammers, 2020; Jones et al., 2017; Robinson et al., 2016). With training, aerobic fitness as measured by 2.4 km run time is a modifiable recruit injury risk factor.

High, low and asymmetry in ankle dorsiflexion range of motion was observed in this program of research. New Zealand Army recruits display high, low (approximately 45%) or asymmetry (31%) at entry to training (Study 2). High, low or asymmetry in dorsiflexion has previously identified recruits and soldiers at high risk of lower limb musculoskeletal injury (Pope et al., 1998; Teyhen et al., 2015). Identifying recruits with low (<9.4 cm) or high (>16.1 cm) dorsiflexion range of motion (Bennell et al., 1998; Pope et al., 1998) and asymmetry (>1.5 cm) (Hoch & McKeon, 2011) is important as these risk factors are potentially modifiable and most, quickly addressed. For instance, low or restricted dorsiflexion range of motion is potentially modifiable using ankle mobilisation (Vicenzino et al., 2006), while high dorsiflexion mobility may be quickly modified with ankle taping (Romero-Morales et al., 2023) or external ankle bracing (Olsen et al., 2005; Parkkari et al., 2011; Pasanen et al., 2008). Alternately, neuromuscular training improves limb stability with training overtime (Butler et al., 2013; Nakagawa et al., 2020; Plisky et al., 2006).

Recruits enter New Zealand Army training with poor lower limb dynamic stability. High posterolateral reach asymmetry was observed in 51% of recruits, including 70% of females, while over 60% of recruits scored below 94% with composite reach normalised to leg length. Both have previously been associated with injury risk in military recruit or sports populations (Butler et al., 2013; Nakagawa et al., 2020; Plisky et al., 2006). For instance, high posterolateral asymmetry (≥ 4.08 cm) was associated with approximately 5.5 times greater risk of developing patellofemoral pain during army recruit training (Nakagawa et al., 2020). Low composite reach score (<94%) was found to be associated with 6.5 times greater risk of lower extremity injury in female basketballers using the modified Star Excursion Balance Test (Plisky et al., 2006). Potentially, New Zealand Army recruits with high posterolateral asymmetry may be at higher risk of developing patellofemoral pain and recruits with low composite score (<94%) may be at higher risk of lower limb injury. As this is one of the first studies to report dynamic lower limb stability in male and female army recruits using the Y Balance Test™ more research is required to better understand its effectiveness to identify recruits at risk of injury at entry to basic training.

8.2.3 Screening for injury risk is important and should be undertaken

Screening recruits at entry to training is important to undertake as doing so could identify recruits with injury risk factors and measures could be taken to lower injury risk. Low cost, staff and resource efficient performance characteristics were identified in this program of research that could be used for injury screening of recruits upon entry to training.

Slow 2.4 km run time was associated with lower limb injury risk in the current cohort, and findings are in agreement with previous reports in multiple recruit populations (Hall, 2017; Heller & Stammers, 2020; Jones et al., 2017; Robinson et al., 2016). Findings from this program of research support two recommendations to reduce future recruit injury. Firstly, prospective recruits should train to exceed minimum entry run pass requirements (10.1 Appendix A), and this should be strongly encouraged by military recruitment agencies. Secondly, military entry run-time cut off points should be adhered to (Hall, 2017; Heller & Stammers, 2020; Jones et al., 2017; Robinson et al., 2016). Collectively, these actions will likely lead to fewer lower limb injuries sustained by New Zealand Army recruits during basic training and similar recommendations are echoed across multiple recruit studies to lower recruit injury risk during training (Hall, 2017; Heller & Stammers, 2020; Jones et al., 2017; Robinson et al., 2016). The challenge for militaries is however finding a balance between recruits meeting entry requirements and achieving entry quotas. Screening 2.4 km pass outcomes at entry to training is important and should continue to be undertaken to identify New Zealand Army recruits at high risk of injury due to low aerobic fitness.

Recruit lower limb injury risk was also associated with low dynamic stability score for right posterolateral Y Balance Test^{TM} reach. Poor performance of posterolateral reach is potentially associated with low hip abduction strength and altered motor control (Wilson et al., 2018). Additionally, posterolateral reach asymmetry (a difference in performance between right and left limbs) has been associated with development of patellofemoral pain in basic training male Brazilian Army recruits (Nakagawa et al., 2020). Potentially, if low posterolateral reach (or asymmetry) is determined in Week 1 of training, or even prior to training, interventions which target hip abduction strength and motor control may be introduced to lower injury risk (Francis et al., 2018; Wilson et al., 2018). Given knee injuries represented the greatest injury and health care burden for New Zealand Army recruits, application of a quick dynamic stability test to identify an association to knee injuries early in training could be transformative for prevention efforts. Screening recruits for risk of injury at entry to training is important, however more research is required to better identify if there is an association between lower limb dynamic stability, hip strength and knee injury risk.

Future injury screening could incorporate low-cost, resource efficient muscular strength and endurance testing to help identify recruits at risk of injury. Performance on push ups has previously been found to be associated with injury in military populations (Knapik et al., 2001; Rhon, Molloy, et al., 2022), while evidence supporting sit up (crunches) performance is more scarce (Knapik et al., 2010). In the New Zealand Army, the army Regular Fitness Level test includes the 2.4 km run test and a 2-minute maximum repetition test for push ups and sit-ups, although these were not included in this program of research. Performance benchmarks have been established with sex and age specific pass grades (10.1 Appendix A).

The idea of a fitness assessment including strength tests as a screening tool has been explored in military recruits previously. Low performance on the US Army 1-1-1 fitness assessment which includes 1-minute maximum tests for both push up and sit-ups and a 1-mile (1.6 km) timed run, was found to predict musculoskeletal injury in US Infantry, Basic Combat, Armor and Cavalry trainees using a single overall score of performance (Sefton et al., 2016). Further research could investigate if a single score method similar to that used by Sefton et al. (2016) could be developed and tested for injury risk of New Zealand Army recruits.

For future recruit injury screening to be feasible, tests should include those that already exist, such as the New Zealand Army Regular Fitness Level test for a timed 2.4 km run. At the time this program of research was conducted, both the weight-bearing dorsiflexion lunge test and the Y Balance Test™ were included as part of New Zealand Army regular recruit Week 1 testing. These screening tests also had utility beyond initial screening on entry to training and could be used across different military environments including in camp, in the field, on deployment and at recruitment centres. Recruitment centres, for example, could use these tests to inform recruits of potential injury risk and readiness for entry to the military. Prospective recruits could then seek opportunities to improve fitness through personal training or a fitness website (Force Fit, Defence Careers, 2024) and seek rehabilitation (physiotherapy) of pre-existing injuries before commencing training. Additionally, future studies could investigate the addition of low cost and resource efficient muscular strength and endurance tests such as push ups with New Zealand Army recruits.

In addition to screening, other approaches have recently been proposed to reduce recruit injury. Roll-out of proven musculoskeletal injury risk reduction programs, applied across all recruit training is emerging as a cost-saving option (Bahr, 2016; de la Motte, Clifton, et al., 2019). A combination of injury reduction programs together with prediction modelling using strong injury risk factor association has also been proposed (Bahr, 2016). Bahr (2016) suggests another step would be to examine if a risk reduction program, solely targeting high injury risk recruits identified through screening, is more beneficial than providing an intervention applied to all recruits. Such a comparison is yet to be identified in both recruit and sports populations.

8.2.4 Neuromuscular training reduces health care burden

This program of research found neuromuscular training led to less health care burden for overall lower limb and knee injuries during basic training. Developing and implementing an injury prevention program and assessing its effectiveness fulfills the third and fourth steps in the 'sequence of injury prevention' model (van Mechelen et al., 1992). Findings from this study support implementation of neuromuscular training to lower health care encounters and burdens for injury sustained by army recruits.

This research program is one of few to compare the effectiveness of a neuromuscular and usual training programs on lower limb injury incidence sustained by recruits during basic training. In previous research, the effectiveness of a neuromuscular training program to lower injury across all lower limb anatomical regions was unclear (Coppack et al., 2011; Parkkari et al., 2011), and it was unknown if neuromuscular training could lead to fewer health care encounters for injury. By categorising injuries according to lower limb anatomical region and reporting injury healthcare burden, this research begins to fill the gap in the literature reporting neuromuscular training effectiveness in military recruits. Occupational endpoint findings from this cohort also show that more neuromuscular training recruits successfully completed training on time and, although not significant, fewer accumulative light duties days for injury were required. Only two other military recruit studies previously reported outcomes on occupational endpoint (Coppack et al., 2011) and time loss (Parkkari et al., 2011). Outcomes from this program of research further contribute to understanding the extent of the recruit injury burden and effectiveness of neuromuscular intervention, which is the fourth step of the ‘sequence of injury prevention’ model (van Mechelen et al., 1992).

For neuromuscular training to be effective in lowering army recruit injury, health care encounters and associated burdens, exercise dosage and prescription was important. Neuromuscular training in the current research was described as a supplemental training program comprising both general warm up running drills and specific exercises that target motor control deficits (Myer et al., 2011), which were delivered by qualified professionals. The three anatomical regions of the knee, shin/calf and ankle were targeted due to the frequency of injury reported by New Zealand Army recruits to physiotherapy during basic training (Study 1).

Exercise prescription of 2-5 times per week, for 18-20 minutes was established based on existing military recruit neuromuscular programs and recommendations from sporting populations which aimed to reduce lower limb injury (Brushoj et al., 2008; Coppack et al., 2011; Parkkari et al., 2011). Specific exercises included 12-13 circuit stations of 1-minute intervals (10.3 Appendix C). To avoid neuromuscular fatigue, circuit exercise types alternated between stations and most exercises progressed in challenge fortnightly.

While the neuromuscular intervention prescription in this program of research was implemented in 2012, it is still applicable today. A similar exercise prescription was recommended in 2017 in a meta-analysis investigating neuromuscular injury prevention programs, although this was in a population of young athletes (age ≤ 21 years) (Steib et al., 2017). Steib et al. (2017) found neuromuscular training two to three times per week with a session length of 10-15 minutes was the most effective prescription to reduce lower limb injuries. Additionally, an intervention period of 1.5 to six months was sufficient to reduce injuries (Steib et al., 2017). The neuromuscular training in this program of research was implemented for six weeks and was therefore on the lower limit of these findings from the meta-analysis (Steib et al., 2017).

Future research investigating injuries in New Zealand Army recruits should consider a larger sample size, with more than two recruit intakes and for periods longer than six months to better understand the effectiveness of neuromuscular training. Additionally, research is required to investigate if implementing neuromuscular training prior to basic training as a preconditioning program or even throughout training (> 6 weeks) further reduces lower limb injuries in recruits. Other military and tactical training populations may benefit from neuromuscular injury prevention training, however research with each population is needed as they have different training regime, environment and different march out requirements.

8.2.5 Neuromuscular training implementation

Outcomes from this program of research identified that multiple factors should be considered to ensure successful implementation of future neuromuscular training programs. Factors such as exercise program compliance, supervision by qualified staff, execution of correct exercise technique, exercise modification, translation of research into the real-world, and stakeholder involvement are important. These findings are in accordance with historical and emerging research of military and sports populations (Bullock et al., 2023; Coppack et al., 2011; Finch, 2006; Myer et al., 2011; Parkkari et al., 2011; Rhon, Oh, et al., 2022).

8.2.5.1 **Compliance/adherence to implementation**

High compliance or participation to physical training exercise (approximately 90%) was observed from both the usual training and neuromuscular intervention recruit groups in this program of research and possibly contributed to its effectiveness. Compliance and individual adherence to neuromuscular training programs is strongly emphasised in sports and military research. In military populations, high compliance/participation (>90%) can be attributed to the controlled and standardised military training environment (Coppack et al., 2011; Parkkari et al., 2011). In New Zealand, basic training recruits are required to attend all physical training sessions, with exceptions only made for those attending administrative or medical appointments or for recruits on light duties for injury or illness. Attendance at physical training is typically recorded by physical training instructors, and a separate attendance sheet was used to inform this program of research. The combination of compulsory training and auditing of recruit participation potentially enhanced neuromuscular exercise compliance in this population. Approximately 10% of recruits in this cohort were unable to participate in physical training warm ups due to appointments or had been assigned to light duties. Where possible, recruits were encouraged to participate in physical training within the restrictions of modified light duties, and this was standard practice on camp.

In sports research, compliance or adherence to neuromuscular training varies and may affect injury prevention outcomes. Lack of adherence to neuromuscular training may cause useful evidence-based interventions to appear ineffective (Owoeye, Rauvola, et al., 2020). For example, low compliance to neuromuscular training in female soccer players (60% for first half of season), led to no difference in injury rate between neuromuscular and control groups (Steffen et al., 2008). However, high adherence to neuromuscular training significantly improved injury risk and functional balance (Steffen et al., 2013). Despite convincing evidence of neuromuscular injury prevention effectiveness or efficacy, implementation and uptake to neuromuscular programs is not often adopted in real-world contexts for sports populations (Finch, 2006; Minnig et al., 2022; Owoeye, Rauvola, et al., 2020; Rommers et al., 2022). This was not the case with this recruit cohort or other recruit populations. The regimented military environment, controlled delivery of neuromuscular training and mandatory participation ensures effective programs are complied with and adhered too. As such, beneficial injury prevention outcomes in the real-world military recruit context can be realised.

Ongoing compliance and adherence to neuromuscular training programs requires auditing to ensure the effectiveness of prevention training is maintained into the future. The four-step Adherence Optimisation Framework for research of neuromuscular warm up programs has been proposed to optimise adherence (Owoeye, McKay, et al., 2018). Step 1 identifies neuromuscular adherence levels. Step 2 determines predictors of adherence/non-adherence. Step 3 develops strategies for improving adherence and Step 4 evaluates the effectiveness of adherence strategies (Owoeye, Emery, et al., 2020; Owoeye, McKay, et al., 2018). These simple steps could be adopted in the military context to identify barriers to implementation of neuromuscular training exercise, including compliance by recruits and the military.

8.2.5.2 **Supervision, correct technique and lower limb alignment**

Supervision of neuromuscular intervention exercises was provided by qualified army physical training staff for all physical training sessions in this program of research. This is in-line with previous published studies in military recruits (Coppack et al., 2011; Myer et al., 2011; Parkkari et al., 2011) and some cadet populations (Carow et al., 2016). Supervision by qualified staff or coaches is strongly emphasised in both sports and military prevention research, and likely increases both compliance and adherence to an exercise protocol and ensures exercises are performed with correct technique and optimal alignment (Coppack et al., 2011; Myer et al., 2011; Parkkari et al., 2011).

The importance of supervision by qualified persons has been shown in research of USMA cadet basic training. Dynamic Integrated Movement Enhancement (DIME) that included neuromuscular type exercise was more effective when supervision was provided by experts such as athletic trainers or a physiotherapist than cadre cadet supervision or unsupervised usual warm up exercise for lowering injury (Carow et al., 2016). Over the academic year in training, a 41% reduction in lower extremity injury was observed in DIME expert supervised training compared to DIME cadre supervised (Carow et al., 2016).

Similarly, in sports populations, neuromuscular injury prevention may be more effective when delivered by experts. In sports research, experts are defined as qualified trainers, coaches and physiotherapists (Olsen et al., 2005; Pasanen et al., 2008) and delivery may be enhanced with feedback on exercise carried out in pairs of athletes educated in exercise technique (Olsen et al., 2005; Pasanen et al., 2008). More recently, a meta-analysis of exercise-based injury prevention programs in sports reported supervision was associated with better adherence and lower injury rate than unsupervised programs (Valentin et al., 2023).

Supervision ensures neuromuscular exercises are performed with correct or proper technique and optimal lower limb alignment. Execution of correct exercise technique implies exercises are carried out consistently with consideration of movement control. Parkkari et al. (2011) describes correct technique as the use of good posture, maintenance and consistency of core stability or appropriate positioning of the hip, knee and ankle to achieve knee-over-toe position. Optimal alignment aims to reduce excessive hip adduction and internal rotation of the stance leg (Powers, 2010) and reduces adverse knee valgus moments and valgus angles affecting the knee during training (Hewett, Myer, Ford, et al., 2005; Nakagawa et al., 2020; Powers, 2010).

Potentially, poor biomechanical lower limb alignment during basic training activities may contribute to common knee injuries such as iliotibial band syndrome, patellofemoral pain and anterior cruciate ligament tears (Hewett, Myer, & Ford, 2005; Nakagawa et al., 2020; Powers, 2010).

Correct technique and optimal alignment during neuromuscular training was encouraged through demonstration and feedback by physical training instructors and display posters with photographs of correct and incorrect hip, knee and ankle positioning. Specifically, correct technique and lower limb alignment were emphasised for ¼ squats, step downs and lunge exercises through demonstration and feedback by instructors (Section 10.3 Appendix C). Correct hip, knee and ankle alignment is suggested for consideration in frontal and sagittal planes of movement for injury rehabilitation and prevention (Powers, 2010). Supervision, correct technique and lower limb alignment are important factors to consider in future neuromuscular training programs.

8.2.5.3 Modifying prescribed recruit neuromuscular training may change effectiveness

Modification or adaption of individual exercise or even whole neuromuscular program delivery away from the intended program could affect neuromuscular intervention effectiveness. Modification of neuromuscular training programs is considered problematic in sports and potentially lowers neuromuscular prevention training programs effectiveness (Owoeye, Rauvola, et al., 2020; Shamlaye et al., 2020).

Modification of neuromuscular training is however unlikely in this cohort of recruits due to the controlled regimental military delivery and environment. Army physical training staff were issued clear exercise descriptions, exercise posters displaying correct technique and completed a brief post-exercise attendance sheet for this research. Collectively, these factors contribute to consistent delivery and adherence to the neuromuscular program, as modification could threaten injury prevention effectiveness of the intended program. Potentially, these factors strengthen the fidelity of delivery of neuromuscular training in this program of research (Owoeye, 2022). Once a neuromuscular program is found to lower injury incidence, any further modification of individual or whole programs requires consideration of injury incidence data and involvement of key stakeholders such as physical training instructors who deliver the training, medical staff involved in injury diagnosis and rehabilitation such as doctors and physiotherapists, recruit training staff and recruits themselves. Applying the four-step Adherence Optimisation Framework for research of neuromuscular warm up programs should be undertaken to audit neuromuscular exercise delivery and adherence (Owoeye, Emery, et al., 2020; Owoeye, McKay, et al., 2018).

8.2.5.4 **Translation of neuromuscular training into practice**

Neuromuscular training effectiveness is affected by issues regarding translation of results from research into practice. Translation research is mostly reported in sports populations (Emery et al., 2015; Owoeye, Rauvola, et al., 2020) and emerging for military populations (Heagerty & Sharma, 2018; Rhon, Oh, et al., 2022). Potentially, knowledge of neuromuscular injury prevention effectiveness is lost for army recruits if it is not applied. Translation of neuromuscular training into the daily real-world routine of recruits and scaling neuromuscular training to other military populations is important (Owoeye, Rauvola, et al., 2020).

After completion of this research, neuromuscular training was rolled out with all recruit training populations at the request of the Commander of Training and Doctrine (TRADOC) NZ Army in 2014. Ongoing delivery of the proposed neuromuscular prevention program was therefore at the discretion of the physical training instructors on-site. Anecdotally, aspects of this neuromuscular training continue to be delivered in the Waiouru Military Camp in the central North Island of New Zealand (Personal communication Maj (Dr) Rousseau, 9th May 2023). However, the neuromuscular training program was later implemented as an addition to the usual training program, which was not how the program was originally intended to be delivered. Detrimental injury risk consequences have been observed when neuromuscular type prevention training was additional to existing military recruit physical training syllabus (Goodall et al., 2013). Neuromuscular intervention should therefore be maintained within the existing physical training program to prevent overtraining.

Investigation of the maintenance or sustainability of neuromuscular prevention or other prevention training is scarce for military recruits and tends to be commentary based (Heagerty & Sharma, 2018; Molloy, Pendergrass, Lee, Hauret, et al., 2020; Rhon, Oh, et al., 2022). If undertaken with New Zealand Army recruits, research would now describe results one decade after neuromuscular training implementation. Such research would be unique because rarely has the maintenance and sustainability of neuromuscular training been investigated 10 years after intervention. Potentially, only one study of anterior cruciate ligament injury incidence in female handball players in Norway reports neuromuscular training maintenance and effectiveness one decade after implementation (Myklebust et al., 2013).

8.2.5.5 **Engagement of key stakeholders**

Good engagement with key stakeholders at the point of care where research is undertaken can be vital to research success or failure (Bullock et al., 2023; Rhon, Oh, et al., 2022). Successful implementation of neuromuscular training for this research program was only possible due to collaboration and engagement of key stakeholders involved with recruit training and requires consideration for future neuromuscular training research.

Stakeholders for this program of research included military leadership such as the Waiouru Army Camp Headquarters, The Army Depot which is the recruit training unit, and medical unit leadership. Important stakeholders at the point of care also included clinicians within the medical centre, the physiotherapist who manage injuries on-site and physical training instructors who deliver physical fitness training and testing. Further stakeholders were army recruits, who were the patients and beneficiaries of research. Early engagement and buy-in from all stakeholders was identified as an essential component to injury prevention effectiveness in this military recruit population and key to improve compliance and adherence at the point of care (Heagerty & Sharma, 2018; Rhon, Oh, et al., 2022).

This research required authorisation from the Commander of TRADOC NZ Army to proceed. The candidate (NH) liaised with the Commander and headquarters staff to underline the extent of the historical recruit injury problem, the need for identifying recruits at risk of injury and the proposed neuromuscular injury prevention training intervention (van Mechelen et al., 1992). As suggested by Heagerty and Sharma (2018), buy-in from the leadership was expected to permeate down to empower neuromuscular training delivery and potentially enhanced compliance and adherence.

Integration between key stakeholders for training delivery and health provision was essential (Heagerty & Sharma, 2018). Liaison with training and health leadership included The Army Depot Commanding Officer, training unit headquarters, the course coordinator, and staff from the medical centre was required to accommodate timings within the recruit program for questionnaires, and physical performance tests such as the weight-bearing dorsiflexion lunge test and Y Balance Test™.

Disruption to research data collection occurred due to deployment of one outcome assessor and this is a common limitation identified with clinical military research in the US (Rhon, Oh, et al., 2022). Replacement by a remedial instructor ensured physical performance testing could continue. This was only possible due to the integrative culture and liaison of key stakeholders within medical and physical training units across multiple military camps (Heagerty & Sharma, 2018). The ability to quickly overcome unexpected research challenges may be an advantage of smaller militaries. These are important lessons learned, and pre-empting such events will improve success of future research and delivery of neuromuscular prevention training.

This program of research has identified that knee injury is common in recruits, that recruits enter training with risk factors for injury, and potentially these factors could be screened at entry. Another key finding was that neuromuscular training lowers health care encounters and other associated injury burdens. Exploring these key findings has identified that consistency in use of injury definitions and injury surveillance is lacking across recruit research. Potentially, consensus documents for recruit injury reporting in research is required to improve comparability of study findings and is explored in the following section.

8.2.6 Consensus for injury surveillance is needed for recruit populations

Several challenges pertaining to injury surveillance reporting were identified in this program of research. Injury definition and incidence descriptors have varied across research and terminology has expanded over the last decade. Consensus on injury surveillance and injury terminology is needed and consideration of consensus statements, data dictionary and injury coding systems will be discussed.

Consensus for injury surveillance is needed for recruit populations. For instance, recruit injury definitions typically include a medical attention injury (Goodall et al., 2013), however some studies use an injury time-loss (Heller & Stammers, 2020) or occupational outcome definitions such as attrition due to injury (Dijksma et al., 2019). These variations make comparisons between studies difficult. A combination of these definitions was included in Study 3 and more holistically describes the extent of recruit injury burden. Additionally, variation also exists across research for injury incidence rates, exposure time and injury severity (Molloy, Pendergrass, Lee, Hauret, et al., 2020; Stannard et al., 2022) which collectively limits comparison of results to findings in this program of research.

Another more recent challenge for this program of research has been the inclusion of expanded injury incidence definitions which have evolved over the last decade (Finch & Cook, 2014; Hamilton et al., 2011; Toohey & Drew, 2020; Toohey et al., 2018). In sports populations, a new injury is described as a first new index injury, while subsequent, recurrent and exacerbation definitions have also emerged (Hamilton et al., 2011). A subsequent injury is any injury (or illness) that occurs after the first index injury (Hamilton et al., 2011). Recurrence is used when the index injury had fully healed or recovered, while exacerbations described when the index injury has not yet fully healed or recovered (Hamilton et al., 2011; International Olympic Committee et al., 2020).

An attempt to report subsequent and recurrent injury was made for Study 3, however data often lacked enough detail to use these labels accurately. For instance, recruits' injury recovery status was often not clear, and no agreed time to demarcate recovery status was established. This resulted in uncertainty between use of a new index injury versus a subsequent injury, and an injury recurrence versus an exacerbation which describe injury healing status (Hamilton et al., 2011; International Olympic Committee et al., 2020). Coding aggravation of a pre-existing injury was also difficult and requires expert consensus to report consistently. This issue is challenging and may be sensitive for recruits to report as failure to disclose a pre-existing injury can result in being dismissed from training. Additionally, recruit non-reporting or concealing injuries during basic training can lead to subsequent and chronic injury and can underestimate the injury problem (Cohen et al., 2019). Injury non-reporting requires consensus for effective inclusion in future recruit injury surveillance research.

International military recruit injury consensus statements are needed and could be modelled on those established by the IOC for athletes (International Olympic Committee et al., 2020) and for football/soccer (Fuller et al., 2006). By reaching agreement and standardising reporting including injury surveillance, injury definition, incidence rate, time-loss, exposure, and injury severity, this process would likely improve comparability of military recruit research in the future.

Research is now emerging for injury surveillance consensus in law enforcement recruits and military Special Operations Forces populations (International Olympic Committee et al., 2020; Molloy, Pendergrass, Lee, Hauret, et al., 2020; Murphy et al., 2022). Using a Delphi study method, agreement was sought from experts in injury surveillance and injury definitions while also outlining challenges faced reporting military and law enforcement injury data (Murphy et al., 2023; Stannard et al., 2022). While establishment of injury consensus of trained military and other tactical populations is encouraging, research of injury surveillance specific to recruit populations is required as differences exist in training duration, regime and experience from these different tactical populations. Beyond this program of research, development of a recruit injury consensus statement using a Delphi study approach (Murphy et al., 2023; Stannard et al., 2022) and with expert collaboration from the military, health practitioners and researchers could lead to improved research reporting. Such a process will contribute to a better understanding of injuries affecting military recruits.

An electronic data dictionary such as one used within the Australian Institute of Sport Athlete Management System (Toohey & Drew, 2020), with standardised medical injury history reporting should be established for recruits. Injury information could be gathered and collated quickly such as body location, mode of injury onset, injury time-loss and recovery status (Toohey & Drew, 2020). Minimal changes would be required to accommodate recruit populations, such as inclusion of the week of injury and military activity when an injury is sustained, such as field exercise. Injury recovery status may be more difficult in recruit populations as field exercises and busy training schedules potentially interfere with formal return-to-training medical appointments. Instead, recovery for recruits with minor injury is often signified by 'coming off light duties'.

Additionally, use of established injury coding such as the Orchard Sports Injury and Illness Classification System (OSIICS) that includes injury anatomical location (segment and joint) and tissue and pathology codes could improve comparability of research findings across recruits, but also to other military, tactical and sports populations (Orchard et al., 2020; Stannard et al., 2022). The OSIICS has been translated to other injury databases such as Sports Medicine Diagnosis Coding System and International Classification of Diseases, further improving injury surveillance comparability to research using other injury code systems (International Olympic Committee et al., 2020; Orchard et al., 2020). The OSIICS is included with the Australian Institute of Sport Athlete Management System data dictionary, and version 13.1 has been identified as the preferred method of injury coding for Special Operations Force military populations (Stannard et al., 2022). The inclusion of OSIICS (Version 10.1) data collection reporting was originally planned in this program of research, however a lack of detail in injury histories meant injury was reported more broadly by anatomical site (joint and segment). Similar limitations for detailed injury incidence reporting are described across other military services (Molloy, Pendergrass, Lee, Chervak, et al., 2020).

Consensus on injury surveillance, coding and reporting would likely improve reliability, accuracy, and consistency comparing research of recruits (Stannard et al., 2022), and enhances the collective effort to lower recruit injury incidence and severity during basic training.

8.2.7 Clinician led research

This program of research was borne from a clinician's frontline experience observing patterns of injury over many intakes of military recruits, officer cadets and trained military personnel and from militaries across two countries. Clinicians such as physiotherapists provide point of care injury surveillance (Pope & Orr, 2017). Having a single clinician perform injury surveillance provides high intra-rater reliability (Phillips, 2000) and improves accuracy and consistency for medical diagnosis compared to external or non-clinician researchers (Finch et al., 2014).

For benefits of injury research to be effective longer term, knowledge gathered of recruit injury, injury risk factor and prevention interventions need to be recorded, analysed, and be published. Utilising rigorous research methodology to establish interventions and record outcomes will ensure high quality evidence is generated, that is clinically meaningful and of value to the military. Publishing research findings confirms that knowledge is retained and ensures sustainability of injury prevention is available for future use.

For clinicians undertaking military population research with the aim to publish, support and funding is required. Planning, undertaking, and conducting research including the write-up phase may require work being undertaken outside employed hours, and possibly with no grant funding, making researching a gratuitous effort (Rhon, Oh, et al., 2022). These factors potentially impact research completion. In the US military, approximately 12% of registered trials do not take place or are incomplete due to issues with research enrolment and funding (Cook & Doorenbos, 2017). It is therefore recommended that additional time and funding be allocated to support future civilian and uniformed clinicians to complete research with the New Zealand Army. Support for clinician researchers may help avoid clinician burnout from competing demands from clinical practice, organisational requirements and research, which has been reported as problematic for military personnel from medical centres in the US (Rhon, Oh, et al., 2022).

Supporting clinician researchers can have other benefits for the military. In military studies which modified training load, recruit or soldier injury and associated burdens are potentially reduced (Heagerty & Sharma, 2018; Rhon, Oh, et al., 2022; Rudzki & Cunningham, 1999; Sharma et al., 2015). Additionally, there is also lower health care demand and cost (Rudzki & Cunningham, 1999), and lower costs related to recruitment and retention to replenish injured recruits (Molloy, Pendergrass, Lee, Chervak, et al., 2020). Such benefits may also aid in promoting the military as proactively seeking opportunities to identify common recruit injuries and injury risk factors, and injury prevention interventions that improve the overall wellbeing of recruits and soldiers under training. Given the many benefits of this program of research for recruits and for the military, supporting future clinician researchers to continue injury prevention work is important.

8.3 STRENGTHS AND LIMITATIONS

This program of research involving four studies has several overall strengths and limitations. The overall strengths and limitations are outlined in the following section.

8.3.1 Strengths

Overall strengths of this program of research include use of large comprehensive recruit data sets reported from both physiotherapy or whole medical health care encounters (outpatient, in-patient and external specialist) and the period investigated spanned six months to four years. Injury surveillance also included bilateral and multiple injury presentations and common conditions effecting recruits such as skin blisters. Collectively, these factors and the research timeframes likely represent the actual extent to the New Zealand Army recruit injury problem across basic training (van Mechelen et al., 1992). In addition, both male and female recruits were included in all four studies of this research program. Given western militaries are actively seeking to increase female representation in the services (Nindl et al., 2016), research of injury risk factors and prevention interventions specific to female military populations will become increasingly important (Schram, Orr, et al., 2022).

Low cost, resource efficient objective measures were used to screen for injury risk factors and to identify actual occurrence of injury in New Zealand Army recruits undertaking basic training. A combination of self-reported questionnaire and physical performance measures were used throughout this program of research because they were ideal for screening large groups, and repeatable across a military career. Additionally, this may be one of the first studies to investigate physical performance results of male and female recruits using both the weight-bearing dorsiflexion lunge test for distance and the Y Balance Test™ for dynamic lower limb stability, providing important baseline values and may identify recruits at risk of injury during training. Furthermore, the 2.4 km timed run and the posterolateral reach using the Y Balance Test™ were found with association to actual injury experienced by New Zealand Army recruits and these tests could be used at recruitment centres to identify recruits at risk of injury so that injury mitigation measures could be taken prior to training commencement. Research is needed to identify entry cut points with greater number of recruits and over longer periods.

A rigorous double-blinded cluster randomised controlled trial was conducted and is one of few studies to investigate neuromuscular training effectiveness of military recruits across six months of intakes and injury incidence across the whole lower limb. Neuromuscular intervention exercises were not additive, were delivered within the existing syllabus to avoid overtraining, required no additional staffing, low equipment cost, and could be used in a variety of military environments including in camp, in the field and on deployment.

8.3.2 Limitations

Across this program of research, minor injuries sustained by recruits that were not reported to the medical centre were not recorded; this may underestimate recruit injury. Presentations for skin, nail and cramp were included in two studies, however debate continues for their inclusion in military recruit research. Excluding these injuries could underestimate the real-world recruit injury problem (Knapik et al., 2019). A minor volcanic eruption nearby camp occurred on the first day of the second intake (NASA earth observatory, 2012). While this naturally occurring event did not detract from recruit training, it may have influenced voluntary release numbers for Study 3. This was beyond control of researchers.

The Military Pre-training Questionnaire (Robinson et al., 2010) comprising five health domains, while thorough, was long and took approximately 15 minutes to administer. Because diet and alcohol intake are standardised or controlled at entry, these domains may not be as important for injury risk as training progresses. Potentially a modified, shorter questionnaire which captures previous injury, smoking status and injury recovery status is suggested for inclusion in futures studies due to their known association to recruit injury risk (Knapik et al., 2013a). Finally, as the scope of injury risk is unknown across different cultural or ethnic groups entering New Zealand Army training, research of this information may better inform future recruit research.

Several limitations are acknowledged during the implementation of the randomised controlled trial. Blinding of recruits, assessors, and physical training instructors was planned within the trial design. Assessors and physical training instructors remained blinded throughout the implementation. Blinding of recruits was not completely successful and is difficult to manage in recruit environments due to shared living and eating conditions. This could be improved by studying whole intakes, preferably at separate periods throughout the year. The candidate was the sole physiotherapist on site in this remote location. This could possibly contaminate/create ascertainment bias however injury presentations were triaged initially via medics, doctors and nurses and injury incidence, occupational endpoint and light duties days data were not analysed until after completion of basic training to limit this bias.

Health care encounter costs had originally been planned for inclusion in the randomised controlled trial, however updates in clinician cost and inflation meant historical costing were out of date. Inclusion of a cost-benefit analysis would better explain the financial burdens of recruit injury comparing neuromuscular and usual training groups in the future.

8.4 CONCLUSION

Four studies comprised this program of research investigating injuries in New Zealand Army recruits. The first observational study found New Zealand Army recruits were predominantly males who sustain injuries at the knee and below over four years of intakes. The second study identified recruits entering training were predominantly 20-year-old males with some recruits presenting with pre-existing injury, a history of smoking, slow 2.4 km run time for distance, altered ankle dorsiflexion range of motion, and low dynamic lower limb stability. A double-blind cluster randomised controlled trial investigated the effectiveness of six-weeks neuromuscular program compared to usual training and found fewer health care encounters for overall lower limb injuries, fewer knee health care encounters and more recruits successfully completed training from the intervention group. A fourth study found two variables of slow 2.4 km timed run and low dynamic stability of right posterolateral reach, were associated with lower limb injury risk in New Zealand Army recruits undertaking basic training.

Future research should investigate inclusion of existing military fitness tests for muscular strength and endurance and risk of injury, consider neuromuscular training implementation for longer periods or as a preconditioning program and establish a recruit injury consensus statement for consistency in injury surveillance and reporting. Findings of this program of research have potential to be applied to other military, tactical and service populations, however further research of injury risk and neuromuscular training effectiveness of each is required.

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10. Appendix

10.1 Appendix A Required Fitness Level (RFL) Test

Defence Force Order Volume 7, Book 1 Chapter 5. Annex B. (Personal Communication WO2 Stanbridge to N.Hall 20th May 19).

NZ ARMY

RFL							
MALES				**FEMALES**			
REQUIREMENT	RUN	PRESS UPS	CURL UPS	REQUIREMENT	RUN	PRESS UPS	CURL UPS
100%	8:00	55	130	100%	10:05	36	118
G1 All Ages	10:00	30	66	G1 All Ages	11:50	15	55
G2 16-24	10:30	28	60	G2 16-24	12:20	14	50
G2 25-29	10:55	26	57	G2 25-29	12:50	13	47
G2 30-34	11:20	24	54	G2 30-34	13:20	12	44
G2 35-39	11:45	22	51	G2 35-39	13:50	11	41
G2 40-44	12:20	18	48	G2 40-44	14:30	9	38
G2 45-49	13:00	14	45	G2 45-49	15:20	7	35
G2 50-54	13:40	10	42	G2 50-54	16:10	5	32
G2 55-59	14:25	8	39	G2 55-59	17:10	4	29
G2 60-65	15:00	6	36	G2 60-65	17:50	3	26

FITNESS TESTING STANDARDS

10.2 APPENDIX B ETHICAL APPROVALS

UNCLASSIFIED

HEADQUARTERS NEW ZEALAND DEFENCE FORCE
Organisational Research
MINUTE

5000/PB/5/3

17 Apr 19

Noted ACDHR

ACDHR
DDH

APPROVAL TO CONDUCT RESEARCH: ARMY RECRUIT INJURY PREVENTION (2018/57)

References:
A. DFO 3, Chap 5, Part 14: Authority to Conduct Human-related Research
B. Minute SPA5 Research/209 of 7 Jan 12

Background

1. In accordance with Ref A, MS Narelle Hall, master's student at Australian Catholic University and former physiotherapist with NZDF, has requested approval to complete analysis on data that was collected for her degree while she was an NZDF member.

2. This research has already been approved per Ref B.

3. The research will analyse data that was collected in 2012 on the impact of neuromuscular training on preventing lower limb injuries.

4. This project is complimentary to work that has been undertaken since that time within the Defence Directorate of Health.

5. This project is sponsored by COL James Kiao, CMD TRADOC.

Methodology

6. The dataset used by the researcher is already in her possession. The data was collected with informed consent of the participants that the data would be used for this project by this researcher.

7. Any background information required for the project to be completed will be requested by the research via an OIA.

Release and Reporting

8. The researcher will provide a copy of her finished thesis to NZDF for posting in the research repository.

UNCLASSIFIED

Endorsement and Approval

9. It is therefore recommended that ACDHR and DDH:

   a. **Note** previously approved research is now being completed.

[redacted]

Principal Advisor Organisational Research

DTelN Phone: 349-7118
Email: Aidan.Tabor@nzdf.mil.nz

S Signed By Col Williams

NEW ZEALAND ARMY
4HSC – Physiotherapy Department
MINUTE

SPA5 Research/209

7 Jan 12

COMD TRADOC (Through: Lt Ford, TD Psych)

For Information:
CO 2HSB
CO TAD
DAHS
Psych Services (A) (Attn: Maj Steve Kearney)
ADPR
OC 4HSC
Organisational Research Manager (Attn: Mr Jamie Latornell)

REQUEST FOR APPROVAL TO CONDUCT PERSONNEL RESEARCH ON ARMY RECRUITS

References:
A. Minute to Lt Col Dunn, DAHS, dated 31 August 2009.
B. DFO 21/2002, para 5, sub-para c.
C. DFO 21/2002, Annex B.

1. Authority is requested to conduct personnel research within the New Zealand Army for the purposes of reducing the incidence of recruit injury and completion of a Master of Philosophy in accordance with References B and C.

2. The research will look at a structured warm up program that includes neuromuscular training (NMT) to reduce the incidence of lower limb (LL) injuries in army recruits during an AARC. Recent injury prevention programs based on military recruit populations report a 75% reduction in the incidence of overuse anterior knee pain (AKP)[1], and a reduction in the incidence of acute ankle injury and upper limb injuries[2]. Unfortunately the effectiveness of such programs on other common LL injuries experienced by military recruits undergoing basic training is not clear. The effectiveness of an injury prevention program is also yet to be established with NZDF personnel[3].

3. **Scope.** High incidences of LL injuries are reported in the NZDF[4] . These injuries result in diminished performance, reduced participation and over time can lead to loss of function, chronic joint disease and disability[5]. In a military environment this will lead to significant costs in terms of lost working and training days, increased attrition, and decrease deployability[6].

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[1] Coppack, Etherington & Wills, 2011
[2] Parkkari et al., 2011
[3] Davidson, Wilson, Chalmers, Wilson, & McBride 2009
[4] Davidson et al., 2009
[5] Davidson et al., 2009
[6] Davidson et al., 2009; Kaufmann, Brodine & Shaffer, 2000; Sherrard, Lenne, Cassell, Stokes & Ozanne-Smith, 2004

4. A descriptive epidemiological study of NZDF personnel in 2002-2003 reported 1116 LL injuries from 10500 personnel over an 11 month study period[7]. The same study also reports injury rates for NZDF recruits are five times greater than trained personnel[8].

5. Injury surveillance of recruits in Waiouru suggests LL injuries are responsible for 76% of presentations to Physiotherapy (Graph 1). The period of training most often identified relating to recruit injury is physical training (Graph 2). The most common mechanism of injury (MOI) is running (Graph 3) and the greatest numbers of injuries occur during the first six weeks of an AARC (Table 1).

6. Neuromuscular or stability training is considered a cost-effective approach to reducing the incidence of LL injury within the NZDF[9].

AIM

7. To investigate the incidence of lower limb injuries reported by recruits at Waiouru military camp during a 16 week AARC undertaking one of two possible warm-up training programs.

DEPENDANT VARIABLES (OUTCOME MEASURES)

8. The study will compare two warm up training groups that include NMT and usual training (UT) for a period of six weeks over the first eight weeks of an AARC. The primary outcome measure will be the incidence of LL injury occurring during a 16 week AARC. Secondary outcome measures will include occupational endpoint achievement such as successful graduation, medical discharge (MD), 717 release, unfit for army service (CAT DF), and backsquadding. Other dependent variables will include a comparison of the results from the Entry Fitness Level (EFL), the Required Fitness Level (RFL), and the Battle Efficiency Test (BET).

9. Recruits will be given the Military Pre-training Questionnaire (MPQ) to determine pre-existing injury, previous management and multiple injury-related risk factors for initial military training[10]. The questionnaire will be administered in week one of an AARC.

10. Injury severity will be classified according to time out of training (light duties): mild < one week; moderate > one week but < one month; and severe > one month[11].

11. Dynamic stability will be measured using the Y Balance test[12]. Ankle dorsiflexion range of motion (DF ROM) will be measured with the weight-bearing lunge test[13]. These measurements will occur in weeks one, eight and 16 of training.

12. The research will also include the number of sessions with internal and external health care providers which will be expressed as a financial cost for each injury.

SUMMARY

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[7] Davidson et al., 2009
[8] Davidson et al., 2009
[9] Davidson et al., 2009
[10] Robinson, Stokes, Blizon et al., 2010
[11] Wedderkopp, Kaltoft, Holm and Froberg, 2003
[12] Plisky, Gorman, Butler, Kiesel, Underwood and Elkins, 2009
[13] Bennell, Talbot, Wajswelner, Technovanich and Kelly, 1998

13. Many lower limb injuries exist within the NZDF whose incidence may be reduced using a cost-effective NMT program. This pilot study will investigate the effectiveness of a structured warm up programme involving NMT versus UT to reduce the incidence of lower limb injury of AARC recruits at Waiouru in 2012.

14. In summary the research will include:

a. Two matched groups identified:

1. group one will perform a NMT programme for six weeks during the first eight weeks of AARC; and

2. group two will perform the UT program for the same timeframe.

b. The number of new injuries sustained during an entire AARC will be recorded; additionally, achievement of occupational endpoints and other dependant variables will be compared between groups; and

c. A cost benefit analysis will be conducted comparing groups for total medical treatment costs incurred.

15. The research will preferably commence with February and March recruit intakes in 2012, pending ethical approval. Data collation will take 20 weeks. A basic brief to DAHS, CO TAD, Psych (A) and OC 4HSC is planned for June 2012. Final completion of this research project will be December 2012.

CONCLUSION

16. If approved it is anticipated that the injury prevention program will produce an observable, if not significant reduction in the incidence of lower limb injuries in military recruits.

17. The primary POC and head researcher is the undersigned.

[redacted]

Narelle Hall
AppSc(Phty), MMSP
Senior Physiotherapist Waiouru
Waiouru Military Camp

DTelN Phone: (06) 367 5599 #7135
External Phone: 387 5599 #7135
Email: NARELLE.HALL@nzdf.mil.nz

Enclosures:

1. RESEARCH DETAILS – Injury prevention in recruits
2. Injury statistics Waiouru Physiotherapy Dept. 2008-2011

ENDORSED/NOT ENDORSED

D. FORD
LT
TD Psych TRADOC

Date:

APPROVED/~~NOT APPROVED~~

[redacted]

Date: 2/2/12.

Enclosure One to
4HSC, SPA5
Research/209
Dated Jan 12

RESEARCH DETAILS – INJURY PREVENTION IN RECRUITS

Requirement for Research to be Conducted

1. The research will be of significant use to the NZDF, as it has the potential to reduce the incidence of injuries sustained during an AARC, reduce the cost of an injury in time, money and resources to the medical services locally, and improve the likelihood that recruits will finish training in the expected timeframe with fewer injuries carried over to next phase of training.

2. The risks to the NZDF include possible injuries related to unstable surface training, running, jumping, changing direction and lifting. These types of injuries are possible during normal army training due the nature of army PT and the environment in Waiouru. The risk of injury will be minimised with supervision of activities by qualified staff and will be managed through the usual procedures including medical treatment at the local medical treatment centre in Waiouru.

3. The research will be supervised externally by Maria Constantianou, Griffith University, assisted by Mark Brown from Sports Medicine Australia. In addition the military point of contact will be Officer Commanding (OC) 4HSC, Major Sara Marsden who will maintain visibility of the project. The final report will be distributed to the DAHS, Mr Jamie Latornell, OC 4HSC, Maria Constantianou, Mark Brown and an external examiner. Annex B to DFO 21/2002 'Deed Pro Forma' will be signed by the researcher before the research begins.

Methodology

4. This research will be conducted initially as a pilot study. The study sample will consist of two AARC intakes in 2012 at Waiouru Military camp upon subjects consent to the study.

5. Recruit intakes will commence in 6^{th} February and 7^{th} March 2012 which will include approximately 150 soldiers per intake.

6. Prior to application of the program, recruits will be given a MPQ. Measurements of stability (Y Balance test) and fitness (EFL, RFL, BET) will be recorded in week one, week eight and at completion of training in week 16.

7. Each intake will consist of three to four platoons who will be randomly allocated to a NMT or UT groups. The two groups will train for 15-20 minutes during the same allocated PT warm-up, but in separate locations over six weeks. The program will commence in week two of an AARC and be completed in week eight as no PT sessions occur in week one or seven.

8. Staff required to administer classes will include at least two physical training instructors (PTIs) who will implement the program during normal PT warm up for six weeks. A physiotherapist will educate the PTIs on the program requirements and exercise prescription prior to the start of the intake.

The programmed classes will be overseen by a Physiotherapist where possible. Two physiotherapists will perform measurements of stability in weeks one, eight and 16. Platoon commanders will assist with administration of questionnaires. Members of the medical centre will be involved in collation of injury data for subsequent visits to medical staff and any other health related referral for injuries sustained by recruits during training. Injury severity will be collated by Mr David Redfern via the medical database Profile.The total cost of medical treatment visits per injury will be calculated and requested through the 4HSC Accounting Officer (S9) and Mr David Redfern.

Resources required

9. The research will require the following equipment which is already available in the gym, can be borrowed, or is currently issued to the recruits:

a. Six dura discs;

b. Six wobble boards;

c. Six tape star excursion patterns;

d. Six tape box patterns;

e. Four measuring tapes;

f. Gym mats;

g. Towel;

h. Two stop-watches; and

i. a 20cm step or bench.

Researcher

10. The project officer for this research will be Ms Narelle Hall, Senior Physiotherapist, currently employed by 4HSC. The researcher holds a Bachelor of Applied Science in Physiotherapy from Sydney University and a Master of Musculoskeletal and Sports Physiotherapy completed 2010 from Griffith University Australia. Ms Hall is planning to begin a Master of Philosophy in conjunction with this research project commencing in 2012.

Timeline

11. The research will preferably begin February 2012. Data collection is anticipated to take 20 weeks per intake. Analysis is anticipated to take three to six months and writing of the report should take another six months. Therefore DAHS, Mr Jamie Latornell, CO TAD, Psych (A) and OC 4HSC can expect an early brief on findings in July 2012. Final completion of the research will occur in December 2012.

Ethical Guidelines.

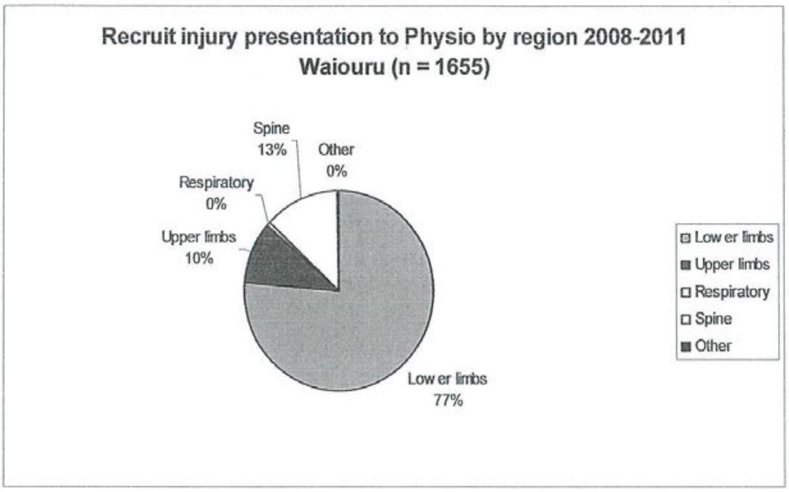
12. This research will be conducted in accordance with the Privacy Act 1993 and ethical guidelines outlined in Reference C. No identifying information about any participants will be reported.

Conclusion

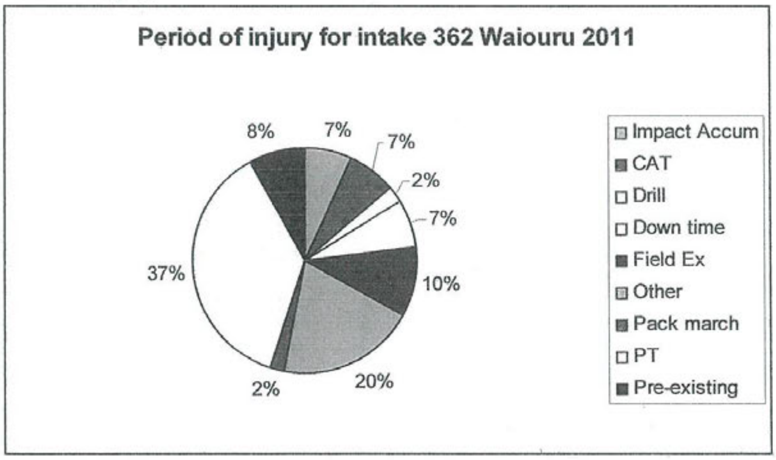
13. This research aims to investigate if a structured warm up program can reduce the incidence of lower limb injuries reported during a 16 week AARC?

Enclosure Two to
4HSC, SPA5
Research/209
Dated Jan 12

Graph 1
Total number recruit presentations to Physiotherapy March 2008- September 2011.



Graph 2
Period of injury AARC intake 362



Graph 3
Mechanism of injury intake 362

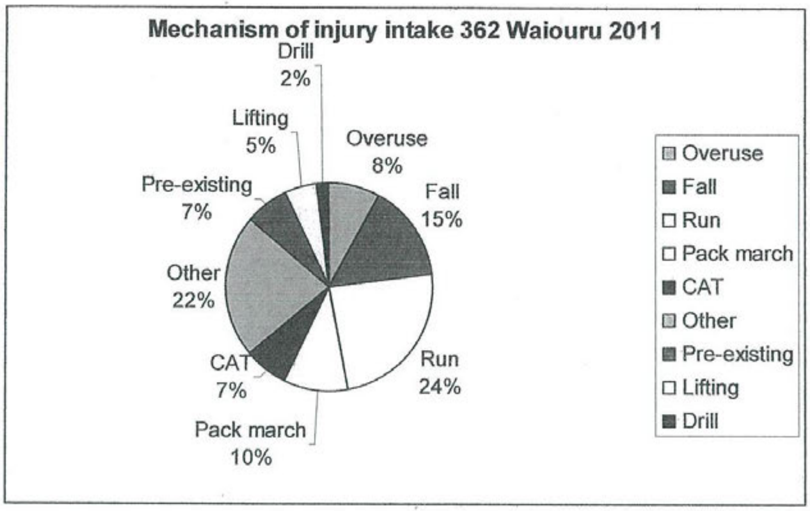
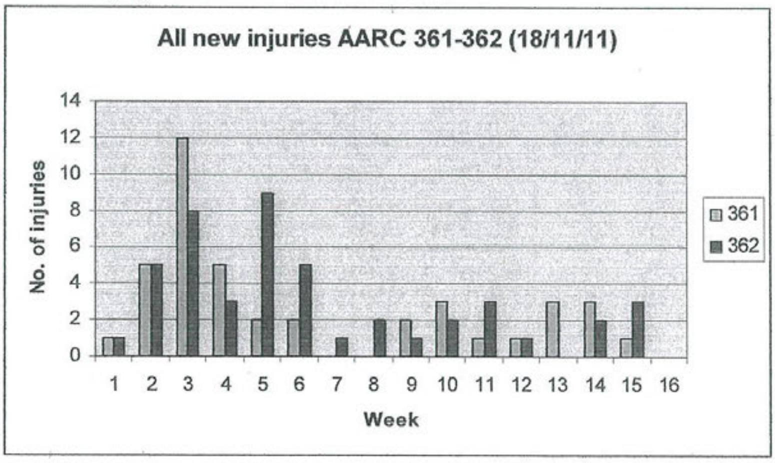


Table 1
Week of injury occurrence AARC 361-362



Received from M. Constantinou 23/5/12

GRIFFITH UNIVERSITY HUMAN RESEARCH ETHICS COMMITTEE

22-May-2012

Dear Ms Constantinou

I write further to the additional information provided in relation to the conditional approval granted to your application for ethical clearance for your project "Does the use of a lower limb neuromuscular training program reduce first time and reoccuring lower limb injuries in new army recruits?" (GU Ref No: PES/36/11/HREC).

This is to confirm receipt of the remaining required information, assurances or amendments to this protocol.

Consequently, I reconfirm my earlier advice that you are authorised to immediately commence this research on this basis.

The standard conditions of approval attached to our previous correspondence about this protocol continue to apply.

Regards

Dr Gary Allen
Manager, Research Ethics
Office for Research
N54 room 0.10 Nathan Campus
Griffith University
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Cc:

At this time all researchers are reminded that the Griffith University Code for the Responsible Conduct of Research provides guidance to researchers in areas such as conflict of interest, authorship, storage of data, & the training of research students.
You can find further information, resources and a link to the University's Code by visiting
http://www62.gu.edu.au/policylibrary.nsf/xupdatemonth/e7852d226231d2b44a25750c0062f457?opendocument

10.3 Appendix C Neuromuscular Training Program

Intervention exercises for research of neuromuscular training on new army recruits

Week 1-2 (Military training Week 2-3)
Initial run warm up

Number	Exercise type	Description	Equipment	Repetitions	Time
1	Slow speed run	i) Light jog forward/backwards ii) Heel flicks iii) Knees up iv) Carioca	Nil	X 6 across gym	3 min
2	Medium speed run	Shuttle runs	Nil	X 4-6	2 min

Circuit exercises

Number	Exercise Type	Description	Equipment	Performance	Time
3	Strength	Walking lunges	-	2x10 reps L/R	1 min
4		Gluteal strengthening-isometric	Wall	Sustained 10-20 sec L/R	1 min
5		Adductor squeezes (hand or ball)	Mat	2x10	1 min
6	Strength and technique	¼ squats single leg	-	2x10 reps L/R	1 min
7		Step forward and hold		2x10 reps L/R	1 min
8	Neuromuscular	Star excursion	Taped star pattern (x7)	30 sec L/R	1 min
9		Wobble board single leg standing	Wobble boards (x7)	30 sec L/R	1 min
10		Single leg standing, running motion with opposite leg	-	30 sec L/R	1 min
11	Core stability	Prone plank	-	20-30sec x 2	1 min
12		Side plank	-	20-30sec L/R	1 min
13	Plyometric	Lateral jump	-	30 sec L/R	1 min
14		Box jump	Box pattern (x7)	All directions	1 min
15		Horizontal/vertical jump bilateral		1x10	1 min
				Total time	18 min

Week 3-4 (Military training Week 4-5)

Initial run warm up

Number	Exercise type	Description	Equipment	Repetitions	Time
1	Slow speed run	i) Light jog forward/backwards ii) Heel flicks iii) Knees up iv) Carioca	Nil	X 6 across gym	3 min
2	Medium speed run	Shuttle runs	Nil	X 4-6	2 min

Circuit exercises

Number	Exercise Type	Description	Equipment	Performance	Time
3	Strength	Walking lunges	-	2x10 reps L/R	1 min
4		Nordic hamstrings in pairs	Mat or towel/elastic band	< 6 each in pairs	2 min
5		Gluteal strengthening-isometric	Wall	Sustained 10-20 sec L/R	1 min
6		Adductors-Standing (fists or water bottle)		2x10	1 min
7	Strength and technique	¼ squats single leg	-	2x10 reps L/R	1 min
8		Step downs 20 cm step (step forward)	Step	2x10 reps L/R	1 min
9	Neuromuscular	Star excursion	Taped star pattern (x7)	30 sec L/R	1 min
10		Wobble board single leg standing	Wobble boards (x7)	30 sec L/R	1 min
11		Single leg standing skiing/running opposite leg with balancing disc	-	30 sec L/R	1 min
12	Core stability	Prone plank	-	20-30 sec x 2	1 min
13		Side plank	-	20-30 sec L/R	1 min
14	Plyometric	Lateral jump	-	30 sec L/R	1 min
15		Box jump	Box pattern (x7)	All directions	1 min
16		Horizontal/Vertical jump bilateral		1x10	1 min
				Total time	20 min

Week 5-6 (Military training Week 6-7)

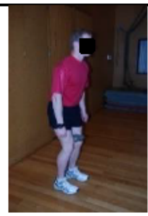
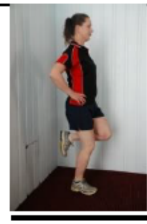
Initial run warm up

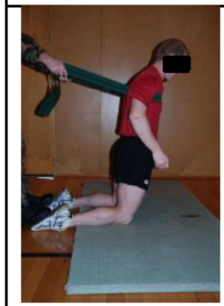
Number	Exercise type	Description	Equipment	Repetitions	Time
1	Slow speed run	i) Light jog forward/backwards ii) Heel flicks iii) Knees up iv) Carioca	Nil	X 6 across gym	3 min
2	Medium speed run	Shuttle runs	Nil	X 4-6	2 min

Circuit exercises

Number	Exercise Type	Description	Equipment	Performance	Time
3	Strength	Walking lunges		2 x 10 reps	1 min
4		Nordic hamstrings in pairs	Mat or towel	Approx 6 or 1 min each	2 min
5		Gluteal strengthening-isometric	In pairs	Sustained 10-20 sec L/R	1 min
6		Adductors standing	In pairs	2 x 10	1 min
7	Strength and technique	¼ squats single leg	-	2 x 10 reps L/R	1 min
8		Step downs 20 cm step (step forward)	Step	2 x 10 reps L/R	1 min
9	Neuromuscular	Star excursion	Taped star pattern (x7)	30 sec L/R	1 min
10		Wobble board single leg standing	Wobble boards (x7)	30 sec L/R	1 min
11		Single leg standing skiing/running opposite leg with balancing disc	-	30 sec L/R	1 min
12	Core stability	Prone plank	-	30 sec x 2	1 min
13		Side plank	-	30 sec L/R	1 min
14	Plyometric	Lateral jump	-	30 sec L/R	1 min
15		Box jump	Box pattern (x7)	All directions	1 min
16		Vertical jump bilateral/single leg		1-2 x 10	1 min
				Total time	20 min

Appendix D (Part 2) Neuromuscular training exercise performed by the intervention group images and description.

 Lunges (Week 2-3)	 Isometric gluteal strengthening (Week 2-3)	 Adductor squeezes (Week 4-5)	 ¼ squats
 Step forward (Week 4-5)	 Star excursion	 Wobble board	 Single leg standing – Running motion (Week 4-5) on disc.

 Prone plank	 Plank	 Lateral jump	 Box jump
 Assisted Nordic hamstring.	 Horizontal/vertical jump		

Note. Individuals shown gave their consent to publish.

10.4 Appendix D Physical Training in Brief

Table 10.1

Physical Fitness Training Program Week One to Seven of Basic Training

Week	Theme
1	RFL
2	Formal tab
3	Intro circuit
4	Intro cross-country
5	Circuit 2
6	Rep runs
7	Light run and stretches
8	Cross-country 2
9	Circuit 3
10	Rep runs 2
11	Intro boot run
12	Assault course/Intro boot run
13	Intro pack march
14	Rep runs 3
15	Light run and stretch
16	RFL 2
17	Cross-country 3
18	Push, Pull, Lift, Carry
19	Intro ropes
20	Pack march

Note: Gymnasium introduction briefing not included in table. RFL is regular fitness level.

10.5 APPENDIX E RESEARCH PORTFOLIO

Contribution to Research

As the PhD Candidate, I acknowledge that my contribution to nominated papers as indicated in the table below is correct.

Signature Narelle Hall. Date 14th Dec 23

Study	Contribution	Statement of Contribution	Estimated %
Study 1	Narelle Hall	Conceptualised, ethics, wrote and edited paper, data collection, analysed data	70
	Maria Constantinou	Conceptualised, ethics, edited paper, analysed data	10
	Mark Brown	Conceptualised, edited paper, analysed data	7
	Belinda Beck	Edited paper	3
	Suzanne Kuys	Edited paper, analysed data	10
Study 2	Narelle Hall	Conceptualised, ethics, wrote and edited paper, data collection analysed data,	65
	Maria Constantinou	Conceptualised, ethics, edited paper, analysed data	10
	Mark Brown	Conceptualised and edited paper	5
	Belinda Beck	Edited paper	2.9
	Michael Steele	Assisted with statistical analysis and editing	7
	Jacque Rousseau	Reviewed paper	0.1
	Suzanne Kuys	Conceptualised, edited paper, analysed data	10
Study 3	Narelle Hall	Conceptualised, ethics, developed exercise program, data collection, wrote and edited paper, analysed data	65
	Maria Constantinou	Conceptualised, ethics, developed exercise program, edited paper, analysed data	10
	Mark Brown	Conceptualised, developed exercise program and edited paper	5
	Belinda Beck	Editing	2.9
	Michael Steele	Assisted with statistical analysis and editing	7
	Jacque Rousseau	Reviewed paper	0.1

	Suzanne Kuys	Conceptualised, edited paper, analysed data	10
Study 4	Narelle Hall	Conceptualised, wrote and edited paper, data collection, analysed data	65
	Maria Constantinou	Conceptualised, edited paper, analysed data	10
	Mark Brown	Conceptualised and edited paper	5
	Belinda Beck	Editing	2.9
	Michael Steele	Assisted with statistical analysis and editing	7
	Jacque Rousseau	To review paper	0.1
	Suzanne Kuys	Conceptualised, edited paper, analysed data	10

I acknowledge that my contribution to nominated papers as indicated in the above table is correct.

Signature **Date** 14 December 2023

I acknowledge that my contribution to nominated papers as indicated in the above table is correct.

Signature **Date** 14 December 2023

I acknowledge that my contribution to nominated papers as indicated in the above table is correct.

Signature **Date** 14 December 2023

I acknowledge that my contribution to nominated papers as indicated in the above table is correct.

Signature Belinda Beck **Date** 14th December 2023

(Personal email)

I acknowledge that my contribution to nominated papers as indicated in the above table is correct.

Signature Michael Steele **Date 14/12/23**

(Personal email)

I acknowledge that my contribution to nominated papers as indicated in the above table is correct.

Signature: Jacques Rousseau **Date :** 14th Dec 2023

(Personal email)