Assessing the Acute and Chronic Effects of Basic Training in New Zealand Army Recruits

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Thesis Abstract

Initial military training (IMT), or "basic training" in New Zealand, is a mandatory transition from civilian to soldier. It builds essential soldiering skills by pushing mental and physical limits through high workloads, sleep and calorie restriction, and achieving strict fitness standards. This complicated mix of training is not always carefully managed, and accordingly, injury attrition is a large and costly issue for global militaries. Despite its importance, the physical and cognitive effects on recruits are poorly understood, likely due to heterogenous global practices. The overarching question of this thesis is: What are the effects of basic training on neuromuscular performance in army recruits? To address this question, this thesis included a narrative review, two experimental chapters and a practical commentary. The review synthesised global literature on acute and chronic physiological and neuromuscular effects of basic training, noting that high heterogeneity in duration, intensity and design, ultimately complicating synthesis of the effects identified in the literature. Findings suggest that while acute training bouts (e.g., load carriage, field exercises) temporarily decrease strength and power, cardiovascular strain and maximal oxygen consumption increase. Longitudinally, consistent improvements were identified in cardiorespiratory endurance, full body strength, upper body muscular endurance, and power. However, there was evidence gains often plateau or diminish in longer duration courses and seem to vary by sex and entry fitness levels. Subsequently, two experimental chapters were employed to better quantify the acute and chronic effects of basic training to determine how specific training modalities influence long-term health and readiness in the New Zealand Army. The first explored the effects of 14 weeks of basic training on countermovement jump height. A sample of convenience was recruited from two New Zealand Army recruit intakes ($n = 388$). Jump height did not clearly change over the duration of the course (e.g., $p = .206$, $\omega^2 p = 0.002$). Descriptively, there was evidence of large baseline differences between intakes ($p < .001$, $d = 0.71$), complicating interpretation. The second explored the change in neuromuscular performance variables immediately after, 24 and 48 hours post-field exercise, adjusting for relative strength, and whether it varied between sexes. Estimates were variable, with few clear differences between sexes. Where jump height and power remained unchanged ($p > .05$), force production and movement strategy were altered ($p < .05$, $\omega^2p = 0.01\text{-}0.07$); specifically, concentric, eccentric and isometric peak force, flight time:contraction time and concentric duration, often persisting at 48-hours, particularly in males (Pre-48h: $p < .05$, $d = -0.55$ to 0.84). These learnings informed a commentary chapter providing practical guidance for neuromuscular profiling and monitoring during basic training. This thesis highlights significant heterogeneity in global recruit training practices and outcomes, a trend that may be present within New Zealand Army recruits. While sex-based differences exhibited high variability, the observation of shifts in force production and movement strategy in response to basic-training activities, but not more common assessments, suggests a more nuanced approach to assessing and managing recruit readiness may be warranted.

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Attestation of Authorship

I hereby declare that this submission is my own work and that, to the best of my knowledge and belief, it contains no material previously published or written by another person (except where explicitly defined in the acknowledgements), nor used artificial intelligence or generative artificial intelligence tools (unless it is clearly stated, and references, along with the purpose of use, nor material which to a substantial extent has been submitted for the award of any other degree or diploma of a university or other institution of higher learning.

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Date: 30/4/26

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Co-Authored Works

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Matt Cross	Conception and design, contribution of knowledge, critical revision

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Aaron Uthoff	Conception and design, contribution of knowledge, critical revision
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Jacques Rousseau	Conception and design, acquisition of research data

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Ethics Approval

The Auckland University of Technology Ethics Committee (AUTEC) and the New Zealand Defence Force (NZDF) Ethics Committee granted ethical approval for this research. AUTEC Ethics application number: 24/284: approved on 16/9/24, with subsequent amendments approved 21/11/24.

List of Common Abbreviations

1RM: one repetition maximum

CI: confidence interval

CMJ: countermovement jump

d: Cohen’s d effect size

ES: effect size

IMT: initial military training

IMTP: isometric mid-thigh pull

M: mean

NZDF: New Zealand Defence Force

RMANCOVA: repeated measures analysis of covariance

RMANOVA: repeated measures analysis of variation

RSI: reactive strength index

SD: standard deviations

VO2: maximal oxygen consumption

ω^2p: partial omega squared

r_B = Rank-Biserial Correlation

Chapter 1: Introduction And Rationale

1.0 Background

Soldiers globally function as part of a defence force that acts as the primary instrument of national security. A defence force is charged with protecting its nation and interests from external threats and managing crises at home and abroad. Soldiers must maintain high mental and physical readiness to manage the diverse physical and mental demands of combat, disaster response, and peacekeeping. Part of the selection process for all personnel is initial military training (IMT), termed "basic training" in New Zealand. This course is designed to transition civilians into soldiers through a progressive, high-stress course. However, despite the prevalence of recruit training courses globally, there remains significant ambiguity about the effects it has on physical performance. Further, despite its developmental goals, literature suggests that key physical qualities often stagnate or decline during the course (Dyrstad et al., 2006; Santtila et al., 2008). The exact mechanisms behind these declines and the influence of individual factors such as sex and strength remain poorly understood.

During basic training, recruits are deliberately placed in demanding situations to hone their discipline and resilience, whilst teaching them the essential skills of soldiering. While countries and military organisations tend to share similar overarching structures and objectives for basic training, and similarity may be presumed, this is not necessarily true. Courses can vary in length, often ranging from six to fourteen weeks (Varley-Campbell et al., 2018), and can be either voluntary or conscription (mandatory) (Bingley & Lyk-Jensen, 2024). Typically, it involves two main phases: initial skill development (e.g., marksmanship, tactics) (Blacker et al., 2009; Kyröläinen et al., 2018) followed by intensive field-based scenarios (Bulmer, Aisbett, et al., 2022; Bulmer, Drain, et al., 2022; Laroche et al., 2023). To build resilience, recruits are often subjected to suboptimal recovery and high physical loads while simultaneously being exposed to severe psychological and environmental stressors. This combination frequently places recruits into a state of nonfunctional overreaching, which is known to cause prolonged declines in both physical and cognitive performance (Armstrong et al., 2023; Piirainen et al., 2019). Compounding this issue, training regimens often feature concurrent strength and high-volume endurance loads. This overlap results in an interference effect, causing a plateau or decline in physical adaptations (Hickson, 1980). While traditional athletes might heavily manipulate their programming to avoid this interference, for a tactical population, maintaining a balanced—albeit sub-maximal—blend of both strength and endurance is an operational necessity for survivability. Accordingly, high levels of physical fitness are critical for soldiers to perform well in both combat and training situations (Knapik et al., 2012; Mala et al., 2015; J. Robinson et al., 2018; Vaara et al., 2022). These standards must be met and developed throughout the course (Laroche et al., 2023). This mix of training makes it difficult to optimise performance adaptations. However, although global basic trainings share some distinct similarities, the methodology utilised to measure performance makes understanding the effects of the course difficult. As such, it remains unclear what the effects of basic training are, and whether they differ between organisations. The emergence of increasingly precise and data-rich technologies makes this more accessible for those in the field. Accordingly, characterising the physiological responses to various training stressors is fundamental in managing recruit readiness. This allows for a more nuanced approach to load management, identifying when recruits are prepared for the continuing demands of training or when the accumulation of fatigue necessitates an altered training load. Current research indicates consistent improvements in cardiorespiratory and muscular endurance. However, other attributes, such as strength and power, show inconsistent or negative trends (Varley-Campbell et al., 2018). While not fully understood and lacking a clear narrative, these effects may stem from an outdated, endurance-based training regimen (Kyröläinen et al., 2018), acting contrary to recent literature suggesting alternate forms of training may provide more optimal outcomes (Knapik et al., 2004; Kraemer & Szivak, 2012; Vaara et al., 2022). In addition, recovery is further impeded by a lack of sleep in garrison (Larsen et al., 2022) and, notably, field environments (Laroche et al., 2023). In part, these may explain the staggering number of injuries sustained by recruits worldwide, which is around 31.4% (Murphy et al., 2023), with New Zealand's rates shown as around 56% in one study of two consecutive intakes (Hall et al., 2026). This difficult balance of adaptation and stress is not always carefully managed, leading to high attrition rates through injury (B. H. Jones et al., 1993; Murphy et al., 2023) and further highlighting the importance of tracking recruits' responses to this high-stress environment.

The physiological effects of basic training do not affect both sexes equally. Female recruits have been found to have lower levels of entry fitness, suffer higher physiological strain, and greater injury rates than males (Allison et al., 2015; Bhambhani & Maikala, 2000). Since body mass (Nimphius et al., 2019) and relative strength (Comfort et al., 2024) have been shown as important factors when comparing sexes, one explanation of these differences is the allocation of absolute loads during activities (e.g., the same weighted pack) without regard to individual characteristics. Therefore, consideration toward these factors when comparing sexes is important.

A significant barrier to recruit readiness is the lack of a nuanced profiling and monitoring framework. Fatigue, whether central (reduced neural drive) (Tornero-Aguilera et al., 2022) or peripheral (impaired muscle-nerve control) (Akbar et al., 2022), can suppress performance up to 96 hours (Heilbronn et al., 2023) in response to strenuous military tasks. These tasks, such as load carriage [sometimes exceeding half of a soldier's bodyweight (Armstrong et al., 2023; Orr et al., 2021)], manual material handling and casualty evacuation, are among the most common and physically demanding (Burley et al., 2018; G. E. Giles et al., 2019; Vaara et al., 2022). Field exercises often combine this into multi-day real-world scenarios, creating a combination of stressors shown to be amongst the most demanding military tasks. While acute responses to strenuous activity are likely to result in normal short-term reductions in cognitive or physical performance (Pageaux & Lepers, 2018), chronic fatigue over a longer period, often lasting more than a few days, is more problematic, increasing injury risk (Larsen et al., 2022). Because differentiating between different types of fatigue is difficult in the field, proxies such as neuromuscular strength and power are utilised (Anicic et al., 2023; Bishop et al., 2023). Recent advancements in technology allow for the simultaneous monitoring of output (performance) and strategy (movement patterns) to develop a well-rounded assessment strategy (Philipp et al., 2024).

While many studies have tracked specific performance variables over the course of basic training, few have specifically investigated what influence fatigue has on both output and strategy. This multi-dimensional approach is vital, as recruits may maintain performance levels by altering their movement strategies, which can mask underlying fatigue and increase injury risk (Knihs et al., 2022; Yu et al., 2020).

This thesis investigates both the acute and chronic effects of basic training on neuromuscular performance. The term basic training is applied primarily in this thesis referencing Army basic training, however IMT is used in Chapter 2 to represent broad military training due to the inclusion of wider literature. It also aims to determine how these effects are influenced by sex, body mass, or relative strength. The research is organised into three sections: first, a comprehensive narrative review to establish what is known regarding the effects of initial military training, then two experimental chapters covering both a high-level overview of the chronic change in countermovement jump height over time and a more nuanced investigation into the immediate effects of a field exercise on both performance output and movement strategy, concluding with a practical commentary chapter which focuses on the implementation of a neuromuscular profiling and monitoring protocol using force plate technology. Together, these chapters will provide a clear overview of the existing literature while highlighting specific physical attributes that may be insightful and ultimately can be easily tracked using modern technology to monitor soldiers' performance and readiness. These findings will help practitioners better measure and monitor outcomes for recruits, with implications for programming, and injury risk management.

1.1 Research Aims

This thesis aims to explore the effect of army basic training on neuromuscular performance in army recruits.

This broad aim will be addressed in a variety of chapters, each answering specific research questions:

1. What are the acute and chronic effects of basic training on neuromuscular performance in army recruits?
2. Does countermovement jump height differ over the duration of an Army basic training program?
3. Do measures of lower-body power, strength, and jump strategy differ before and after a field exercise, and does this vary by sex when adjusting for relative strength?
4. How can practical, evidence-informed profiling and fatigue assessments be implemented within basic training to optimise performance and reduce attrition?

1.2 Thesis Structure & Format

This thesis follows the pathway two format (manuscript structure) and comprises multiple chapters that are individually prepared for peer-reviewed publication. The thesis includes an abstract, introduction and rationale (Chapter 1), narrative review (Chapter 2), two experimental studies (Chapters 3 & 4), a practical commentary (Chapter 5) and finally a chapter that summarises the main research outcomes, future research directions and a conclusion (Chapter 6). As the thesis is formatted for publication, each chapter is written as a stand-alone body of work, with Chapters 2 and 4 written for publication as their own manuscript; some themes may recur throughout multiple chapters. Additionally, Chapter 5 is included in this thesis to supplant the typical practical applications chapter. All other relevant material from the studies is present in the appendices.

Chapter 2: A narrative review that focuses on synthesising the available research pertaining specifically to the acute and chronic effects of IMT on neuromuscular performance and fatigue. The review discusses the structure of IMT and outlines the acute and chronic effects on the cardiorespiratory system, muscular strength, endurance, power and whether any sex-specific differences exist. It will be used to answer the first research question.

Chapter 3: This is the first experimental chapter, which utilises a dataset from two recruit training cohorts to analyse changes in neuromuscular lower-body power (using countermovement jump height) over time during 14 weeks of Army basic training. Further, as a secondary analysis, it seeks to explore descriptive differences between different basic intakes. This chapter will answer the second research question.

Chapter 4: This is the second experimental chapter, which seeks to identify the acute effects of basic training on neuromuscular performance during a week-long field exercise and monitors the trajectory of change through immediate, 24-hour, and 48-hour post-exercise assessments and whether these effects differ by sex when controlling for relative strength. By using neuromuscular output and strategy metrics derived from force plates as fatigue proxies. This will answer the third research question.

Chapter 5: This chapter will seek to provide an evidence-informed, practical commentary for profiling and monitoring neuromuscular performance during basic training. It leverages both existing literature and the learnings obtained from previous chapters to form a better understanding of how neuromuscular performance assessments can be utilised to provide greater insight into recruits' performance and neuromuscular responses to training load, with the overall goal of improving performance outcomes and reducing attrition.

Chapter 2: What are the Acute and Chronic Effects of Initial Military Training on Physiological and Neuromuscular Performance in Military Populations? A Narrative Review

2.0 Prelude

Despite being conducted globally by militaries, the physiological effects of the basic training course are not well understood, and existing literature fails to provide a clear narrative. A first step in addressing the overarching aim of the thesis was to review the pre-existing literature on the topic. The purpose of this chapter was to synthesise the available literature to form a narrative of the physiological and neuromuscular effects of initial military training. While the eventual focus of the thesis was on basic training as it pertains to the army (and more specifically the New Zealand Army), we chose to use a broad search strategy, encompassing all facets of initial military training (IMT), and therefore this terminology is applied in place of basic training for this chapter. This was in part due to the limited scope of the literature identified during preliminary searches. Additionally, it was determined that reasonable parallels could be drawn from other branches of the military. It sets the foundation for the thesis by framing the effects of IMT and limitations identified with current research and military practice and feeds forward into the subsequent chapters by highlighting the need for more specific literature to gain a better understanding of how basic training affects New Zealand Army recruits.

This chapter comprises the following paper, published with Sports Medicine:

McCleary, Sean C., Aaron Uthoff, and Matt R. Cross. 2026. "What Are the Acute and Chronic Effects of Initial Military Training on Physiological and Neuromuscular Performance in Military Populations? A Narrative Review." *Sports Medicine*. doi:10.1007/s40279-026-02431-6.

2.1 Introduction

Life in the military (e.g., Army, Air Force and Navy) is demanding. The role of military personnel varies by nation, branch of the military, specific role, and level of rank (among other factors), but all must be prepared for a range of tasks, including wartime deployments, peacekeeping, and disaster relief. (Kaspersen, 2021). Tasks often involve strenuous physical activity, including combat engagement, marching, digging and marksmanship, which at times are performed under high cognitive and physical demands (e.g., sleep deprivation). A critical part of these tasks is movement, which often occurs while carrying significant loads (e.g., a pack with food, water, ammunition and other survival equipment) and operating in stressful environments. Particularly, heavily-loaded marching is commonplace and taxing; for example, soldiers deployed in Afghanistan carried a mean load of 57kg (Armstrong et al., 2023). Personnel must be mentally and physically fit for service, and so the military strives to maintain strict physical fitness standards. Initial Military Training (IMT), often termed as recruit training, boot camp or basic training, is a mandatory high-intensity course, typically ranging between six and fourteen weeks (Varley-Campbell et al., 2018). It is designed to turn civilians into military personnel, serving to improve occupation-specific skills, physical readiness and discipline. Unlike ongoing military training, it focuses on basic soldiering skills for recruits who have minimal prior preparation. Consequently, the physical and cognitive effects differ significantly from those experienced by trained soldiers. While the training regimen and demands of these courses may differ significantly, they are all designed to physically and mentally challenge recruits, with sleep deprivation, caloric deficits, load carriage and psychological stress to prepare them for potentially extreme situations.

Research shows that improved cardiorespiratory fitness reduces the physical strain of military personnel and enhances recovery between activities (Tomlin & Wenger, 2001). Further, elevated physical capacities are also closely linked to subsequent performance in specific operational tasks (Knapik et al., 2012; Mala et al., 2015; J. Robinson et al., 2018; Vaara et al., 2022) and help to reduce injury risk (B. H. Jones & Knapik, 1999; Kaufman, 2000; Orr et al., 2020). It is well documented that initial military training increases cardiorespiratory fitness (Varley-Campbell et al., 2018), but also features a high prevalence of injuries with up to 58% of recruits sustaining an injury (Murphy et al., 2023; M. Robinson et al., 2016), which often result in high levels of attrition and financial burden (Molloy et al., 2020). This is in part due to the predominantly high endurance-based load of training (Jurvelin et al., 2020; Kyröläinen et al., 2018), exposing recruits to high physical stressors with little to no preparation. This is heightened by the modern recruit's increasingly sedentary lifestyle before entry (Hruby et al., 2015; Knapik et al., 2017; Santtila et al., 2018). Recruits also face significant cognitive load in addition to physical training stressors (Kyröläinen et al., 2018). Furthermore, during IMT, there is often inadequate energy consumption (Baker et al., 2020) or time allowed for recovery, with research identifying that up to 85% of recruits are underslept (Larsen et al., 2022), which is of concern as Belenky et al. (2003) have noted that eight hours of sleep is optimal, with just one hour less causing declines in cognitive performance. Giles et al. (2019) found that higher loads had the greatest relationship with declines in cognitive function and an increased rate of perceived exertion, aligning with recent systematic research that also noted the effect was greater in female recruits (Blacker et al., 2009; Vickery-Howe et al., 2024) who are at significantly greater risk of injury than males (Bell, 2000; Nindl et al., 2016). Accordingly, an understanding of why these sex-based differences might occur is critical for maintaining an effective military force by mitigating potential risk. Combined, these factors create a perfect storm for fatigue, which is a performance loss from poor sleep, stress or exertion and can be split into central (neural drive) and peripheral (motor control) types (Akbar et al., 2022; Tornero-Aguilera et al., 2022). Though distinct, they often overlap: central issues like sleep loss impair physical performance (Tornero-Aguilera et al., 2022), while peripheral exertion rarely causes central fatigue. This complexity makes them hard to isolate, yet both consistently degrade vital reaction times, marksmanship accuracy, strength and vertical jump performance (Knapik et al., 1991; Piirainen et al., 2019). While the effects of fatigue may be deliberately imposed at times, there is a clear lack of individualised periodisation or intervention targeting the effects of fatigue and the subsequent predisposition to injury that recruits may face if it is left unmanaged (Larsen et al., 2022).

The training that occurs during IMT will differ between branches of the military and between nations. This makes fully understanding the effects and outcomes of the training difficult to measure. However, there is a lack of breadth in the literature; as such, this review synthesises the available literature to help form a greater understanding of the effects of IMT more broadly. Generally, IMT follows a progressive structure where recruits are slowly exposed to more stressors, such as physical tasks like load carriage, manual material handling and casualty evacuation of which load carriage is frequent and amongst the most physically demanding tasks to be conducted by recruits (Vaara et al., 2022), requiring high levels of physical fitness. They will develop their physical fitness through a combination of physical training, corrective exercises and scenario-based training. This training often focuses on endurance-based qualities, despite recent literature suggesting that concurrent strength and aerobic training is optimal to enhance performance during physically demanding tasks such as load carriage (Knapik et al., 1996; Santtila et al., 2010; Tomlin & Wenger, 2001; Vaara et al., 2022). Additionally, development of some qualities may be impacted by an interference effect, which can inhibit the development of neuromuscular strength and power when not carefully periodised (Santtila et al., 2012). They will also participate in classroom sessions learning essential skills relevant to their branch of the military, which may include live firing, tactics and drills. Often, these aspects are combined, where skill-based qualities will be tested under physical and/or mental duress, such as marksmanship during or following tactical manoeuvres. This is to train recruits to operate in a wartime scenario where they are likely to face fatigue and high stress. Ideally, recruits should enter with a base level of neuromuscular and physiological fitness to ensure they can withstand its demands. This is often assessed before and/or early in the course and is further developed as it continues. The physical assessments tend to mimic those which are used throughout all levels of the respective branch, such as runs for time, push-ups and sit-ups (Harman et al., 2008; Wood & Krüger, 2013). Some branches have begun expanding and improving their testing methods, such as maximum strength and vertical jump testing (Burley et al., 2018, 2020; Harman et al., 2008; Rosendal et al., 2003; Santtila et al., 2008; Rue et al., 2023; Santtila et al., 2010; McFadden et al., 2024), in the aim of enhancing insight into adaptations occurring. Unfortunately, a complicating factor in synthesising results drawn from official military assessment events is whether recruits' rate-limit their performance to meet the passing threshold, or whether they represent true maximal intent. This makes it difficult to draw concise conclusions. Accordingly, while these tests often have different age groups or sex standards (Orr et al., 2022), operational scenarios are non-discriminatory; all personnel must carry the same loads and engage in the same combat scenarios.

Despite the rigorous nature of IMT, a significant gap remains in our understanding of how these elevated physical and cognitive loads influence recruit performance and injury risk. While traditional assessments provide a snapshot of fitness, they often fail to capture the nuanced physiological and neuromuscular fatigue that predisposes recruits, particularly females (Bell, 2000) to injury and attrition. As demands remain uncompromising regardless of a recruit's background, there is a need to synthesise the current literature on these stressors. Given the scarcity of recruit literature, a broader lens was taken to encompass all military branches. Furthermore, training regimens and methodology are not fully transparent in the literature. Subsequently, this makes drawing valid conclusions difficult. Therefore, this review aims to collect and synthesise the existing literature specifically relating to the acute and chronic effects of IMT on physiological and neuromuscular performance in military populations, with a specific focus on the sex-based differences. By doing so, it seeks to provide a foundation for more individualised training and periodisation, by ultimately enhancing responses to training during IMT.

2.2 Methods

2.2.1 Literature Search Strategy

This review followed a narrative format with a systematic search strategy. A predetermined search string was validated by all authors, utilising combinations of key terms: *("military", "army", "navy", "air force") AND ("basic training" OR "basic military training" OR "initial military training") AND ("neuromuscular", "fatigue", "performance", "strength", "power", "cardiovascular",* *"cardiorespiratory", "loaded marching", OR "load carriage")*. The search strategy was set to encompass all military branches to strengthen the breadth of literature included in the review. Selection bias was further mitigated through the application of stringent inclusion and exclusion criteria. Data were extracted using a standardised approach, ensuring that all relevant findings were synthesised regardless of the direction of the results, thereby providing a balanced overview of the current evidence base. Per the aims of the review, we set out to capture literature pertaining to the long (chronic) and short-term (acute) effects of IMT more broadly, and load-carriage more specifically (as a critical element of IMT). The long-term effects were categorised by pre- and post-measurements taken at the start and end of the course, with studies presented first that did not feature any form of intervention (i.e. the effects of an unaltered course), while short-term effects were immediately following an activity but no later than three days afterwards. Furthermore, elements of physical fitness were categorised into four areas: cardiorespiratory fitness, maximal strength, muscular endurance and muscular power. Tests for cardiorespiratory fitness were defined by those commonly performed to understand heart and lung function to provide oxygen during sustained physical activity. Maximal strength was identified as either a short-duration maximal isometric or dynamic muscular strength assessment. Muscular endurance was defined as sustained submaximal strength assessments. Muscular power was defined as assessments inclusive of an expression of force in as little time as possible.

2.2.2 Inclusion Criteria

The inclusion criteria required any identified articles through the search strategy to (1) be peer reviewed, (2) written in English or have a relevant translation available, (3) the population to be military recruits, (4) related specifically to the effects of IMT, (5) include participants that were injury free, (6) were of an acute and/or longitudinal study design and (7) contained methods capable of objectively quantifying relevant variables. All articles that did not meet the above criteria were excluded. The study selection process involved removing duplicates, screening for relevance on title and then abstract, and finally screening the full-text articles and their reference sections for additional relevant literature, using the inclusion criteria.

2.3 Results

2.3.1 Study Characteristics

Through the literature search, twenty-eight studies were identified that examined the acute and chronic effects of IMT. A total of six studies featured investigations into the acute effects of IMT and were included after the inclusion criteria were applied. These studies totalled 1244 recruits (Male, 822; Female, 422) from Finland, Norway, UK and USA, and spanned five to eighteen weeks in duration. Twenty-six longitudinal studies investigating chronic effects were identified, totalling 6184 recruits (Male, 4442; Female, 1142; Unspecified, 600) from Australia, Canada, Denmark, Finland, Greece, Norway, South Africa, South Korea, Switzerland, UK and USA. Of the twenty-eight studies included, twenty-six had a focus more broadly on the overall effects of IMT, while three focused on the effects of load carriage. All literature included are presented in Table 1. Additionally, studies in non-recruit populations used to bolster sections lacking sufficient data are presented in Table 2. For the included chronic studies, Figure 1 presents the durations, country and branch of military, including the frequency with which the specified duration appeared in the included studies.

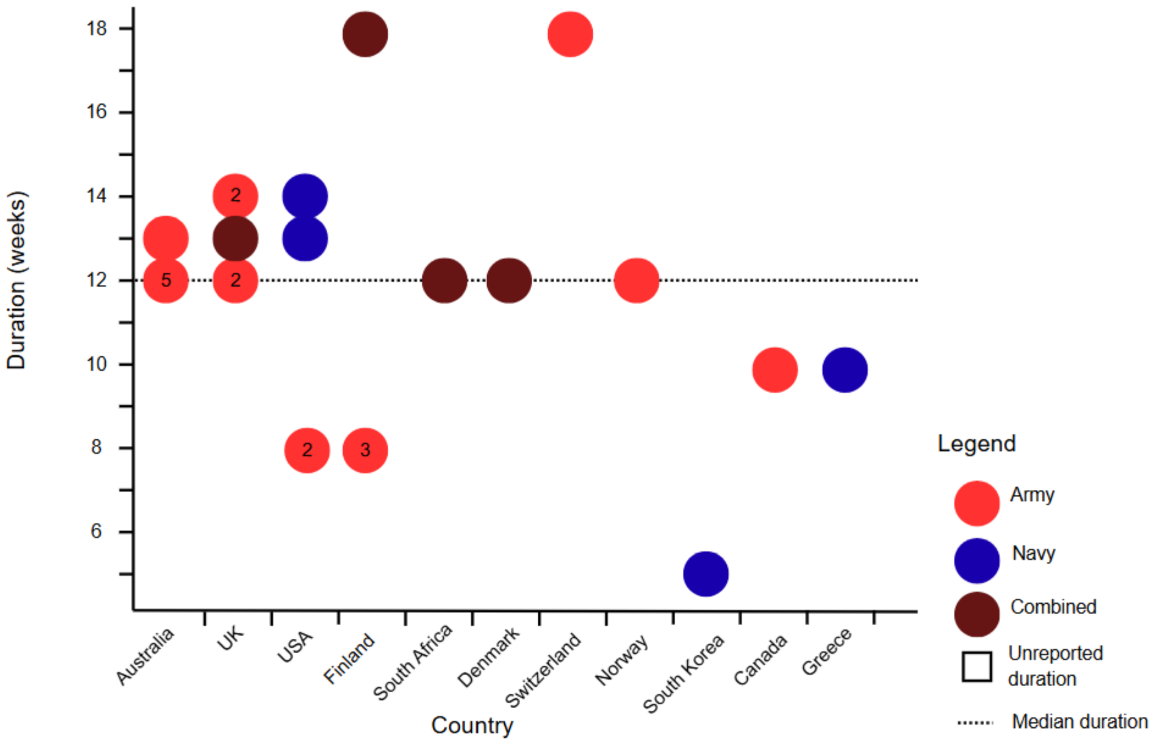

Figure 1. *Comparison of Reported Basic Training Durations Across Countries, Military Branches, Characterised by Study Publication Frequency*

Note: The number corresponds to N studies.

Table 1. *Summary of Literature Investigating Acute and Chronic Effects of Initial Military Training Included in the Narrative Review*

Study	Subjects (sex, mean age ± SD, weight ± SD)	Branch	IMT Duration	Test	Outcome
Santtila et al. (2012)	57 males, 19.2 ± 0.9 years, 73.8 ± 12.4 kg	Finnish Military	16 weeks	Cardiorespiratory endurance Lower-body strength Upper body strength	↑ VO2 peak 5.6% (p<.001) ↑ Isometric leg extension 3.8% (p<.001) in first 8 weeks, no further change ↑ Isometric arm extension 8.1% (p<.001) in first 8 weeks, no further change
Santtila et al. (2008)	72 males, 19.4 ± 0.8 years, 69.7 ± 8.5 kg	Finnish Army	8 weeks	Cardiorespiratory endurance Lower body strength	↑ VO2 peak NT: 13.4% (p<.001), ST: 12% (p<.01), ET: 8.5% (p<.05) ↑ Isometric leg extension NT: 5.2% (p=.45), ST: 9.1% (p<.05), ET: 12.9% (p<.01)
Rue et al. (2023)	339 males, 42 females, JE: 16 ± 1 years, SE: 21± 4 years, RAF: 21±3 years, JE: 68.6 ± 9.2 kg, SE: 71.7 ± 11.1 kg, RAF: 71.4 ± 9.9 kg	British Army & Air Force	13 weeks	Cardiorespiratory endurance Lower body strength Upper body power	2 km run time ↓ for all (JE:2.1%, p<.001, SE: 4.8%, p<.001, RAF: 4.5%, p<.001) IMTP ↑ for JE 10.8% (p<.001), SE & RAF no change Medicine Ball Throw (4kg) ↑ for JE 6.8% (p<.001), SE 2.3% (p=.04), ↓ for RAF 1.4% (p=.02)
Larsen et al. (2022)	57 males, 11 females, 23 ± 5 years, 76 ±15 kg	Australian Army	12 weeks	Sleep duration and efficiency	Mean 06.24 ± 00.18 h per night ↓ sleep time (06:06 ± 00:36 h) and efficiency in field (p<.01)
Wood & Kruger (2013)	173 males, 200 females, NT: male 20.5 ± 3.4 years, female =19.9 ± 3.1 years, EXP: male: 20.2 ± 3.3 years, female: 20.0 ± 3.2 years, NT: male 62.3 ± 6.7 kg, female: 59.1 ± 8.7 kg, EXP: male: 61.8 ± 6.9 kg, female: 60.2 ± 9 kg	South African Military	12 weeks	Cardiorespiratory endurance Upper body endurance Lower body endurance	2.4 km run time NT ↑ 6% (p=.001), EXP ↓ 12% (p=.0001) ↓ Shuttle run test (22m x10) time 6% (p=.0001) ↓ 4 km walk time 6% (p=.0001) ↑ Push up NT: Improve 37%, EXP: 91%, (p<.05) ↑ Sit up NT: 62%, EXP: 90%, (p<.05)

Santtila et al. (2010) [b]	72 males, 19.2 ± 0.9 years, 73.8 ± 12.4 kg	Finnish Army	8 weeks	Cardiorespiratory endurance Lower body strength	↑ VO2 peak NT: 13.4% (p<.001), ST: 12.0% (p<.01), ET: 8.5% (p<.05) ↓ 3km loaded march time NT: 10.2%, ST: 12.4%, ET: 11.6% (p<.001) ↓ Isometric leg extension (following loaded march) 10% (NT: p<.001, ST & ET p<.05)
Harman et al. (2008)	32 males, ST: 27 ± 4.7, NT: 29 ± 4.6 years, ST: 80.9 ± 12.7 kg, NT: 84.5 ± 10.4 kg	Civilian (following a US Army BT program)	8 weeks	Cardiorespiratory endurance Upper body strength Lower body strength Upper body endurance Lower body power	↓ 3.2km loaded run (32kg) time ST: 15%, NT: 14% (p<.05) ↓ 400m loaded run (18kg) time ST: 16%, NT: 11% (p<.05) ↓ Obstacle Course time ST: 10%, NT: 16% (p<.05) ↓ 30m Rush x5 time ST: 2%, NT: 6% (p<.05) ↓ Casualty Rescue time ST: 23%, NT: 36% (p<.05) ↑ VO2 peak ST:13%, NT: 10% (p<0.05) ↑ 1RM bench press ST: 12%, NT: 11% (p<.05) ↑ 1RM back squat ST: 12%, NT: 10% (p<.05) ↑ Push up ST: 32%, NT: 31% (p<.05) ↑ Sit up ST: 28%, NT: 50% (p<.05) ↑ Vertical jump ST: 5%, NT: 1% (p<.05) ↑ Horizontal jump ST: 3%, NT: 3% (p<.05)
McFadden et al. (2024)	182 males, 99 females, 19 ± 2 years, Male: 73.9 ± 10.4 kg, Female: 61.7 ± 8.1 kg	US Marines (Navy)	13 weeks	Lower body strength Lower body power Sleep duration	IMTP Relative peak Force, no change IMTP Peak Force, no change ↓ CMJ Relative peak power (Male: 11%, Female: 5% (p<.001) ↓ CMJ Peak Power (Male: 10%, Female: 5% (p<.001) Mean time 6.2 ± 1.1 h per night
Wyss et al. (2014)	600 (sex unspecified), 20.7 ± 1.2 years, 73.7 ± 10.6 kg	Swiss Army	18 weeks	Sleep duration	Mean time 6.5 h per night
Rosendal et al. (2003)	330 males, 20 ± 1 years, well trained: 77.2 ± 0.8 kg, trained: 79.2 ±	Danish Military	12 weeks	Cardiorespiratory endurance Lower body power	Multistage fitness test, untrained: ↑ 62%, all others no change Coopers 12min run test, untrained: 16%, trained 4%, others no change

	0.7 kg, less trained: 79.4 ± 1.2 kg, untrained: 85.9 ± 2.5 kg				CMJ (unloaded), ↓ well trained: 13%, trained: 9%, less trained: 12% (p<.05), untrained: no change CMJ (15kg pack), ↓ well trained, trained, less trained (p<.05), untrained: ↑ 9% (p<.05)
Saner et al. (2024)	1318 males, 263 females, 22.4 ± 5.1 years, 75.5 ± 17.1 kg	Australian Army	12 weeks	Cardiorespiratory endurance	↑ Multistage fitness test 6.6% (p<.001, ES 0.58), Male: 10.8 ± 7.9%, Female: 3.1 ± 6.8%
Ahn et al. (2020)	270 males, 15 females, male: 18.83 ± 0.76, female: 18.18 ± 0.54 years, weight unspecified	Korean Navy	5 weeks	Cardiorespiratory endurance Upper body endurance Mood profile	↓ 3km run time 17% (NS) ↑ Push up 45% (NS) ↑ Sit up 21% (NS) Weeks 1-5 spiked anger and fatigue (NS). Initial fitness had no relationship with mood or fatigue.
Burley et al. (2018)	173 males, 22 females, 21.5 ± 4.2 years, 76.2 ± 12.4 kg	Australian Army	12 weeks	Cardiorespiratory endurance Lower body strength Upper body endurance	↓ 3.2km loaded carry (22kg) 9% (p<.05) ↑ Multistage fitness test 9% (p<.001) ↑ 1RM box lift (1.5m) 22% (p<.001) ↑ Push up 11% (p=0.018)
Bulmer et al. (2022a)	29 males, 6 females, 24.8 ± 6.8 years, 75.6 + 14.7 kg	Australian Army	12 weeks	Cardiorespiratory endurance Wellness questionnaire	↑ Multistage fitness test (p<.001) ↑ reported stressors in field (NS)
Bulmer et al. (2022b)	37 males, 8 females, 25.2 ± 7.2 years, 76.8 ± 15 kg	Australian Army	12 weeks	Sleep duration Sleep efficiency Sleep questionnaire	Mean time 6.3 ± 1.2 h per night Efficiency 85.6 ± 5.5% Sleep quality had a strong relationship with stress, fatigue. Sleep was worse at the start of BT.
Vantarakis et al. (2022)	153 males, 32 females, 18.3 ± 0.6 years, 75.3 ± 7.6 kg	Greek Navy	10 weeks	Cardiorespiratory endurance	↑ Coopers 12min run test 10.8% (p<.01)

Burley et al. (2020)	162 males, 52 females, 21.7 ± 3.9 years, 73.4 ± 12.4 kg	Australian Army	12 weeks	Cardiorespiratory endurance Upper body strength Lower body strength Upper body endurance Lower body power	↓ 3.2km load carriage (22kg) time, EXP: 11.9%, NT: 8% (p=.030, ES: -0.30) ↑ Multistage fitness test, EXP: 13.2%, NT: 8% (p=.022, ES: 0.58) ↑ 1RM bench press, EXP: 26.3, NT: 17% (p<.001, ES: 0.26) 1RM squat, EXP: ↑ 23.7%, NT: ↓ 2% (p<.001, ES: 1.05) ↑ Box lift (1.5m), EXP: 10.5%, NT: 3% (p<.001, ES: 0.27) ↑ Push up, EXP: 34.5%, NT: 30% (p=.029, ES: 0.26) Squat jump power, EXP ↑ 7.2%, NT: ↓ 15% (p<.001, ES: 0.65) ↓ 30s Wingate mean power, EXP: 4.6%, NT 2% (p =.282)
Dyrstad et al. (2006) [b]	107 males, 19.02 ± 0.8 years, ST: 76.8 ± 10.5 kg, NT: 74.2 ± 6.9 kg	Norwegian Army	12 weeks	Cardiorespiratory endurance Upper body endurance	Treadmill stepwise protocol, no change ↑ Sit ups 55% (p<.01) ↑ Push ups 33% (p<.01) Chin ups, no change
Williams (2005)	19 males, 18 ± 1 years, 67.9 ± 5.3 kg	British Army	12 weeks	Cardiorespiratory endurance	↑ Multistage fitness test 13.1% (p<.0005)
Woodhead & Moyinhan (1994)	26 male, 4 female, 24.7 years, weight unspecified	US Navy	14 weeks	Cardiorespiratory endurance Upper body endurance Upper body power Lower body power	↓ 1.5-mile run time 6% (p<.05) ↑ Sit ups 18% (p<.05) Push ups, no change ↑ Shot Put (8lb) 6.3% (p<.05) ↑ Vertical jump height 6.3% (p<.05)
Bell (2000)	509 males, 352 females, 20 years, Male: 76.3 ± 12.3 kg, Female: 57.8 ± 6.3 kg	US Army	8 weeks	Cardiorespiratory endurance Upper body endurance	↓ 1 mile run time Male: 54%, Female: 156% (NS) ↑ Push up Male: 44%, Female: 98% (NS) Sit up Male: ↓ 16%, Female: ↑ 23% (NS)

Blacker et al. (2009) [b]	26 males, 28 females, 20.1 ± 3.4 years, 65.3 ± 8.5 kg	British Army	12 weeks	Cardiorespiratory endurance Cardiovascular strain	↓ 2.4 km run time 6% (p=.001, ES: 0.7) Weeks 1-6: no change, Week 9 ↓ HRR% (p<.05, ES =1.2)
Laroche et al. (2023)	32 males, 8 females, 24 ± 5 years, weight unspecified	Canadian Military	10 weeks	Cardiorespiratory endurance Sleep duration	↑ VO2 peak estimation Mean time 5.4 ± 0.4 h per night and decreased to 4.2 h ± 0.4 h during field
Richmond et al. (2012) [b]	30 males, 30 females, male: 18.9 ± 1.6 years, female: 18.6 ± 1.9 years, male: 73.8 ± 12.9 kg, 57.2 ± 6.5 years	British Army	14 weeks	Cardiorespiratory endurance Cardiovascular strain	↑ VO2 peak estimation 10% (p<.05) ↑ HRR% Male: 32%, Female: 31% (p=.19)
Vogel et al. (1978)	254 males, 19.5 ± 2.4 years, 67.9 ± 9.5 kg	British Army	3 months	Cardiorespiratory endurance Upper body strength	↑ VO2 peak estimation 8.9% (p<.001) Isometric grip strength, no change
Piirainen et al. (2019)	24 males, 18-21 years, NOR: 83.0 ± 21.4 kg, OR: 79.2 ± 19.0 kg	Finnish Military	8 weeks	Upper body strength Lower body strength H-reflex and V-wave Neuromuscular function Muscle contraction	Isometric elbow flexion, NOR: ↑ 18% (p<.01), OR: no change Isometric elbow extension, no change Isometric knee extension NOR: ↑ 19% (p<.05), OR: no change, H-reflex and V-wave, no change Single twitch (contraction time) NOR: no change, OR: ↑ (p<.01)
Schram et al. (2024) [a]	565 males, 364 females, 18-22 years, male: 72.9 ± 12.2 kg, female: 61.6 ± 7.4 kg	US Marines (Navy)	N/A	HR average HR max	↑ to both HR max/average in females compared to males during hikes with 4, 5 and 6 (p<.001). Intervention featured 6 hikes with ascending loads (1&2: 10 kg, 3&4: 15kg, 5&6: 20kg)
Fallowfield et al. (2012) [a]	12 males, 22 ± 3 years, 80.7 ± 6.8 kg	Royal British Marines (Navy)	N/A	Lower body power	↓ CMJ jump height 8.9% (p<.001) ↓ CMJ power 5% (p<.001) (acute change following loaded march)

[a]Acute study only, [b]Combined acute & Longitudinal study, CMJ: countermovement jump, ET: endurance-based intervention, EXP: experimental group, HR: heart rate, HRR%: percentage of heart rate reserve, JE: Army Junior Entry, OR: overreached, NOR: non-overreached, NS: no statistics, NT: normal training/control, RAF: Royal Air Force, SE: Army senior entry, ST: strength-based intervention, TRIMP: training impulse, 1RM: one repetition maximum

Table 2. *Summary of Acute Studies Included from Non-Recruit and Civilian Cohorts Included to Bolster the Narrative Review*

Study	Subjects (sex, mean age ± SD, weight ± SD)	Branch	Intervention	Outcomes
Armstrong et al. (2023)	12 males, 10 females, male: 23.6 ± 3.6 years, female: 22.8 ± 3.7 years, male: 77.9 ± 8.4 kg, female: 71.4 ± 9.1 kg	British Army	4x 3-hour marches at varying loads (21, 26, 33, 43 kg). Total distance covered:12.25 km at 4.9 km/h). Followed by cognitive tests (go/no go, n-back, reaction)	↑ VO2 uptake with load (p<.01) ↑ work rate in females (p<.005) ↓ accuracy during n-back and visual go/no go tests
Giles et al. (2019)	31 males, 24.4 ± 4.1 years, weight unspecified	US Army	4-hour operational scenario with 2x 1 h foot marches with 8.8, 47.2 and 50.7 kg across 3 days, followed by cognitive tests (go/no-go)	↓ hit rate (p<.025) and sensitivity (p<.001) RPE (borg scale) ↑ with load and time (p<.001) %HRR ↑ with load (p<.001), higher values associated with reduced hit rates (p=.039)
Grenier et al. (2012)	10 males, 38.96 ± 8.9 years, 82.9 ± 9.3 kg	Army (mixed nation, retired)	21 h simulated military mission (27 kg load for battles, 43 kg during marches)	↓ Isometric knee extension, 10.2% (p<.01) Isometric plantar flexion, no change Twitch-interpolation (knee extensor and ankle plantar flexors), origin of fatigue was peripheral for both ↑ Perceived fatigue, 91.6% (p<.01)
Scales et al. (2021)	21 males, 5 females, NT: 21 ± 5, EXP: 22 ± 6 years, NT: 73.8 ± 34.8, EXP: 78.3 ± 36.8 kg	Civilian	Loaded (32 kg) and unloaded groups marched on a treadmill for 2 hours on consecutive days	Isokinetic knee extension, EXP: ↓ on both days (p<.05). CON: no change VO2 uptake, EXP: ↑ on day 2, CON: no change
Looney et al. (2018)	8 males, 1 female, 21 ± 3 years, 83.4 ± 12.9 kg	US Army	2x laps around 2.5 km course, 5 min rest between (repeated with 30% BM (fighting) and 45% BM (approach) loads)	↑ HR in Lap 2 for fighting (p=.01) and approach loads (p<.01) Respiration rate, fighting load no change, approach load ↑ (p<.01) ↑ %HRR in Lap 2 for both loads (p<.05) ↑ TRIMP in Lap 2 for fighting (p=.01) and approach loads (p<.01) Time to completion, no change

CON: control, EXP: experimental group, HR: heart rate, %HRR: percentage of heart rate reserve, NT: normal training/control, RPE: rating of perceived exertion, TRIMP: training impulse

2.3.2 Initial Military Training Structure

Much of the identified literature did not clearly detail the structure or training regime. Of the available information, the duration of each course varied substantially (five to eighteen weeks) and included both voluntary and conscription-based (compulsory military service) recruitment. Two key phases were commonly reported, with the initial spent in team building and on basic skill work such as marksmanship, marching, drill, tactics and physical training (Ahn et al., 2020; Blacker et al., 2009; Bulmer, Drain, et al., 2022; Kyröläinen et al., 2018; Laroche et al., 2023). The latter phase included field/scenario-based training (Bulmer, Aisbett, et al., 2022; Bulmer, Drain, et al., 2022; Laroche et al., 2023), following a progressive model with increased exposure to physical stress as the course progresses (Blacker et al., 2009). Daily energy expenditure has been estimated at around 18,000 kJ (Bulmer, Drain, et al., 2022; Wyss et al., 2014), likened to that of elite athletes (Jurvelin et al., 2020). Of the research that reported sleep (Bulmer, Aisbett, et al., 2022; Larsen et al., 2022; McFadden et al., 2024; Wyss et al., 2014), recruits slept between 5.4 and 6.5 hours per night. This was, however, variable across studies and within phases of IMT, with decreases in sleep duration as low as 4.2 ± 0.4 h (Laroche et al., 2023) and subjective quality noted in field environments (Larsen et al., 2022).

One study of Finnish conscripts (Santtila et al., 2015) noted that approximately 40% of the time spent training involved a physical element, with around 13% dedicated to improving physiological and neuromuscular qualities. Another study reported over two hours of physical activity being conducted daily (Males: 2.3 ± 0.2h, Females: 2.2 ± 0.2h) (Richmond et al., 2012). Research on Australian Army recruits suggests <10% time is spent on specific physical training sessions, equating to around 250 minutes per week (Bulmer, Drain, et al., 2022), which is similar to the US, British and Singaporean armies average 227, 284 and 240 minutes per week, respectively (Wyss et al., 2014). This contrasts with Dyrstad et al. (Dyrstad et al., 2006), which states that the minimum standard for specific physical training during IMT in the Norwegian military is only 120 minutes per week (with only 12% of the cohort meeting the minimum standard). While these variations may reflect differences in what is classified as targeted conditioning for specific physical qualities, it nonetheless highlights the large differences possible between organisations. Time spent on structured physical training appears to be largely divided up between forms of cardiovascular and strength training, utilising running, strength, circuit training, sport, swimming and obstacle courses (Bulmer, Drain, et al., 2022; Vantarakis et al., 2022; Wyss et al., 2014). These training sessions run for approximately one hour and occur multiple times a week (Dyrstad et al., 2006; Harman et al., 2008; Vantarakis et al., 2022) and usually lack individualisation (Saner et al., 2024). Most courses adopt traditional training methodology and focus on prolonged low-moderate intensity endurance-based training. Few explicitly identified alternate methods, such as properly structured strength training, which could be argued as beneficial for adaptation of key physical qualities for potential soldiers (Burley et al., 2018, 2020; Santtila et al., 2008, 2012).

Outside of structured training sessions, recruits' time was separated by specific skills such as weapons training, drill, field craft and classroom sessions and other physical activity (Santtila et al., 2008; Wood & Krüger, 2013; Wyss et al., 2014). The remaining physical activity was spread across a range of different activities, such as load carriage, which was among the most reported and investigated activities identified in the literature search (Harman et al., 2008; Rosendal et al., 2003; Rue et al., 2023; Saner et al., 2024; Wyss et al., 2014). Additionally, one study on Swiss recruits noted that the average recruit was covering fourteen kilometres per day on foot (Wyss et al., 2014) with another study noting that most distance covered on foot was conducted at “double time”, referring to running (Woodhead & Moynihan, 1994). While physical activity varies between organisations, generally, the total duration appears very high among recruits.

2.4 Physiological and Neuromuscular Effects of Initial Military Training

2.4.1 Cardiorespiratory System

Cardiorespiratory endurance is the heart and lungs' ability to deliver oxygen to muscles (Cheng et al., 2019). It is a critical factor for sustaining physical output over time (A. M. Jones & Carter, 2000; Whipp et al., 1982). Enhanced endurance improves oxygen uptake and exercise economy, making it perhaps the most vital physical quality for tactical personnel, particularly during prolonged load carriage (Richmond et al., 2012).

2.4.1.1 Acute Effects

Acute cardiorespiratory responses were discussed in four studies (Blacker et al., 2009; Dyrstad et al., 2006; Richmond et al., 2012; Schram et al., 2024). Three studies investigated the responses of heart rate during fitness tests (multi-stage fitness test, 2.4km run and during VO2 peak testing) (Blacker et al., 2009; Dyrstad et al., 2006; Richmond et al., 2012) and one during an intervention involving 6 hikes with progressively increasing loads (total duration 225 minutes) (Schram et al., 2024), which was the only study to investigate acute aerobic responses to a military-specific task. In another study, the daily average for percentage heart rate reserve (HRR), which is used to measure cardiovascular strain (higher percentages represent greater strain), was higher in the initial stages of IMT but there were no changes between Weeks One and Six (31 ± 5 vs. 31 ± 5% HRR, $p = .246$, $d < 0.1$) but was significantly lower in Week Nine (29 ± 5% HRR, $p < .05$, $d = 1.2$) (Blacker et al., 2009). Accordingly, Richmond et al. (2012) observed that Week One had the highest %HRR for both male and female British recruits, but throughout IMT, there were no daily differences between sexes despite lower comparative fitness levels recorded in the female group. However, there were significant differences detected within individual weeks for both sexes. In contrast, another study found HRR% was significantly lower in British male than female recruits (24 ± 2 vs. 32 ± 2% HRR, $p < .001$, ES = 4.0) (Blacker et al., 2009), albeit likely explained by lower cardiorespiratory endurance rather than sex alone (females had significantly lower levels compared to males).

During loaded and unloaded marching over varying distances (3-12.25 km) and durations (single short bouts to multiple day repeated bouts), increases in intensity and or load increased cardiovascular strain (Dyrstad et al., 2006; G. E. Giles et al., 2019; Looney et al., 2018; Schram et al., 2024) and VO2 consumption (Armstrong et al., 2023; Scales et al., 2021; Vickery-Howe et al., 2024) in both male and female recruits. Overall, females worked at 33% greater percentage of their maximal oxygen consumption (%VO2 max) than males under the same conditions (Vickery-Howe et al., 2024).

Additionally, as required load carriage was increased, so too were the physical demands placed on personnel (Armstrong et al., 2023; Looney et al., 2018; Schram et al., 2024), showing that an increase in load equivalent to 15% body mass increases %HRR by around 10% (Looney et al., 2018). Of these studies, Armstrong et al. (2023) and Looney et al. (2018) investigated the effects of repeated bouts of load carriage, with both studies finding significant increases in measures of physical strain in both sexes. Armstrong et al. (2023) found an increase in 10% HRR compared to the first march in males and 19% in females. While Looney et al. (2018) tested eight males and one female in three different loading conditions: unloaded, fighting load (30% body mass (BM) and approach load (45% BM). Both fighting and approach loads showed significant increases to HR, %HRR and training impulse in the second bout of marches, while for respiration rate (RR), only the approach load increased significantly (all $p \leq .01$).

2.4.1.2 Chronic Effects

The chronic effects of IMT on the cardiorespiratory system were included in twenty-one studies (Ahn et al., 2020; Bell, 2000; Blacker et al., 2009; Bulmer, Drain, et al., 2022; Burley et al., 2018, 2020; Dyrstad et al., 2006; Harman et al., 2008; Laroche et al., 2023; Richmond et al., 2012; Rosendal et al., 2003; Rue et al., 2023; Saner et al., 2024; Santtila et al., 2008, 2010, 2012; Vantarakis et al., 2022; Vogel et al., 1978; A. G. Williams, 2005; Wood & Krüger, 2013; Woodhead & Moynihan, 1994) assessed via a range of different methods over five to sixteen weeks; for example, multistage fitness tests (Bulmer, Drain, et al., 2022; Burley et al., 2018, 2020; Richmond et al., 2012; Rosendal et al., 2003; Saner et al., 2024; A. G. Williams, 2005), runs for time at varying distances (1.6, 2, 2.4, and 3 km) (Ahn et al., 2020; Bell, 2000; Blacker et al., 2009; Richmond et al., 2012; Rue et al., 2023; Wood & Krüger, 2013; Woodhead & Moynihan, 1994), loaded runs with varying loads for 3.2 km (18, 22, and 32 kg) (Burley et al., 2018, 2020; Harman et al., 2008; Santtila et al., 2010), shuttle runs (Harman et al., 2008; Wood & Krüger, 2013), Coopers 12min Test (Rosendal et al., 2003; Vantarakis et al., 2022), treadmill and bicycle VO2 analysis tests, both using estimation and gas analysis (Harman et al., 2008; Laroche et al., 2023; Santtila et al., 2008, 2010, 2012; Vogel et al., 1978). Among these, there is evidence that IMT increases cardiorespiratory endurance, the degree to which varies substantially (ranging from a decrease of 6% to increase of 61%), albeit on average appearing positive. These findings align with a review of twenty-nine studies on military recruits across the UK, USA, Australia, Canada, South Africa and Germany (Varley-Campbell et al., 2018) which reported improvements in all studies across male and female recruits, showing increases to VO2 Max of 7.4% in males and 4.0% in females. Of the twenty-one studies included in the current review, all generally observed positive improvements. Nonetheless, two studies during a twelve-week block of IMT included a stepwise treadmill protocol (VO2 peak via gas analysis), which found no significant change (Dyrstad et al., 2006), and a 2.4km time trial, finding a 6% decrease ($p<.001$) (Wood & Krüger, 2013). This broad variation is likely a result of homogeneity of training focus and progression, and length of IMT (not all of which is clearly reported, as described earlier).

Most improvements to cardiorespiratory endurance appear to occur within the first eight to ten weeks of IMT (Dyrstad et al., 2006; Santtila et al., 2008), which might suggest IMT initially is sufficient to evoke improvement in cardiorespiratory endurance, after which it is then potentially obscured by a lack of appropriate periodisation. However, in Australian, British and Finnish Army and Air Force recruits, mean pre and post IMT differences in aerobic performance have been largely made up of those with the lowest levels of initial fitness (Rue et al., 2023; Saner et al., 2024; Santtila et al., 2008, 2012), while those with a VO2 peak above 55.5 mL/kg/min made no significant progress (Santtila et al., 2008). This is supported by Dyrstad et al. (2006) who found that a medium initial VO2 peak (54.6 mL/kg/min) saw no change, and a high initial VO2 (59.7 mL/kg/min) had actually decreased by 1.1% (albeit not statistically significantly, $p = .07$). These findings suggest that IMT is broadly insufficient in improving cardiorespiratory endurance in those with exceptional fitness levels, and that early increases may simply be attributed to lower starting fitness and may not continue to be developed during the later stages of IMT.

Further, in a study of British recruits, the magnitude of improvements in recruits tended to vary by sex. However, the main explanation would appear to be that males expressed higher fitness levels at the start of the course (Blacker et al., 2009), in line with previous findings (Saner et al., 2024; Santtila et al., 2008). This is further supported by the findings that while female recruits have 2.1 times greater relative injury risk compared to male recruits, this difference becomes negligible when adjusted for fitness (Bell, 2000). These results suggest a relationship between cardiorespiratory endurance and injury during IMT, which suggests that those working at a greater relative level of strain (notably females) are at higher risk (Blacker et al., 2009).

2.4.1.3 Summary

The literature suggests that IMT acutely increases cardiovascular strain while chronically improving cardiorespiratory endurance. These improvements appear to be largely attributed to lower entry-level fitness, and progress seems to stall in the latter stages of IMT, with those entering with a high level of cardiorespiratory endurance showing trivial progress throughout the duration of IMT. Although the reported studies hypothesise different reasons for these effects, this is likely a result of compounding variables such as chronic poor sleep quality, peripheral fatigue due to insufficient recovery and a lack of individualisation of training. Nonetheless, variation in testing methodology, time between pre/post measures, and differences in underlying characteristics of IMT complicate further synthesis.

2.4.2 Maximal Strength

Muscular strength is the maximum force muscles exert on their environment (Bohannon, 1987), and strength training (ST) can reduce injury risk by up to 66% (Lauersen et al., 2018) and significantly improve performance in demanding tasks like load carriage, lifting, and casualty evacuation (Knapik et al., 2012; Kraemer & Szivak, 2012; Vaara et al., 2022). These benefits are further amplified when strength work is combined with aerobic training.

2.4.2.1 Acute Effects

One study (Santtila et al., 2010) investigated the acute effects of military IMT on maximal strength. In this study, male Finnish Army conscripts, divided into groups prioritising strength, endurance, or normal training, completed a timed 3 km loaded run with 14.2 kg of additional load. Interestingly, all groups experienced a significant decrease in knee extensor strength by approximately 10% (p=.01–.05) immediately following the activity. Other studies conducted in military populations outside of IMT reported similar lower-limb strength output decreases of around 10% (isometric knee extension and plantar flexion) immediately following load carriage (Grenier et al., 2012; Scales et al., 2021), which can persist up to ninety-six hours (Heilbronn et al., 2023). Only one paper was able to infer that this was isolated to peripheral fatigue by using twitch interpolation on the knee extensors and plantar flexors; however featured a non-recruit population (Grenier et al., 2012). Logically, these effects tend to scale with relative load increase, placing greater stress on the musculature (Vickery-Howe et al., 2024), which is notable for those of smaller stature or strength in conditions of absolute loading. While there is scarce literature specific to IMT, it seems that loaded tasks impair maximal muscular strength in the short term.

2.4.2.2 Chronic Effects

Ten studies investigated the chronic effects of IMT on maximal strength measured over eight to sixteen weeks (Burley et al., 2018, 2020; Harman et al., 2008; McFadden et al., 2024; Piirainen et al., 2019; Rue et al., 2023; Santtila et al., 2008, 2010, 2012; Vogel et al., 1978). Of these, one paper focused solely on upper-body effects (Vogel et al., 1978), five on lower body effects (Burley et al., 2018; McFadden et al., 2024; Rue et al., 2023; Santtila et al., 2008, 2010) and four on both upper and lower body effects (Burley et al., 2020; Harman et al., 2008; Piirainen et al., 2019; Santtila et al., 2012).

Upper body strength was assessed using a 1RM bench press over eight and twelve weeks (Burley et al., 2020; Harman et al., 2008), an isometric bench press over sixteen weeks (Santtila et al., 2012), isometric elbow flexion and extension over eight weeks (Piirainen et al., 2019), and an isometric grip strength test over three months (Vogel et al., 1978). Four of these studies showed statistically significant improvements in bench press and isometric elbow flexion (Burley et al., 2020; Harman et al., 2008; Piirainen et al., 2019; Santtila et al., 2012), while the elbow extension and grip strength showed no change (Piirainen et al., 2019; Vogel et al., 1978). A recent review of recruits (Varley-Campbell et al., 2018) reported median improvements of 8.5%, with larger improvements typically observed in females (6.9 vs. 13.0%).

Lower-body strength was assessed using a variety of different methods, including a 1RM squat over eight and twelve weeks (Burley et al., 2020; Harman et al., 2008), 1RM box lift (1.5m) over twelve weeks (Burley et al., 2018, 2020), isometric mid-thigh pull (IMTP) over twelve and thirteen weeks (McFadden et al., 2024; Rue et al., 2023) and an isometric knee extension over eight weeks (Piirainen et al., 2019). Within these studies, four found overall improvements (Burley et al., 2018; Harman et al., 2008; Piirainen et al., 2019; Rue et al., 2023), one found no change (McFadden et al., 2024), and one was relatively inconclusive, where the 1RM box lift had improved by 3%, and 1RM squat decreased 2% (percentages calculated from data) (Burley et al., 2020). In line with the effects of cardiorespiratory endurance, the effects of IMT on lower body strength also appear more pronounced in those with lower initial strength; notably, where recruits in the lowest quartile of strength saw a 24.4% increase in IMTP force ($p<.001$), whereas the highest quartile showed no change (−2.8%, $p= .202$) (Rue et al., 2023). While these results seem to show generally positive improvements overall, the identified literature itself is inconclusive and features significant variations in testing methodology and outcome. Notably, a previous systematic review of pre- and post-changes to physical performance in military training by Varley-Campbell et al. (2018) observed an overall significant improvement in lower body strength of 8.9%, the majority of the identified literature in this review observed positive changes in 14 total groups, while five returned no significant difference. This seems to align with the literature identified in the current review, where improvements to lower-body strength are observed in four studies, while two found no difference.

When looking more specifically at studies which tested strength during several time points during IMT, we see similar effects as with the cardiorespiratory adaptations, where most improvements are made within the initial periods of IMT, where isometric elbow and knee extension strength increased by 3.8% and 8.1% ($p < .001$) in the first eight weeks and no additional improvements were made in the remaining eight weeks (Santtila et al., 2012). The authors attributed these inconsistent results to an interference effect or lack of progressive stimulus but given that this effect appears to occur across other physical qualities as well, accumulated general fatigue may be another explanation. In addition, it appears that most positive adaptations take place within those with the lowest levels of entry strength (Rue et al., 2023). Only one of the studies sought to investigate sex-based differences (McFadden et al., 2024), finding males had greater IMTP peak force ($p < .001$), which approached significance ($p = .09$) when normalised to body mass .

Large variances exist in the physical training regimen, but most tended to adhere to a traditional, moderate-low endurance-based load, which is suboptimal for maximal strength development. Studies that featured an experimental design comparing a control group (NT), which performed an unmodified IMT, to a group that conducted an alternate strength training (ST) program with better control over volume and load, also found more favourable results in the ST groups (Burley et al., 2020; Santtila et al., 2008). Both studies featured a design where the ST group performed strength and high-intensity interval sessions. The study by Santtila et al. (2008) found an increase of 9.1% ($p < .05$) during isometric leg extension and elbow extension, whereas there was no change observed in the NT group over the course of IMT (5.2%, $p = .45$). This is supported by Burley et al. (2020), who found that compared to the NT group, the ST group experienced small improvements in load carriage, 1RM bench press and 1RM box lift, with large improvements in 1RM Squat. In contrast, a study that compared standard IMT to a circuit training protocol found no significant difference in strength for 1RM bench press or squat (Harman et al., 2008). Utilising a circuit style protocol with very short rest periods has been shown to produce suboptimal strength improvements (De Salles et al., 2009;

Schoenfeld et al., 2016). These findings suggest that a more targeted approach to training results in less fatigue and offers more favourable results.

2.4.2.3 Summary

IMT (and associated military tasks) appear to acutely suppress strength and scale to relevant activities. Chronic effects overall seem to elicit improvements in strength, although results are inconsistent and heterogeneity is present amongst testing methodologies. This may, in part, be due to different organisational practices and training methodology, and varying testing methodology and timeframes, as described earlier. To support this hypothesis, most observed improvements were made early in the IMT and largely within those in the lowest levels of strength, suggesting that fatigue might play a role in these effects. Further, intervention studies featuring groups with more strength-based volume, better control over load and rest periods tended to see better improvements to maximal strength. To enhance and optimise maximal strength adaptations, military practitioners might consider a more periodised approach to their training, adjusting endurance loading to allow for better strength adaptations.

2.4.3 Muscular Endurance

Neuromuscular endurance is a critical component of military readiness, allowing recruits to sustain maximal effort (Buchheit & Ufland, 2011) and perform repeated operational tasks like load carriage. Despite its importance in IMT, the multifaceted nature of force and velocity makes standardised assessment difficult.

2.4.3.1 Acute Effects

There were no studies identified that investigated the acute effects of IMT on muscular endurance. However, the impacts of difficult activities are reasonably well understood in human physiology and may persist for up to ninety-six hours in soldiers (Heilbronn et al., 2023). The negative effects of IMT observed in strength likely transfer to strength-endurance. For example, one study (Santtila et al., 2010) identified that knee extensor strength declined 10% in male Finnish Army conscripts following a three-kilometre loaded run (14.2 kg). Byrne et al. (2004) reviewed evidence showing that repeated submaximal eccentric exercise causes greater muscle function impairment compared to concentric exercise, suggesting that increased muscle damage further diminishes muscular endurance and stretch-shortening cycle efficiency during repetitive activities such as running. Given the intense repeated physical demands of IMT, it is likely that these effects would also be observed in recruits during IMT.

2.4.3.2 Chronic Effects

Eight studies have looked at the chronic effects of IMT on muscular endurance measured over five to fourteen weeks (Ahn et al., 2020; Bell, 2000; Burley et al., 2018, 2020; Dyrstad et al., 2006; Harman et al., 2008; Wood & Krüger, 2013; Woodhead & Moynihan, 1994), typically determined using maximum repetitions in sit-ups, push-ups and chin-ups. Given the endurance-based nature of IMT (Kyröläinen et al., 2018), it may come as no surprise that all eight studies showed significant improvements in muscular endurance between 5 to 156% over the duration of the course (calculated manually across studies). However, all endurance-based tests used an upper-body focus, and no lower-body measures were used. In the absence of sufficient literature, some other tests that were deemed to be more aerobic in nature may be used to strengthen this section. The tests, including a 400 m loaded run, shuttle runs, an obstacle course, and a casualty rescue (Harman et al., 2008; Wood & Krüger, 2013), showed performance improvements between 6 and 36% across all measures (averages calculated manually across studies from the provided data).

The chronic improvements in muscular endurance resulting from IMT seem to be greater in female recruits, with Bell (2000) showing females improved more than males in the push-up (156% vs 54%) and sit-up (98% vs 44%, respectively) over eight weeks. These findings align with systematic research, which shows muscular endurance is significantly improved for both men and women during IMT (Smith et al., 2022a; Varley-Campbell et al., 2018), averaging 52% for push-ups and 47% for sit-ups, with females showing the greatest improvements in both push-ups (71% vs. 50%) and sit-ups (53% vs. 36%). Further, the testing methodology identified was primarily upper limb dominant, with just a single paper identified in the Varley-Campbell et al. (2018) systematic review investigating lower limb endurance using a leg press until failure, finding no significant differences between male and female recruits. Ultimately, larger improvements were observed in females' upper-body strength endurance, likely attributed to lower initial strength levels, which are markedly lower among female compared to male active populations (Varley-Campbell et al., 2018), but lower body endurance requires more research.

2.4.3.3 Summary

While acute responses to IMT have not been documented in recruit studies, broader research suggests that neuromuscular endurance is likely impaired following strenuous physical activity. This impairment tends to increase with greater muscle damage, especially from eccentric loading, such as that experienced during cross-terrain marching, where downhill sections impose high eccentric demands. Overall, IMT has resulted in a significant improvement in muscular endurance in both male and female recruits, but there were no studies identified in recruits that measured lower-body endurance objectively and found no significant differences. Systematic research in recruits supports these results for upper body endurance, noting that significant improvements were seen over the duration of the course, with females making the largest changes. Where testing methodologies were more closely aligned and comparable than other qualities assessed, timeframes still varied significantly. Further research is required with lower body assessments to draw valid conclusions, with only a single study identified in systematic research, which found no change between sexes.

2.4.4 Muscular Power

Neuromuscular power is the ability to produce force rapidly and is essential for military performance (Mala et al., 2015). High power levels enhance explosive efforts and agility (Bosco et al., 1983), enabling personnel to manoeuvre quickly, navigate obstacles, and perform forceful tasks like throwing or seeking cover.

2.4.4.1 Acute Effects

In the only study that we found that examined the acute effects of IMT on neuromuscular power, Fallowfield et al. (2012) investigated the acute effects on an all-male sample of a 19.3 km loaded march taking 270 minutes to complete while carrying 31 kg of additional load. Lower body power was measured with a countermovement jump (CMJ) on a jump mat, which is a commonly used assessment to measure lower body power (Anicic et al., 2023). Jump height and power (calculated using an equation) were recorded. They found that immediately following the loaded march, there was a decrease of 8 ± 9% in jump height, and power decreased 5 ± 5% ($p < .001$). These findings align with previous research showing decreases in neuromuscular function following endurance activities (Blacker et al., 2010). Similarly, a study on a civilian male cohort performing loaded carries reported a 9 ± 6% decrease in CMJ jump height (Vine et al., 2022), findings that closely mirror those in a military sample (Fallowfield et al., 2012). Laboratory studies have shown that these impairments might last up to forty-eight hours post activity (Blacker et al., 2010) while a military-specific systematic review reported that power may take as long as ninety-six hours to recover fully following periods of field training and casualty evacuation exercises (Heilbronn et al., 2023), highlighting the significant fatigue placed on military personnel. None of these studies featured female subjects, and as such, further research is required to understand the interaction between sex and acute changes to neuromuscular power.

2.4.4.2 Chronic Effects

The chronic effects of IMT on neuromuscular power were investigated in six studies, measured over eight to fourteen weeks (Burley et al., 2020; Harman et al., 2008; McFadden et al., 2024; Rosendal et al., 2003; Rue et al., 2023; Woodhead & Moynihan, 1994). Two investigated upper body power via a medicine ball throw over thirteen weeks (Rue et al., 2023) and shot-put throw over fourteen weeks (Woodhead & Moynihan, 1994). While five of these studies investigated lower body power via vertical and horizontal jumps, or a Wingate 30s test over eight to fourteen weeks (Burley et al., 2020; Harman et al., 2008; McFadden et al., 2024; Rosendal et al., 2003; Woodhead & Moynihan, 1994). Again, there are large variations between test timing, methods and population.

Both upper-body studies utilised a projectile throw/push-based test. Upper-body power is important for personnel as it allows for quick movement from prone positions, which are often utilised during combat scenarios, and may assist with the movement of objects. Woodhead & Moyinhan (1994) found a significant 6.3% increase ($p < .05$) while Rue et al. (Rue et al., 2023) investigated the upper body power in three different branches of the military with improvements of 6.8% ($p < .001$) and 2.3% ($p = .040$) for British Army Junior Entry and Army Senior Entry, respectively, while the Air Force decreased 1.4% ($p = .002$) performance. These groups were all ranked into quartiles based on their throwing distance. The increases in the Army courses were made up by those who were in the lowest half of upper body power within the cohort of both Army Junior and Senior entry. Only the lowest quartile made any improvement in the Air Force group, which suggests that the training stimulus may not be sufficient to enhance upper-body power in recruits with reasonably developed upper-body power. It is unclear exactly why these adaptations occurred; neither study made specific mention of why they believe this happened, but these can likely be attributed to general exposure to structured training, which seems likely due to most improvements being observed in recruits with lower levels of power on entry. The results for the chronic effects of IMT on lower-body power were mixed. Three studies reported significant decreases averaging 8.9% (-2 to -15%) (Burley et al., 2020; McFadden et al., 2024; Rosendal et al., 2003), while two others observed significant increases averaging 3% (1 to 6%) (Harman et al., 2008; Woodhead & Moynihan, 1994) with means calculated manually from the provided data within each paper. Interestingly, both papers showing improvements to lower body power used manually measured vertical and horizontal jumps, with only small increases detected of 1, 3 and 6% for each of these conducted tests (Harman et al., 2008; Woodhead & Moynihan, 1994). The remaining three papers, which observed decreases in power using more advanced technology, such as force plates, jump mats, and a cycle ergometer, all found decreases in power (2-15%) (Burley et al., 2020; McFadden et al., 2024; Rosendal et al., 2003). Only one of these explored the interaction of sex (McFadden et al., 2024), finding that females' peak power and relative peak power from a CMJ measured on force plates had decreased significantly less than males ($p < .001$). Further research is needed to draw valid conclusions about the chronic effects of IMT on lower-body neuromuscular power.

2.4.4.3 Summary

In line with current understanding in athletic populations, muscular power is reduced following strenuous activity. Acute responses to physical activity in recruits showed decreases in power, with one study suggesting males suffered greater reductions over the course of IMT than females. While research was limited, and again, large variances in testing methodologies and timeframes exist, these findings seem to align with a greater body of research in wider military and civilian populations. However, the chronic effects of IMT on neuromuscular power are currently inconclusive. Limited research on upper-body power showed consistent increases across both studies. In contrast, findings on lower-body power were more variable.

2.5 Limitations and Future Directions

The heterogeneity of the included studies presents a challenge to coherently summarising the effects of IMT. As described, studies include IMT instances that span countries, timeframes, and different measurement techniques, which render synthesis challenging. Specifically, the difference between service types, such as conscript versus volunteer populations, introduces significant variance in motivation and pre-enlistment conditioning. Furthermore, baseline fitness levels varied widely among cohorts, complicating the ability to isolate the specific impact of IMT. This is exacerbated by the inability to control for variables known to influence performance, such as sleep deprivation, nutritional intake, and psychological stress, which are common to the military environment. The training itself presented further inconsistencies and lacked clarity, likely in part due to security risks with sharing a detailed training regimen. In many cases, mass training environments limit the feasibility of individualised training methodologies, and frequent shifts in training focus often occur throughout the course. Additionally, the varying lengths of training courses and the specific requirements of different military branches (e.g., Army vs. Air Force vs Navy) limit the generalizability of the results. Finally, the data may be affected by the nature of the assessments themselves; testing may not have been conducted maximally due to recruit fatigue or a lack of standardised motivation, potentially resulting in underestimations of true neuromuscular capacity and obfuscation of true effects. Future research should prioritise the establishment of standardised physical assessment protocols across military cohorts, potentially leveraging more insightful measurement approaches and technologies. Large-scale, longitudinal studies with similar data collection methods are essential to improve comparability and to develop a more cohesive understanding of how specific training modalities influence long-term health and readiness.

2.6 Conclusion and Research Suggestions

This review examines how IMT impacts physiological and neuromuscular performance. Although specific data on recruits is sparse, related research indicates that IMT tasks likely reduce acute neuromuscular and cognitive output. This decline is likely considered a necessary byproduct of the preparatory stress intended to challenge recruits, not only/always for stimulating positive long-term physiological adaptations.

The chronic IMT adaptations generally improve cardiorespiratory endurance, strength, and upper body muscular endurance; however, data on lower body endurance and muscular power are underreported and remain inconclusive. Notably, improvements were predominantly observed in groups with the lowest initial fitness levels, whereas the fittest groups showed minimal or no gains. Furthermore, these adaptations primarily occur during the initial phases of IMT, with progress stalling as training continues, resulting in little to no additional improvement during the latter stages of the course. This plateau, likely driven by a lack of appropriate periodisation, increases injury risk and compromises safety. Research suggests that reducing endurance-based loads offers more favourable outcomes for strength and power. Consequently, tracking fatigue proxies is essential to balance stressors with recovery, ultimately enhancing performance and reducing the high injury rates common in IMT (Bell, 2000; Davidson et al., 2008; B. H. Jones & Knapik, 1999). It is important, though, to reiterate the significant heterogeneity observed across the included studies, which makes a concise synthesis difficult and calls for more specific research.

These physiological responses are further nuanced by sex-based differences in baseline conditioning and training strain. For instance, females typically enter IMT with lower initial fitness levels and consequently exhibit greater cardiovascular strain during load carriage. While both sexes show improvements in muscular endurance, these effects were more pronounced in females. Males maintain higher absolute isometric strength. However, the impact of cumulative fatigue also appears to diverge; limited data suggest that males may experience a greater reduction in jump power than females over the duration of IMT. These sex-specific variations highlight the importance of a degree of individualised monitoring to mitigate the high injury rates associated with the cumulative stress of training.

Chapter 3: Effects of 14-Weeks of New Zealand Army Basic Training on Countermovement Jump Height

3.0 Prelude

In the previous chapter, it was highlighted that significant heterogeneity is present in global military practices, with a general lack of information regarding what basic training constitutes. Nevertheless, there was evidence specific measures of neuromuscular performance differ in response to training more broadly, calling for more specific research. Chapter 2 provided a narrative of the current literature to inform this chapter, where a more specific understanding of the effects of basic training is required. Therefore, the purpose of this chapter is to better understand the effects of basic training over time in New Zealand Army recruits and determine to what extent countermovement jump height can serve as a marker for monitoring longitudinal changes in neuromuscular performance. The primary outcome of jump height was selected as an accessible, field-expedient measurement, commonly used as a proxy for lower-limb neuromuscular capacity in military practice. This chapter leverages both collected and retrospective data, intending to provide more insight into the change over time, and potentially, intake cohorts. However, due to challenges with recruitment and data completeness, the resulting analysis was largely descriptive. This chapter is framed as a short technical note intended to provide normative data of Army personnel and insight into broad neuromuscular changes over time, with some insight into potential differences between intakes.

3.1 Introduction

Initial military training (i.e., 'basic training') is a rigorous transition designed to equip civilians with the skills to handle the extreme physical and psychological stressors of military service (G. E. Giles et al., 2019; Laroche et al., 2023; Santtila et al., 2015; Vine et al., 2021). While basic training aims to develop essential physical qualities, recruits often enter the course with varying levels of fitness, as identified in McCleary et al. (2026) (Chapter 2), with many often being underprepared for the physical demands of the course (Hall et al., 2026; Orr et al., 2020). Furthermore, the loads experienced during basic training are comparable to those of professional athletes (Jurvelin et al., 2020), which probably creates an extreme spike in load for many. Therefore, it is important to monitor whether the training is adequately preparing recruits for the rigours of operational service or unduly breaking them down.

While the effects of basic training are documented to varying degrees, there is little consensus (McCleary et al., 2026) (Chapter 2); this may be attributed to variability in what is involved in basic—both within and across organisations—compounded by lacking information describing the stimulus itself, probably in part due to security concerns. This is even more prominent in lower-body power, a critical physical component for military tasks (Knapik et al., 2012; Kyröläinen et al., 2018; Mala et al., 2015; Maupin et al., 2019; Vaara et al., 2022), where the literature reports both significant improvements and reductions at the end of the course (Burley et al., 2020; Harman et al., 2008; McFadden et al., 2024; Rosendal et al., 2003; Woodhead & Moynihan, 1994). Another explanation is the variability in capabilities of soldiers entering basic, with several reports of adaptations and fatigue varying by fitness level. Highlighted by McCleary et al. (2026) (Chapter 2), this ambiguity is likely exacerbated by a reliance on pre- versus post-training testing methodologies, which provides an incomplete narrative. It is suggested that any gain in performance may plateau or even decline after the mid-point, likely due to diminishing training stimulus or as fitness improves due to a lack of progressive periodisation (Dyrstad et al., 2006; Santtila et al., 2008, 2012). This is supported by studies utilising more specific periodisation (Burley et al., 2020; Piirainen et al., 2019; Santtila et al., 2008).

Given that jump testing is efficient and reliable, it represents an easy assessment to implement (Collings et al., 2024; Hoffman & Kang, 2002; Ishida et al., 2023; Merrigan et al., 2020; Merrigan, Stone, Hornsby, et al., 2021). Accordingly, there is potential for such a measure to provide insight into baseline and ongoing neuromuscular function of recruits around basic training, and military organisations appear to regularly use a measure in practice (anecdotal evidence). Nonetheless, there is a relative lack of normative data published on Army cohorts, and accordingly, little characterising change over time during basic training. Therefore, this study aimed to describe changes in countermovement jump (CMJ) height in recruits during New Zealand Army basic training. We hypothesised that CMJ height would improve, but this would be constrained to earlier in the course, plateauing in the latter stage.

3.2 Methods

3.2.1 Participants

Participants were a convenience sample of 388 New Zealand Army recruits from two basic training intakes. Prospectively collected primary data were obtained from one intake (Intake A; n = 135 Male, 15 Female; age: Male = 19.70 ± 3.09 years, Female = 19.18 ± 1.03 years; weight: Male = 78.47 ± 11.80 kg, Female = 74.71 ± 10.65 kg), while a pre-existing retrospective dataset (Intake B; n = 204 Male, 34 Female; age: Males = 22 ± 4.12 years, Females = 20.26 ± 3.94 years; weight: 76.08 ± 10.34 kg, Female = 77.66 ± 9.00 kg) was incorporated to supplement and provide a degree of exploratory secondary analysis. All participants were medically cleared and injury-free at the time of testing. Ethical approval was gained through the Auckland University of Technology Ethics Committee (24/248) and the NZDF Ethics Committee. All participants provided informed written consent, with the retrospective cohort having previously authorised the use of their data for future research.

This analysis represents a secondary use of data from a broader study protocol (i.e., Chapter 4), with the present research aims specified after the original data collection plan had been established. Accordingly, no a-priori power analyses were conducted for the present research questions, and while inferential statistics and p-values are reported, interpretation emphasises the magnitude, direction, and precision of effects.

3.2.2 Design and Procedures

A longitudinal observational design was implemented to evaluate the effects of New Zealand Defence Force (NZDF) basic training on neuromuscular performance. In this case, basic training lasted 16 weeks and included a range of different activities, with early phases of basic training spent largely in classroom and garrison environments, learning the basic skills essential to soldiering. The latter portion of the course shifts the focus to more practical and scenario-based training, including live firing and three field exercises. The final 1-2 weeks are spent in preparation for march out, which involves a heavy emphasis on drill. Throughout, regular physical training is conducted, and strict sleep periods are adhered to. In garrison, these were approximately 7.5 hours per night.

Assessments were integrated into the standard training schedule at three intervals: Week 1 (Baseline), Week 8 (Mid-course), and Week 14 (Late-course). Broader assessments were included on entry to basic training (e.g., isometric grip strength) but were not included in this research, nor do we expect they influenced the measurements reported. In the 48 hours leading up to measurements, recruits avoided other strenuous activities until after the final data collection, instead focusing on administrative or classroom tasks. Not all participants from intakes provided data at each time point, which impacted the analytical steps (discussed below).

Preceding each testing period, participants performed a standardised warm-up led by instructors, including submaximal repetitions. Jumps were performed barefoot. After system zeroing, participants had their body weight recorded on the force plates and performed three CMJ trials with their hands fixed on their hips to isolate lower-limb power. Trials were separated by 30 seconds of passive rest. Participants were cued to jump "as high, hard, and fast as possible." Data were captured on an iPad Pro (Apple, Cupertino, California, USA) linked to a set of ForceDecks Lite dual force plates (VALD Performance, Brisbane, Australia) via Bluetooth, sampling at 1000 Hz and interfaced with the VALD Hub cloud-based platform. Jump height was calculated via VALD's in-built software algorithms using the impulse-momentum method (Xu et al., 2023). To maximise sensitivity to neuromuscular changes, average performance scores were utilised (Claudino et al., 2017).

The data from each intake differs in sample size and underlying structure. Broadly, Intake A provided a high degree of data granularity as part of the prospective study. Nonetheless, only a subset of these participants completed all three data collection sessions (approximately one-third), with the broader cohort attending a combination of Weeks 1 and 8 or 1 and 14, due to scheduling and accessibility. Data from a retrospective intake (i.e., Intake B) was integrated for secondary analysis to complement that from Intake A. While Intake B followed identical measurement protocols, data were only available for Weeks 1 and 8. The preliminary structure of the data and organisation is as follows:

1. Mid-term Adaptation (Weeks 1 vs. 8): Combined data from Intake A (n = 38 Male, 9 Female) and Intake B (n = 102 Male, 32 Female)

2. Full Course Adaptation (Weeks 1 vs. 14): Intake A only (n = 96 Male, 11 Females).

3. Serial Adaptation (Weeks 1 vs. 8 vs. 14): A subset of Intake A (n = 38 Male, 9 Female) who completed all testing sessions.

Accordingly, 'serial adaptation' data features as the primary analytical dataset, with the other comparisons considered secondary. Data were initially screened for completeness and duplicates; 131 recruits with missing data at different time points were identified and subsequently removed (Intake A: 41; Intake B: 90). Outliers were defined as values exceeding ± 3 *SD* from the group mean. Each outlier was inspected, and within-subjects variance was used to detect and remove any clearly erroneous data. A total of 16 erroneous data points were identified. From the complete dataset for both intakes (before splitting into separate time courses), Intake A had 2 data points removed (W1: 1, W8: 0, W14: 1), and Intake B had 14 (W1: 9, W8: 5). The final representative sample for analysis was n = 241 (Intake A: n = 107 (Male = 96, Female = 11); Intake B: n = 134 (Male = 102, Female = 32)).

3.2.3 Statistical Analysis

Statistical analyses were conducted using JASP (v0.95.4). Descriptive statistics (*M* ± *SD*) were calculated for bodyweight and jump height. To address our primary aim, a RMANOVA was used with jump height as the dependent variable, and time (Week 1 vs. Week 8 vs. Week 14) as the independent variable. For the RMANOVA, no normality violations were observed ($p = .573$). Sphericity was tested using Mauchly's test; as the assumption of sphericity was met ($p = .718$), uncorrected degrees of freedom were used. RMANOVA effects sizes are reported as partial omega-squared (ω^2p) and interpreted using the following thresholds: < 0.01 = very small; 0.01 <= ES <0.06 = small; 0.06 <= ES < 0.14 = Medium; >= 0.14 = large (Field, 2013). To evaluate performance trends, RMANOVA effects were analysed via pairwise comparisons of estimated marginal means. Rather than relying solely on Holm-adjusted *p*-values, this study focuses on the trajectory of change, providing a more robust interpretation of adaptation across the study duration. Results for post hoc comparisons are reported as mean differences with 95% confidence intervals (CI). Effect sizes were quantified using Cohen's d and interpreted as: trivial (< 0.2), small (0.2–0.5), moderate (0.5–0.8), or large (> 0.8). Statistical significance was set at $p < .05$.

Further to the above, a selection of exploratory analyses were performed based on the data available across the intakes. The original intention was to perform a broader analysis with specific models built to explore the differences over time and whether differences existed between cohorts. However, due to issues with data completeness, we opted to prioritise within-group analysis over time, with differences between intakes at baseline and from week 1 to week 8 included as a secondary and descriptive analysis (weeks 1 vs 8: Intake A, n = 47 and Intake B, n = 134; weeks 1 vs 14, n = 47, Intake A). We planned to address these via independent samples t-test (Welch's), and paired samples t-tests, respectively. However, violations of normality were observed for all comparisons (Q-Q plots and Shapiro-Wilk tests); therefore, Wilcoxon signed-rank tests were employed. For these non-parametric tests, the standardised test statistics (z) is reported, with effect sizes expressed via the Rank-Biserial Correlation (r_B) and interpreted as: 0.10 = small, 0.30 = medium, and 0.50 = large. To provide practical context, differences between time points are described using medians and the absolute change in jump height. Results are presented in the following order: baseline comparisons between intakes, the primary serial time-course analysis (Week 1 vs. 8 vs. 14), and finally the mid-term and full-course paired comparisons. 95% confidence intervals are reported where appropriate.

3.3 Results

The primary RMANOVA for Intake A indicated no statistically significant main effect of Time across the 14 weeks, F(2, 82) = 1.612, with a very small overall effect size (p = .206, $\omega^2 p$ = 0.002). Post-hoc comparisons were not statistically significant (p_{Holm} = > .05 for all) with trivial increases and wide estimates for W1 vs W8 (0.097, CI: -0.343, 0.148, p_{Holm} = .653), W1 vs W14 (0.187, CI: -0.464, 0.091, p_{Holm} = .287) and W8 vs W14 (0.089, CI: -0.351, 0.172, p_{Holm} = .653). Mean estimates for jump height are presented in Figure 2.

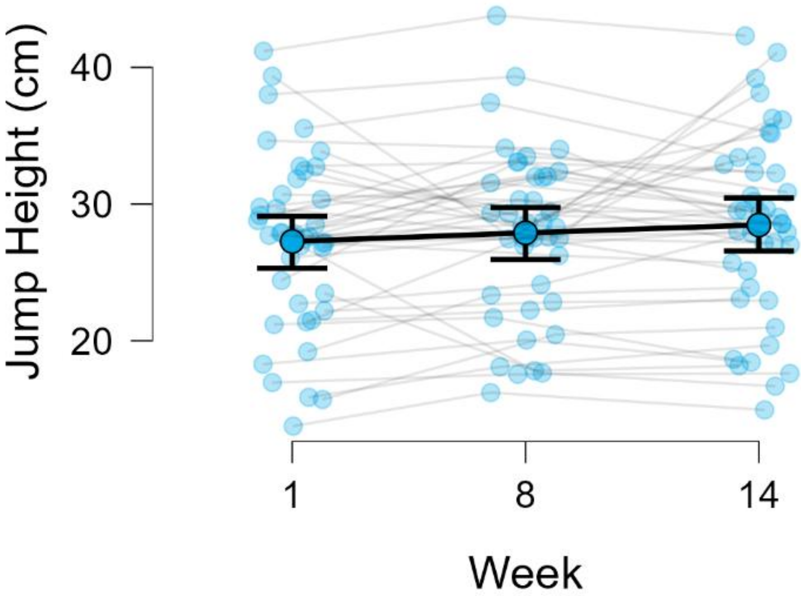

Figure 2. *Change in Jump Height Over Time for New Zealand Army Recruits (Intake A) over 14 Weeks*

The secondary analyses revealed a moderate-to-large difference in jump height at baseline between the two intakes, with Intake A achieving 27.39 cm compared to Intake B at 32.34 cm (d = 0.714, CI: 0.365, 1.060; *df*(91.57) = 4.359, p < .001). Wilcoxon signed-rank tests were conducted between Week 1 and Week 8 for both intakes, and between Week 1 and Week 14 for Intake A. Between Weeks 1 and 8, Intake A showed a moderate increase in jump height of 1.35 cm (r_B = -0.353; W = 365.0, z = -2.106, p = .036). For Intake B, contrasting results indicated a small-to-medium decrease of 0.85 cm (r_B = 0.228; W = 5390, z = 2.272, p = .023). Between Week 1 and Week 14, for Intake A, jump height showed a moderate increase of 1.95 cm (r_B= -0.406; W = 1622, z = -3.595, p < .001). While Intake A demonstrated a moderate increase at both the mid-point and end of the course, Intake B, which started with a higher baseline, showed a small-to-moderate decrease at the mid-point.

3.4 Discussion

This study aimed to describe longitudinal changes to CMJ jump height across New Zealand Army basic training. The results indicate limited support for change over time, although there was some evidence of early-mid basic training improvements in jump height mean estimates (~1.2 cm) for those in one intake, even if potentially explained by the comparatively lower-capability of the cohort. These results may reflect a degree of diminishing returns in more developed recruits, variation in training strategies across cohorts, or regression to the mean.

Intake A achieved a mean jump height of 27 cm compared to Intake B's 32 cm. While there is some variation in the literature regarding normative values of military personnel, Ladlow et al. (2025) report a grouped mean of 28 cm for males and females, with other literature suggesting these values typically exceed 30 cm (Ojanen et al., 2020; Smith et al., 2022b). These roughly cohere with estimates of the wider civilian population, with McMahon et al. (2017) reporting young active men and women exhibited mean heights of 32.1 cm and 24.3 cm, respectively. Accordingly, while the mean values from each cohort are roughly within what might be expected based on these normative values, the magnitude of difference between each is surprising. Given the relatively similar distribution of sexes between the cohorts, it is unlikely that sex influenced these results. The differences between intakes at baseline and week 8 highlight the challenge of interpreting the global impact of basic training, as it may vary by the intakes' entry fitness level, or distribution of sexes. Furthermore, jump height alone, may not serve as a broad enough analysis to understand chronic adaptations. This has implications for the interpretation of changes, discussed below.

This chapter shows limited evidence of changes in jump height, and descriptively different trajectories through week 8. However, it is worth noting that there is variance within the literature for the effects of military training on lower-body neuromuscular power (Burley et al., 2020; Harman et al., 2008; McFadden et al., 2024; Rosendal et al., 2003; Woodhead & Moynihan, 1994). Accordingly, it is possible that adaptations to basic training may not best be captured in simple measures of lower-limb power. The divergent trajectories between intakes at baseline and through to week 8 suggest that Intake A may have benefited from a higher ceiling for adaptation. This leaves greater room for improvement and may partially explain the different outcomes, in addition to potential differences in demographics. Further complicating interpretation, it is probable that basic training is adapted to some degree based on the capabilities of the recruits themselves, amongst other potential reasons for shifts in training focus (e.g., staff with different hierarchies in focus). It is possible that the results also reflect a degree of regression to the mean, as the differences at baseline converge over time between both intakes. Ultimately, utilising more sensitive measures (e.g., either force-data from simple assessments, or other tests) could provide a clearer picture of effects from basic training.

Ultimately, these findings underscore the complicated nature of characterising basic training, and ultimately the probable value of more insightful assessment and individualised benchmarking and monitoring. They suggest that even under a standardised training stimulus, global results can obscure significant, intake-specific physiological responses, particularly when baseline heterogeneity is high. Additionally, the use of more granular metrics (e.g., force plate technology) may facilitate more in-depth comparisons between intakes, making baseline testing valuable for practitioners to individualise training based on group-specific capabilities.

3.5 Limitations and Future Directions

The findings of this study include several limitations that should be considered during interpretation. The training staff adapted the stimulus for Intake A, thereby further complicating any assessment of a standard effect from basic training. Without the presence of any readiness measures, it is impossible to understand what effect this may have had. In addition, countermovement depth was not controlled, and changes in jump height may be explained by shifts in movement strategy. Future research should expand on the snapshot provided in this study by implementing large-scale longitudinal data collection and higher testing frequencies to capture the full effects of basic training on New Zealand Army recruits using a broader range of measures. Given that existing literature highlights performance declines or plateaus, a more granular dataset is required. Additionally, accounting for sex-based differences and relative strength profiles will provide a more comprehensive understanding of recruits' responses to basic training.

3.6 Conclusion and Research Suggestions

In conclusion, these findings highlight that there is likely heterogeneity in jump heights between intakes of recruits, complicating the understanding of the effects of basic training. Primary evidence suggested no clear change; this appears more nuanced. While we observed some changes in another cohort, baseline differences, potential differences in training, and statistical phenomena complicate the interpretation of results. However, it does draw attention to the need for individualised benchmarking and more nuanced monitoring within recruit training, to better understand the effects for each cohort.

Chapter 4: Acute Effects of a Week-Long Field Exercise on Neuromuscular Performance and Fatigue in New Zealand Army Recruits

4.0 Prelude

In Chapter 2, it was identified that certain neuromuscular capacities, such as strength and power, are acutely reduced following strenuous military-specific tasks such as field exercises, taking days to recover. The magnitude of these effects was greater in females, who, on average, carried greater relative loads than males. However, research suggests that the gap between sexes narrows significantly when considering relative fitness levels, as opposed to sex alone. Broadly, the change in neuromuscular capacities across basic training was under-explored. Building on this, Chapter 3 provided broad insight into the change in lower-body power over time, highlighting primarily that there was limited evidence of change (when measured via jump height/simple measurement techniques), but that substantial heterogeneity between intakes likely exists. A conclusion was that more nuanced approaches to assessment and monitoring, whereby more sensitive measures pertaining to jumping strategy may provide greater insight into adaptation (or fatigue). This is bolstered by the finding that many militaries still use traditional, submaximal testing methodologies, which may be unable to detect subtler variations in the expression of change. The purpose of this chapter is to understand how measures of neuromuscular strength and power measured using force plate technology change in response to a week-long field exercise across a 48-hour recovery period (immediately post, 24h, and 48h) while controlling for relative strength. This chapter was originally designed to examine the effects of load carriage alone. However, to encompass a wider array of military-specific training, it was decided that a field exercise, which is noted in the literature to be extremely taxing, was a better approach to ensure the stimuli were difficult enough.

This chapter comprises the following paper, currently in preparation for submission to the European Journal of Sport Science:

McCleary, Sean C., Aaron Uthoff, and Matt R. Cross. “Acute Effects of a Week-Long Field Exercise on Neuromuscular Performance and Fatigue in New Zealand Army Recruits”. *European Journal of Sport Science, In preparation.*

4.1 Introduction

A unique combination of mental and physical demands defines life as a soldier. While modern technological advancements have changed the nature of combat, the fundamental requirement for soldiers to operate in extreme environments remains. Historically, research has focused on load carriage, with mean operational loads at 57kg and peaks around 71kg in Afghanistan (Armstrong et al., 2023). In the field, soldiers regularly experience combinations of environmental exposure, sleep deprivation, caloric deficit and sustained cognitive pressure (Armstrong et al., 2023; Baker et al., 2020; G. E. Giles et al., 2019; Laroche et al., 2023; Looney et al., 2018; Vickery-Howe et al., 2024). To prepare recruits for these demands, militaries utilise initial military training or 'basic training' as the initial preparatory mechanism. Within basic training, field training exercises serve as the culminating stressor, emulating real-world scenarios where recruits must maintain high situational awareness while physically burdened. As the demands placed on recruits during these exercises appear to have risen, so too have injury rates and attrition (Davidson et al., 2008; Murphy et al., 2023). Consequently, identifying the acute effects of the field training environment, beyond just the load carried, is essential for managing injury risk, optimising performance outcomes, and improving attrition rates.

During basic training, recruits are exposed to skills required to be an effective soldier, with a combination of classroom, in-camp, and field environments. As part of this, recruits are gradually exposed to higher physical stressors, which culminate in field training exercises (Burley et al., 2018; Vaara et al., 2022). While there is a significant range in what a field exercise might entail, they typically mimic the responsibilities of real-world operations, which are likely to involve physical activities like load carriage, manual material handling, and casualty evacuation (Burley et al., 2018; G. E. Giles et al., 2019; Vaara et al., 2022). These activities can be conducted in conjunction with, or simultaneously with, tactical manoeuvres or live firing exercises to test recruits' skills. Interrupted sleep and psychological stress (Bulmer, Aisbett, et al., 2022; Larsen et al., 2022) and prolonged caloric deficit (Baker et al., 2020; O'Leary et al., 2020) are commonplace. Combined, these factors can evoke neuromuscular fatigue (Maleček et al., 2023; Tyagi & Mehta, 2021), which is suboptimal for physical function. However, the primary focus is not always on physical performance, and instead, the addition of stressors and fatigue, and the associated physical and psychological tax. This creates a difficult balance of stimuli, which, if not carefully managed, could result in overtraining and subsequently, injury (Kyröläinen et al., 2018; Santtila et al., 2010, 2015; Vaara et al., 2022). This highlights the need to not only understand the effects of field exercises on recruits but to develop effective strategies for monitoring these effects.

The effects of common strenuous activities on soldiers are reasonably well understood (Boffey et al., 2019; Knapik et al., 1996; O'Neal et al., 2014; Vickery-Howe et al., 2024). However, the existing body of literature on recruits is quite scarce and is largely extrapolated from special forces initial military training or full soldiers (Murray et al., 2025). Furthermore, practices (including field exercises) likely vary by military organisation, complicating comparison (Chapter 2). The existing research into recruits has identified that field exercises are the most difficult component of initial training, resulting in measurable decrements in strength and power in addition to muscle damage, which may take up to 96 hours to return to baseline (Heilbronn et al., 2023). While other components, such as load carriage, were shown to inhibit accuracy and reaction times in soldiers during go/no-go tests (Armstrong et al., 2023; G. E. Giles et al., 2019), reduce strength (Grenier et al., 2012; Scales et al., 2021), and increase physiological stress (G. E. Giles et al., 2019; Looney et al., 2018; Vickery-Howe et al., 2024). Strenuous activity performed without sufficient recovery may predispose recruits to possible injury if not appropriately managed (Kraemer & Szivak, 2012). Loading during basic training is comparable to that of professional athletes (Jurvelin et al., 2020), and the lack of specific preparation leading into basic training may explain injury rates being around 30% (Murphy et al., 2023) or higher (M. Robinson et al., 2016). Reports from the New Zealand Army are similar, with significant injury rates, particularly of the lower limb (Hall et al., 2022), and are five times higher when compared to full soldiers (Davidson et al., 2008). This highlights the importance of gaining a greater understanding of the effects on recruits to identify strategies to improve their tolerance to the demands of soldiering and, accordingly, manage injury risk.

Despite the integration of sex-neutral standards across many modern militaries, a significant disparity in injury risk remains. Research consistently indicates that female recruits experience injury rates that are often two-fold higher than their male counterparts during basic training (Bell, 2000). This gap is frequently attributed to the application of absolute loading standards in a mixed-sex environment, where both males and females are exposed to identical task demands (Varley-Campbell et al., 2018). In the context of a field exercise, these absolute demands, such as 30kg of additional load or standardised pace, can translate into a significantly higher relative physiological strain for many female recruits (Armstrong et al., 2023; Schram et al., 2024; Vickery-Howe et al., 2024), who typically enter at lower levels of cardiorespiratory fitness, strength and power than their male counterparts (Blacker et al., 2009; Nindl et al., 2016; Varley-Campbell et al., 2018). Accordingly, disparities in strength may plausibly explain physiological stress and fatigue, rather than biological sex alone (Hunter et al., 2023; Saner et al., 2024). When physical qualities are accounted for, the gap in performance and injury risk narrows remarkably (Ladlow et al., 2026; Saner et al., 2024). Therefore, the "staggering" injury disparity likely reflects the extreme physiological tax placed on recruits who must operate at a higher percentage of their relative maximal capacity to meet the same absolute training benchmarks.

Understanding how stressors manifest during multifaceted tasks like field exercises is critical for practitioners seeking to manage individual fatigue and preserve the health of the entire force. Historically, physical readiness monitoring during initial military training has relied on rudimentary field tests, such as timed runs or bodyweight repetitions. While easy to administer, these metrics often lack the sensitivity to detect subtle physiological shifts, a limitation traditionally dictated by the high cost and poor portability of laboratory-grade equipment. However, the emergence of portable force plate technology has provided a pragmatic solution for objective, high-fidelity monitoring in field environments (Bishop et al., 2023). By measuring ground reaction forces during standardised movements like the vertical jump, force plates quantify specific neuromuscular qualities with superior sensitivity to change compared to traditional performance markers (Alba-Jiménez et al., 2022), such as manually recorded vertical and horizontal jumps. This sensitivity is particularly relevant following a field training exercise, often requiring an extended time course to return to baseline (Grenier et al., 2012; Heilbronn et al., 2023; Scales et al., 2021). To capture this recovery profile, force plates provide two distinct categories of data: output and strategy. While “output” metrics (e.g., jump height, peak power) measure the final result of a movement, “strategy” metrics (e.g., time-based variables) reveal the underlying biomechanical methods utilised to achieve that result (Bishop et al., 2021; Ladlow et al., 2025). In fatigued states, a recruit may work "harder" or "differently" to achieve the same output result (Bishop et al., 2023; Ladlow et al., 2025). Consequently, monitoring both variables in response to field training exercises offers a more comprehensive lens into a recruit’s true readiness and the lingering "hidden" fatigue that traditional testing would likely overlook. This requires minimal time and familiarity to conduct reliably (Collings et al., 2024; Hoffman & Kang, 2002; Ishida et al., 2023; Merrigan et al., 2020; Merrigan, Stone, Hornsby, et al., 2021), which is a necessity for military practitioners managing large cohorts and tight schedules.

With advances in technology facilitating the access to potentially more insightful measurement, this study sought to investigate the acute effects of basic training on New Zealand Army recruits by monitoring changes in key performance metrics for isometric strength and jumping output and movement strategy pre, immediately after, 24 and 48 hours after a 7-day field exercise to determine how these variables change in response to a fatiguing activity, over time. Further, we sought to determine if these responses differ between male and female recruits when adjusting for baseline relative maximal isometric strength. It was hypothesised that both strength and power would be reduced immediately post-exercise, with jumping strategy-based metrics showing the greatest change, which would persist up to 48 hours post-exercise, with inconsistent differences between sexes.

4.2 Methods

4.2.1 Design and participants

This study implemented a repeated-measures longitudinal observational study to explore the effect of an army recruit field exercise instance on the kinetic measures extracted from a countermovement jump (CMJ) and an isometric mid-thigh pull (IMTP), characterising explosivity and strength, respectively. The field exercise lasted seven days in duration, with measurements completed pre- and three follow-up measurements post.

The participants for this study were recruited as a sample of convenience from a New Zealand Army recruit course. Forty-nine army recruits (Males = 40, Females = 9) with a mean age: Male = 20.69 ± 2.87, Female = 21.14 ± 3.25 years, and weight: Males = 78.42 ± 11.22 kg, Females = 73.73 ± 9.38 kg. Given the feasibility-based nature of recruitment, we performed a formal sensitivity analysis based on an anticipated sample of n = 100 (per historical recruitment records and probable participant access), with 80% power and α = .05, within a repeated-measures ANOVA framework (using *pwrss* (Bulus & Jentschke, 2025)) with four repeated measures. Accordingly, we estimated the design and sample size would feasibly allow the detection of effects > eta squared of .013, which was considered reasonable and interesting per similar research investigating fatiguing protocols following military training (Barrett et al., 2024; Kozinc et al., 2023; Ojanen et al., 2018). However, due to unforeseen changes to the training structure and access constraints during basic training, the final sample was considerably smaller and unbalanced. Consequently, the study is likely underpowered, notably in detecting an interaction between time and sex. Therefore, while we present p-values, we prioritise the interpretation of effect sizes and 95% confidence intervals (CI)—particularly in the case of pairwise comparisons between estimated marginal means, which are treated descriptively.

Ethical approval was gained through the Auckland University of Technology Ethics Committee (24/248) and the NZDF Ethics Committee. All subjects provided informed written consent and were made aware of the testing procedures, benefits and risks before participating. Participants were injury-free at the time of testing and had been medically cleared as fit for service as per the requirements of participation in the course.

4.2.2 Procedures

The field activity was completed in the eighth week of basic training. In week 1 of basic training, participants undertook a familiarisation session which included a description of the study protocol and procedures as well as the opportunity to practice the CMJ and IMTP. Testing commenced toward the end of week 8, three days before the seven-day field exercise, and was repeated in week 10 immediately following the exercise, then at 24- and 48-hours post (Figure 3). Participants were barefoot for the data collection. In the 48 hours leading up to baseline testing and post-field exercise, recruits avoided other strenuous activities until after the final data collection. They spent their time conducting pre- and post-field exercise administration.

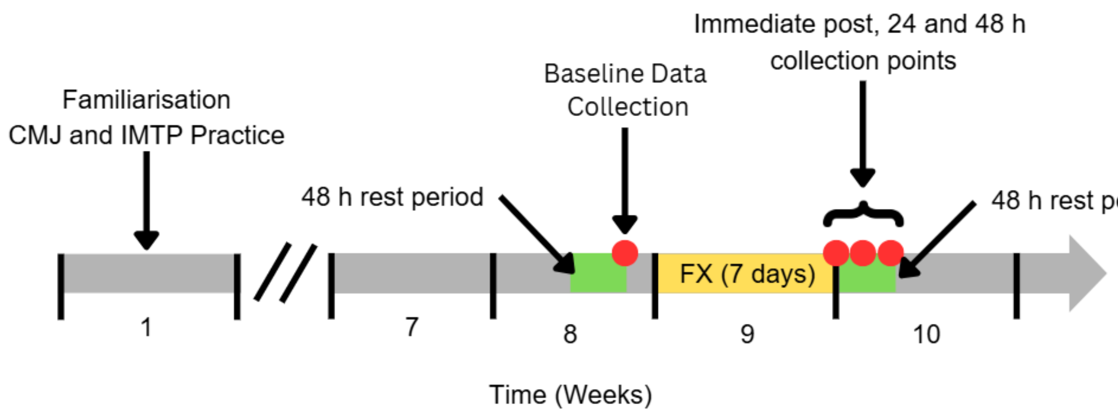

Figure 3. *Experimental Design and Timeline for Familiarisation and Data Collection Sessions*
Note: FX = field exercise

During each testing instance, participants performed several trials of maximal CMJ and IMTP. In each session, a standardised warm-up was completed with the assistance of NZDF physical training instructors, including submaximal repetitions of each of the performance tests used in this study. During testing, participants had their weights recorded in a standard-issue field kit with boots off. This weight was automatically captured prior to each individual commencing the test. All data were collected using an iPad Pro (Apple, Cupertino, California, USA) linked to a set of ForceDecks Lite dual force plates (VALD Performance, Brisbane, Australia), collecting force-time data at 1000Hz and stored in the VALD Hub cloud for further analysis.

4.2.2.1 Countermovement Jump

First, the CMJ was used to as a valid and reliable assessment of jump performance and strategy (Collings et al., 2024; Merrigan, Stone, Hornsby, et al., 2021; Plakoutsis et al., 2023). Participants instructed to stand on the force plates with hands on their hips, and cued to “jump as high, hard, and fast as you can”. Three trials were performed with 30 seconds of passive rest between each trial, and the system zeroed before each. The key variables extracted for further analyses were the flight time:contraction time ratio, eccentric and concentric duration, jump height (impulse-momentum), absolute and relative peak power, and absolute and relative eccentric and concentric peak force. These were used to determine various aspects of neuromuscular performance (Anicic et al., 2023; Bishop et al., 2023; Gathercole, Sporer, et al., 2015a). Variables were pre-selected to directly address the research question whilst maintaining a concise dataset. Where relevant, absolute and relative metrics were included to maximise ecological validity, and reflect the dual physical demands of military operation; for example, managing fixed external loads, such as body armour, weaponry, and equipment, and bodyweight-dependent tasks like sprinting, jumping, and unladen manoeuvring (Maleček et al., 2026). Evaluating both provides a complete profile of a soldier's operational readiness across varying load conditions. All variables were derived from VALD’s in-built algorithms in the ForceDecks software, using a ±20N threshold from the measured body weight to identify the start of movement. Phase identification and impulse-momentum jump height calculations follow established methodologies (McMahon et al., 2018; Xu et al., 2023). Peak power was measured as the maximum power (force × velocity) between movement onset and take-off, while peak force was the instantaneous reading during eccentric/concentric phases. All relative variables were a result of dividing the absolute variable by the participants bodyweight. Additionally, temporal variables, including eccentric/concentric durations and the flight time:contraction time ratio, were derived from specific phase timings. The final average values were used for statistical analysis to maximise sensitivity to neuromuscular changes (Claudino et al., 2017).

4.2.2.2 *Isometric Mid-Thigh Pull*

Following the CMJ, participants performed an IMTP which is a valid and reliable maximal isometric strength assessment (Brady et al., 2018; Comfort et al., 2019; De Witt et al., 2018; Grgic et al., 2022). It was performed without lifting straps on a portable isometric setup where the handle was fixed between the feet via chain link and carabiners (VALD, Brisbane, Australia), with 125 degrees of knee flexion and 145 degrees of hip flexion (Beckham et al., 2018). The length of the chain in this position was also recorded for each participant to ensure standardisation inter-session. Participants were instructed to perform three submaximal repetitions at a self-determined 50%, 70-80% and 90% effort for a total of three seconds each and three five-second maximal trials were performed with 1 minute passive rest between each trial, with the instruction to "pull as hard and as fast as possible" (Brady et al., 2018). Absolute peak force, representing maximal isometric strength, was extracted as the highest instantaneous force value in the identified repetition inclusive of body weight, while relative peak force divided this value by the participants bodyweight. The start of movement was identified using the 5 SD Threshold method, as described elsewhere (Dos'Santos et al., 2016).

4.2.2.3 Field Exercise

The field exercise occurred within the Waiouru Military Training Area, during which weather conditions throughout the week were cold and windy, with daily highs below 10°C and lows of near freezing. It comprised a series of tasks, including marching, fieldcraft, patrolling, and combat scenarios. At the beginning and end of the field exercise, recruits marched to and from their exercise destination for approximately 8 km with an additional load of no less than 17 kg plus carried stores (varying between recruits and not quantified). Once in place, recruits spent time setting up their respective platoon areas. Each night, recruits were placed on sentry duty for up to 2 hours at varying times during the night, resulting in shortened and/or interrupted sleep periods. Activities during the day varied but included patrolling with full kit (180 minutes per day), moving between locations, blank firing combat scenarios, and physical corrective exercise. While unable to fully report activities and accordingly quantify physical exertion, we estimate moderate to high physical and cognitive load in addition to interrupted sleep patterns based on discussions with training staff and previous research (Heilbronn et al., 2023).

Prior to analysis, data were screened; six jumps (each from individual participants) were determined as erroneous, based on implausibility per the surrounding data (from the athletes' other data, and more broadly, other athletes in the dataset, ≥3 SD from the mean). Specifically, in each instance, eccentric durations were twice that of concentric durations, which is atypical (James & Lake, 2021; Kyne & Cronin, 2025; Sarvestan et al., 2018). Ultimately, these were judged as movement or software errors and were removed from the dataset. The remaining data were averaged, with this value used for subsequent analysis. Baseline strength was represented in the variable IMTP relative peak force and was grand-mean centred preceding statistical analysis.

4.3 Statistical Analysis

Statistical analysis was performed using JASP (version 0.95.4). Descriptive statistics (mean and standard deviations) were calculated for participant demographics and outcome variables and are presented in Tables 3 and 4, and visualised in Figures 4 and 5. To address our aim, a series of mixed ANOVAs were built for each dependent variable with baseline relative strength as a covariate (i.e., a mixed RM-ANCOVA), totalling 11 models. Each model had time as a within-subjects factor and sex as a between-subjects factor, and their interaction (sex × time). Models also included an interaction effect for relative strength (relative strength × time), albeit primarily interpreted diagnostically. Following the data removal described below, several models were analysed with a reduced sample size ($n = 43$), while all other dependent variables were analysed using the full sample ($n = 49$).

Preceding model interpretation, data distribution was initially explored using residual plots and Shapiro–Wilk tests, which indicated that most dependent variables were approximately normally distributed within each time point and sex. Sphericity for within-subjects effects was evaluated using Mauchly's test, with several violations identified ($p < .05$). Subsequently, Greenhouse–Geisser corrections were used when violations were substantial ($\varepsilon < .75$), and Huynh–Feldt corrections were applied when violations were mild ($\varepsilon \geq .75$). Variables where corrections were applied are indicated in the results (Table 5) in tandem to appropriate degrees of freedom. Assumptions of homogeneity of variance were assessed using Levene's tests, with minor violations observed for jump height post-exercise ($p = .015$), peak power at baseline ($p = .042$) and at 48h ($p = .010$) and relative peak power post-exercise ($p = .047$). We progressed with these analyses as normal, but given the imbalance in group sizes, the associated analyses should be interpreted critically with these violations in mind. From each model, F-statistics are reported, in addition to effect sizes as $\omega^2 p$. The latter are qualified using the rule of thumb thresholds: < 0.01 = very small; $0.01 \leq \omega^2 p < 0.06$ = small; $0.06 \leq \omega^2 p < 0.14$ = Medium; >=0.14 = large (Field, 2013).

Contrasts between sexes across time points were performed via pairwise comparisons of estimated marginal means (time × sex, at mean relative strength). Magnitude of differences between timepoints are presented in Cohen's d standardised effect sizes and 95% CIs interpreted according to the following criteria: < 0.2 = trivial; 0.2-0.5 = small; 0.5-0.8 = moderate; > 0.8 = large (Cohen, 1988). Raw differences are also presented where relevant, in addition to Holm-adjusted p-values to control for multiple comparisons (and presented for completeness). Statistical significance was set based on an alpha of .05, although applied primarily in the case of the ANOVA tests. Accordingly, the presented sex-specific follow-up contrasts are interpreted descriptively.

Table 3. *Descriptive Statistics (Means ± Standard Deviations) for all Force Plate Output Variables Over All Time Points, Stratified by Participant Sex*

Outcome	Female (n=9)				Male (n=40)			
	M ± *SD*	*M* ± *SD*	*M* ± *SD*	*M* ± *SD*	*M* ± *SD*	*M* ± *SD*	*M* ± *SD*	*M* ± *SD*
	Pre	Post	24h	48h	Pre	Post	24h	48h
Jump Height (cm)	20.43 ± 3.51	19.46 ± 3.43	21.45 ± 6.97	18.91 ± 4.34	30.69 ± 5.38	31.28 ± 7.54	30.03 ± 5.52	30.26 ± 6.79
Ecc. PF (N)	1542 ± 283	1338 ± 227	1380 ± 382	1515 ± 335	1612 ± 342	1264 ± 312	1478 ± 284	1482 ± 274
Con. PF (N)	1613 ± 288	1569 ± 299	1545 ± 349	1717 ± 282	1871 ± 328	1726 ± 293	1771 ± 271	1772 ± 262
Rel. Ecc. PF (N/kg)	20.86 ± 1.95	18.28 ± 2.36	18.82 ± 3.30	20.12 ± 2.83	20.57 ± 3.82	16.19 ± 3.07	18.72 ± 2.87	18.47 ± 2.81
Rel. Con. PF (N/kg)	21.81 ± 1.90	21.30 ± 1.90	21.14 ± 2.53	21.64 ± 2.16	23.90 ± 3.50	22.21 ± 2.64	22.49 ± 2.36	22.36 ± 2.42
Peak Power (W)	2735 ± 363	2644 ± 494	2680 ± 360	2793 ± 230	3809 ± 614	3775 ± 740	3766 ± 689	3767 ± 657
Rel. Peak Power (W/kg)	37.21 ± 3.78	35.92 ± 3.83	37.41 ± 6.46	37.84 ± 6.04	48.61 ± 5.66	48.60 ± 7.91	47.57 ± 6.08	46.87 ± 5.49
IMTP PF (N)	1822 ± 316	2009 ± 376	2000 ± 362	1973 ± 366	2295 ± 433	2337 ± 444	2368 ± 437	2402 ± 440

Note: *M* = mean, *SD* = standard deviation. Pre = baseline, Post = immediate post-test, 24h and 48h = recovery time points. Ecc. = Eccentric, Con. = Concentric, Rel = Relative, PF = Peak Force.

Table 4. *Descriptive Statistics (Means ± Standard Deviations) for all Force Plate Countermovement Jump Strategy Variables Over All Time Points, Stratified by Participant Sex*

Outcome	Female (n=9)				Male (n=40)			
	M ± *SD*	*M* ± *SD*	*M* ± *SD*	*M* ± *SD*	*M* ± *SD*	*M* ± *SD*	*M* ± *SD*	*M* ± *SD*
	Pre	Post	24h	48h	Pre	Post	24h	48h
FT:CT (a.u.)	0.59 ± 0.08	0.48 ± 0.09	0.50 ± 0.10	0.54 ± 0.08	0.65 ± 0.11	0.54 ± 0.12	0.56 ± 0.09	0.56 ± 0.09
Ecc. Duration (ms)	465 ± 59	550 ± 258	491 ± 83	478 ± 82	530 ± 102	555 ± 210	596 ± 118	584 ± 132
Conc. Duration (ms)	245 ± 29	262 ± 39	279 ± 64	252 ± 51	267 ± 48	331 ± 90	296 ± 54	303 ± 72

Note: *M* = mean, *SD* = Standard deviations. Pre = baseline, Post = immediate post-test, 24h and 48h = 24- and 48-hour assessment points. Ecc. = Eccentric, Con. = Concentric, FT:CT = Flight time:contraction time.

4.4 Results

4.4.1 Output Variables

Table 5 presents a summary of results for all output variables, with the means for both sexes visualised in Figure 4. There were small or medium statistically significant main effects of time for eccentric peak force ($F(2.46,113.3) = 9.50$, $p < .001$), relative eccentric peak force ($F(2.38,109.57) = 8.63$, $p < .001$) and IMTP peak force ($F(3,138) = 3.03$, $p = .032$). There was also a small main effect of time for concentric peak force ($F(2.46,113.3) = 4.18$, $p = .012$), albeit in the presence of a higher-order interaction (described below). There were large main effects of sex for jump height ($F(1, 41) = 15.60$, $p < .001$), peak power ($F(1,46) = 18.28$, $p < .001$) and relative peak power ($F(1,46) = 18.29$, $p < .001$). In contrast, no significant main effects of sex for concentric peak force, eccentric peak force, relative concentric peak force, relative eccentric peak force or peak force (IMTP) with very small to small effect sizes. A small time × sex interaction was identified for concentric peak force ($p = .009$). There was a large effect of relative strength for IMTP peak force ($F(1, 46) = 35.56$, $p < .001$), complemented by a small interaction effect with time ($p = .041$).

Pairwise comparisons are presented in Table 6. They indicated negligible-to-small changes in jump height and peak and relative peak power metrics for both sexes. While male estimates were relatively precise, female data were characterised by wide CIs crossing zero. Males demonstrated a larger reduction in eccentric peak force post-exercise that appeared to remain suppressed with a medium effect through 48h, with relatively narrow CIs. Females followed a similar trend but with little certainty around the point estimates. For concentric peak force, males showed a small-to-medium sustained decrease through to the 48-hour mark. The female cohort showed minimal immediate change, but a medium-to-large increase was observed between 24h and 48h (during which CIs exceeded zero). Regarding relative peak eccentric force, males demonstrated a large acute reduction with sustained impairment at 48h, while the female response appeared more moderate and uncertain. Finally, for the IMTP, the male cohort exhibited a moderate, delayed increase at 48h with a precise estimate, whereas the female response suggested a small acute impact followed by a return toward baseline, though high levels of uncertainty persisted.

Table 5. *Overall Analysis of Covariation Model Effects for Performance Outcomes Across Repeated Time Points Pre- to Post-Field Exercise*

Outcome	Repeated-measures ANCOVA				
	Time	Sex	Time × Sex	Relative Strength*	Time × Relative Strength
	p ($\omega^2 p$)	*p* ($\omega^2 p$)	*p* ($\omega^2 p$)	*p* ($\omega^2 p$)	*p* ($\omega^2 p$)
Jump height [a] (cm)	.64 (.00)	< .001 (.25)	.46 (.00)	.19 (.02)	.91 (.00)
Ecc. PF[a] (N)	< .001 (.05)	.87 (.00)	.18 (.00)	.95 (.00)	.73 (.00)
Con. PF[a] (N)	.01 (.01)	.09 (.04)	.01 (.01)	.63 (.00)	.25 (.00)
Rel. ecc. PF[a] (N/kg)	< .001 (.07)	.08 (.04)	.27 (.00)	.16 (.02)	.81 (.00)
Rel. con. PF[b] (N/kg)	.25 (.00)	.24 (.01)	.44 (.00)	.46 (.00)	.45 (.00)
Peak power (W)	.58 (.00)	< .001 (.27)	.62 (.00)	.98 (.00)	.54 (.00)
Rel. peak power (W/kg)	.86 (.00)	< .001 (.27)	.46 (.00)	.11 (.03)	.55 (.00)
IMTP PF (N)	.03 (.01)	.81 (.00)	.58 (.00)	< .001 (.42)	.04 (.01)
FT:CT [a] (a.u.)	< .001 (.07)	.29 (.00)	.83 (.00)	.47 (.00)	.79 (.00)
Ecc. duration[b] (ms)	.52 (.00)	.08 (.05)	.66 (.00)	.79 (.00)	.61 (.00)
Con. duration[a] (ms)	.03 (.02)	.08 (.05)	.16 (.01)	.78 (.00)	.95 (.00)

Note: Effects are reported with partial omega squared ($\omega^2 p$) as the effect size. IMTP = isometric mid-thigh pull, Ecc. = Eccentric, Con. = Concentric, Rel = Relative, PF = Peak force, FT:CT = Flight time:contraction time. [a] = Huynh-Feldt corrected, [b] = Greenhouse-Geisser corrected. *Relative strength was entered as a covariate and corresponds to pre-test maximal force during the IMTP normalised to body-mass.

Table 6. *Post-Hoc Pairwise Differences in Force Plate Output Variables Pre- to Post-Field Exercise*

Outcome	Female (n=9)			Male (n=40)		
	Comparison	*d* [95% CI]	*p*	Comparison	*d* [95% CI]	*p*
Jump height (cm)	Pre – Post	0.23 [-1.02, 1.48]	1	Pre – Post	-0.11 [-0.66, 0.43]	1
	Pre – 24h	-0.11 [-1.05, 0.83]	1	Pre – 24h	0.10 [-0.31, 0.50]	1
	Pre – 48h	0.35 [-0.77, 1.48]	1	Pre – 48h	0.05 [-0.44, 0.53]	1
	Post – 24h	-0.34 [-1.80, 1.12]	1	Post – 24h	0.21 [-0.43, 0.84]	1
	Post – 48h	0.12 [-1.18, 1.43]	1	Post – 48h	0.16 [-0.41, 0.73]	1
	24h – 48h	0.46 [-0.52, 1.45]	.70	24h – 48h	-0.05 [-0.47, 0.37]	1
Ecc. PF (N)	Pre – Post	0.53 [-0.78, 1.85]	.55	Pre – Post	1.16 [0.46, 1.86]	< .001
	Pre – 24h	0.52 [-0.44, 1.47]	.43	Pre – 24h	0.44 [0.000, 0.873]	.003
	Pre – 48h	0.06 [-1.16, 1.28]	1	Pre – 48h	0.43 [-0.13, 0.98]	.02
	Post – 24h	-0.02 [-1.00, 0.96]	1	Post – 24h	-0.72 [-1.22, -0.23]	< .001
	Post – 48h	-0.47 [-1.39, 0.45]	.43	Post – 48h	-0.73 [-1.20, -0.26]	< .001
	24h – 48h	-0.45 [-1.28, 0.38]	.43	24h – 48h	-0.01 [-0.37,0.35]	.94
Con. PF (N)	Pre – Post	-0.01 [-0.70, 0.69]	.98	Pre – Post	0.53 [0.17, 0.88]	< .001
	Pre – 24h	0.25 [-0.63, 1.13]	.69	Pre – 24h	0.34 [-0.07, 0.73]	.03
	Pre – 48h	-0.47 [-1.48, 0.53]	.48	Pre – 48h	0.36 [-0.09, 0.82]	.03
	Post – 24h	0.26 [-0.38, 0.90]	.55	Post – 24h	-0.19 [-0.48, 0.09]	.08
	Post – 48h	-0.47 [-1.20, 0.27]	.18	Post – 48h	-0.16 [-0.48, 0.16]	.18
	24h – 48h	-0.72 [-1.44, -0.01]	.005	24h – 48h	0.03 [-0.27, 0.32]	.74
Rel. ecc. PF (N/kg)	Pre – Post	0.72 [-0.99, 2.44]	.82	Pre – Post	1.45 [0.55, 2.35]	< .001
	Pre – 24h	0.68 [-0.61, 1.98]	.48	Pre – 24h	0.60 [0.004, 1.189]	.003
	Pre – 48h	0.25 [-1.40, 1.91]	1	Pre – 48h	0.68 [-0.08, 1.44]	.006
	Post – 24h	-0.04 [-1.30, 1.22]	1	Post – 24h	-0.85 [-1.48, -0.23]	< .001
	Post – 48h	-0.47 [-1.64, 0.70]	.82	Post – 48h	-0.77 [-1.34, -0.20]	< .001
	24h – 48h	-0.43 [-1.45, 0.59]	.82	24h – 48h	0.08 [-0.36, 0.52]	.54
Rel. con. PF (N/kg)	Pre – Post	-0.01 [-1.00, 0.98]	1	Pre – Post	0.68 [0.18, 1.17]	< .001
	Pre – 24h	0.32 [-0.98, 1.62]	1	Pre – 24h	0.51 [-0.08, 1.10]	.02
	Pre – 48h	0.08 [-1.74, 1.90]	1	Pre – 48h	0.57 [-0.25, 1.39]	.09
	Post – 24h	0.33 [-0.54, 1.19]	1	Post – 24h	-0.16 [-0.54, 0.21]	.46
	Post – 48h	0.08 [-1.44, 1.60]	1	Post – 48h	-0.10 [-0.77, 0.56]	1
	24h – 48h	-0.24 [-1.78, 1.29]	1	24h – 48h	0.06 [-0.61, 0.73]	1
Peak power (W)	Pre – Post	0.14 [-0.69, 0.98]	1	Pre – Post	0.05 [-0.31, 0.42]	1
	Pre – 24h	0.20 [-0.50, 0.91]	1	Pre – 24h	0.04 [-0.27, 0.35]	1
	Pre – 48h	-0.10 [-0.77, 0.57]	1	Pre – 48h	0.07 [-0.23, 0.36]	1
	Post – 24h	0.06 [-0.77, 0.89]	1	Post – 24h	-0.01 [-0.38, 0.35]	1
	Post – 48h	-0.24 [-1.05, 0.56]	1	Post – 48h	0.01 [-0.34, 0.37]	1
	24h – 48h	-0.31 [-1.06, 0.45]	1	24h – 48h	0.03 [-0.30, 0.35]	1

Table 6. *Continued*

Outcome	Female (n=9)			Male (n=40)		
	Comparison	*d* [95% CI]	*p*	Comparison	*d* [95% CI]	*p*
Rel. peak power (W/kg)	Pre – Post	0.23 [-0.96, 1.43]	.82	Pre – Post	-0.00 [-0.52, 0.52]	1
	Pre – 24h	0.15 [-0.87, 1.18]	.48	Pre – 24h	0.13 [-0.32, 0.58]	1
	Pre – 48h	-0.08 [-1.00, 0.83]	1	Pre – 48h	0.28 [-0.13, 0.69]	.15
	Post – 24h	-0.08 [-1.27, 1.11]	1	Post – 24h	0.13 [-0.39, 0.65]	1
	Post – 48h	-0.31 [-1.47, 0.84]	.82	Post – 48h	0.28 [-0.23, 0.80]	.35
	24h – 48h	-0.23 [-1.37, 0.90]	.82	24h – 48h	0.15 [-0.34, 0.65]	1
IMTP PF (N)	Pre – Post	-0.33 [-1.18, 0.52]	1	Pre – Post	-0.18 [-0.55, 0.20]	.36
	Pre – 24h	-0.35 [-1.05, 0.35]	.60	Pre – 24h	-0.26 [-0.58, 0.05]	.03
	Pre – 48h	-0.20 [-0.96, 0.56]	1	Pre – 48h	-0.38 [-0.74, -0.02]	.003
	Post – 24h	-0.02 [-0.66, 0.63]	1	Post – 24h	-0.09 [-0.37, 0.20]	.38
	Post – 48h	0.13 [-0.66, 0.92]	1	Post – 48h	-0.20 [-0.55, 0.15]	.23
	24h – 48h	0.15 [-0.52, 0.81]	1	24h – 48h	-0.01 [-0.41, 0.18]	.38

Note: Effects are reported as Cohen's *d* and 95% Confidence Intervals. Pre = baseline, Post = immediate post-test, 24h and 48h = recovery time points. Ecc. = Eccentric, Con. = Concentric, Rel = Relative, PF = Peak force. Note: P-values adjusted using the Holm correction are based on estimated differences in raw units, whereas effect sizes and associated confidence intervals utilise non-central distributions (and should be interpreted critically given the descriptive nature of the analysis).

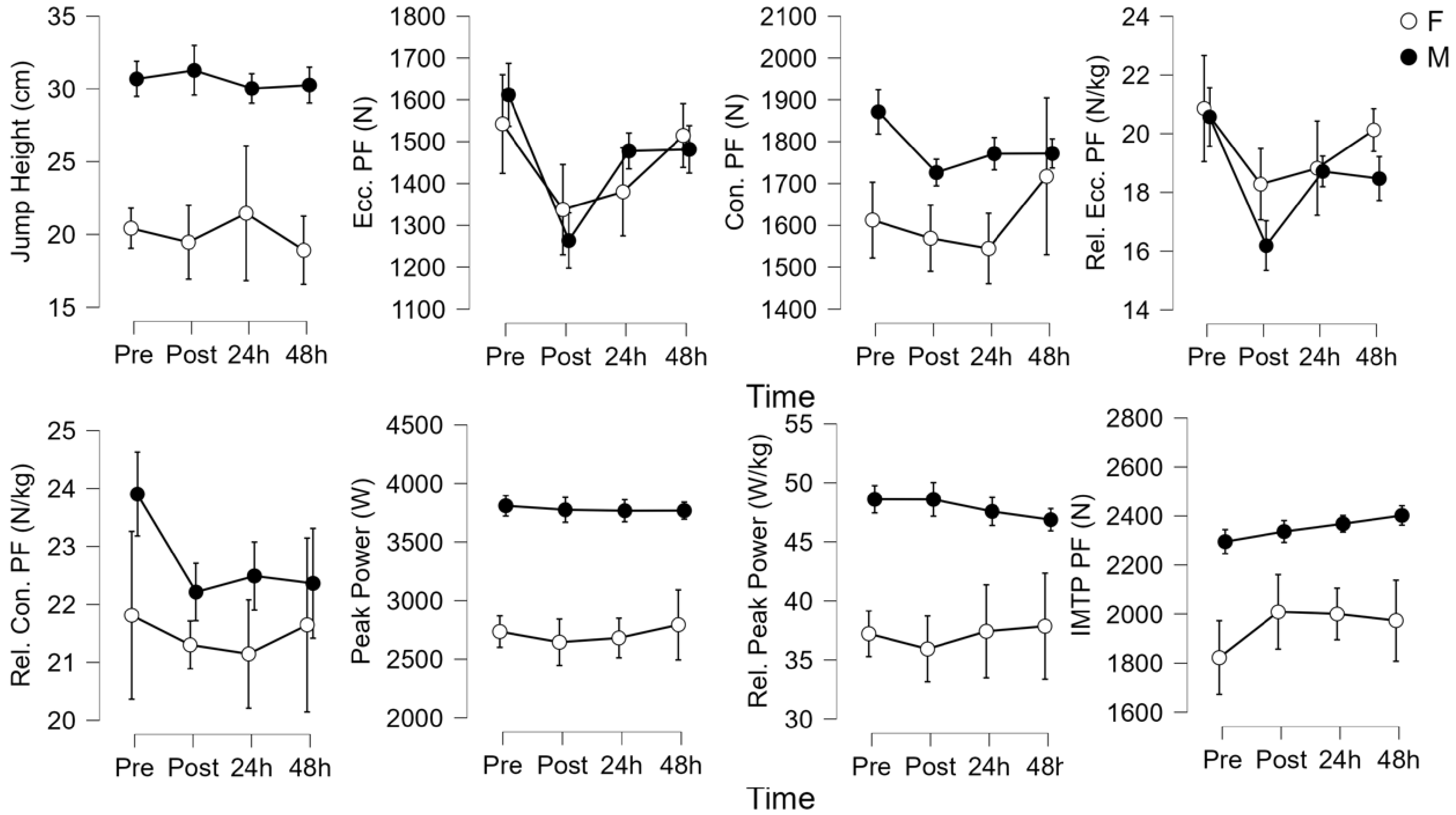

Figure 4. *Change in Force Plate Outcome Variables Pre- and Post-Field Exercise, Stratified by Participant Sex*

Note: Dots correspond to mean estimates with males in solid black and females in open white. Bars correspond to the 95% Confidence Intervals.

4.4.2 Strategy Variables

Table 5 presents a summary of results for all jumping strategy variables, with the means for both sexes visualised in Figure 5. Medium effects of time were observed for flight time:contraction time ($F(2.63,120.77) = 12.20$, $p < .001$) and with small effects for concentric duration ($F(2.41,96.57) = 3.48$, $p = .027$). In contrast, eccentric duration did not change significantly over time ($p > .05$), with no effect size. Furthermore, there were no clear time × sex or time × relative strength interactions, each with trivial-to-small effect sizes. There was no statistically significant main effect of sex or relative strength across strategy variables, with trivial-to-small effects.

Pairwise comparisons for movement strategy are presented in Table 7. For flight time:contraction time, males demonstrated a large immediate decrease that persists through to 48h, with narrow CIs. Females also exhibited a large decrease in mean flight time:contraction time, but with wide CIs indicating considerable uncertainty. Similarly, males demonstrated a large, sustained increase in concentric duration through to 48h. In contrast, the females demonstrated minimal change alongside considerable uncertainty. Eccentric duration increased moderately in males at 24h, albeit in the presence of wide CIs, with female responses highly variable.

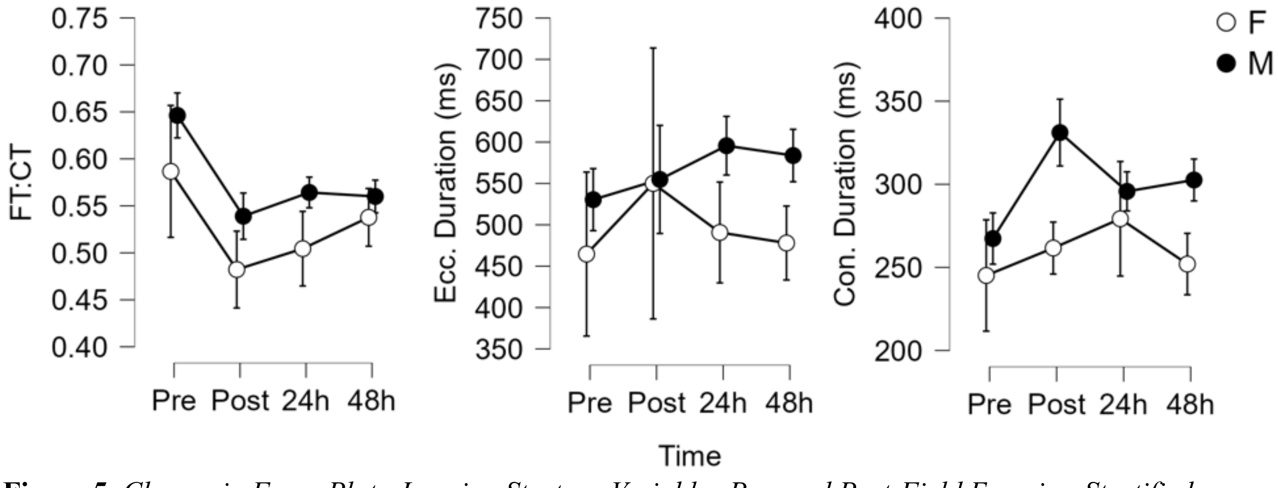

Figure 5. *Change in Force Plate Jumping Strategy Variables Pre- and Post-Field Exercise, Stratified by Participant Sex*

Note: Dots correspond to variable mean estimates with males in solid black and females in open white. Bars correspond to the 95% Confidence Intervals.

Table 7. *Post-Hoc Pairwise Differences in Force Plate Countermovement Jump Strategy Variables Pre- to Post-Field Exercise*

Outcome	Female (n=9)			Male (n=40)		
	Comparison	*d* [95% CI]	*p*	Comparison	*d* [95% CI]	*p*
FT:CT (a.u.)	Pre – Post	0.98 [-0.48, 2.44]	.16	Pre – Post	1.08 [0.36, 1.81]	< .001
	Pre – 24h	0.75 [-0.42, 1.93]	.17	Pre – 24h	0.83 [0.25, 1.41]	< .001
	Pre – 48h	0.55 [-0.64, 1.74]	.51	Pre – 48h	0.84 [0.26, 1.44]	< .001
	Post – 24h	-0.23 [-1.32, 0.87]	.77	Post – 24h	-0.25 [-0.74, 0.24]	.27
	Post – 48h	-0.43 [-1.52, 0.66]	.58	Post – 48h	-0.24 [-0.72, 0.24]	.27
	24h – 48h	-0.20 [-0.98, 0.57]	.77	24h – 48h	0.01 [-0.33, 0.35]	.89
Ecc. duration (ms)	Pre – Post	-0.39 [-2.53, 1.74]	1	Pre – Post	-0.21 [-1.15, 0.73]	1
	Pre – 24h	-0.11 [-1.15, 0.94]	1	Pre – 24h	-0.46 [-0.95, 0.03]	.01
	Pre – 48h	-0.14 [-1.33, 1.04]	1	Pre – 48h	-0.35 [-0.89, 0.19]	.15
	Post – 24h	0.29 [-1.87, 2.45]	1	Post – 24h	-0.25 [-1.21, 0.70]	1
	Post – 48h	0.25 [-1.69, 2.19]	1	Post – 48h	-0.14 [-0.99, 0.71]	1
	24h – 48h	-0.04 [-0.86, 0.79]	1	24h – 48h	0.11 [-0.26, 0.47]	1
Con. duration (ms)	Pre – Post	-0.18 [-1.72, 1.35]	1	Pre – Post	-0.99 [-1.76, -0.22]	< .001
	Pre – 24h	-0.46 [-1.41, 0.50]	.68	Pre – 24h	-0.45 [-0.89, -53.86]	.004
	Pre – 48h	-0.04 [-1.24, 1.16]	1	Pre – 48h	-0.55 [-1.12, 0.01]	.005
	Post – 24h	-0.27 [-1.72, 1.17]	1	Post – 24h	0.54 [-0.13, 1.21]	.02
	Post – 48h	0.14 [-1.06, 1.34]	1	Post – 48h	0.43 [-0.12, 0.99]	.02
	24h – 48h	0.41 [-0.54, 1.36]	.74	24h – 48h	-0.10 [-0.52, 0.31]	.40

Note: Effects are reported as Cohen's *d* and 95% Confidence Intervals. Pre = baseline, Post = immediate post-test, 24h and 48h = recovery time points. Ecc. = Eccentric, Con. = Concentric, FT:CT = Flight time:contraction time. Note: P-values adjusted using the Holm correction are based on estimated differences in raw units, whereas effect sizes and associated confidence intervals utilise non-central distributions (and should be interpreted critically given the descriptive nature of the analysis).

4.5 Discussion

The primary aim of this study was to determine whether neuromuscular strength and power changed following a week-long field exercise, and whether this varied by sex when adjusting for relative strength. Several variables changed over time following the field exercise, including IMTP and CMJ force production and CMJ strategy variables. Indices of jump power (height, relative peak force, and peak power) exhibited negligible changes. There was limited evidence for differences between sexes across most variables. While several key performance indicators remained relatively stable, the CMJ movement strategy appeared to shift. These findings suggest that the global effect of basic training is similar between sexes when adjusting for relative strength.

Of the strength and power output variables assessed in the present study, relatively few appeared to exhibit clear changes in response to the field exercise. Specifically, eccentric, relative eccentric and concentric peak force during jumping, and isometric peak force each exhibited statistically significant changes over time, explaining 10-70% of the variance in the models. Of these variables, only concentric peak force during the CMJ suggested evidence of a clear interaction between sexes, albeit the omnibus test for this factor was limited due to our sample (see limitations). When exploring within groups, male recruits appeared to demonstrate an immediate mean reduction of 302 N that remained suppressed at the 48-hour mark by 99 N. Females exhibited a delayed response, with concentric force production increasing between 24 and 48 hours by 172 N with relatively tight CIs, which contrasted with the high degree of variability observed across all other CMJ variables for females. Other research has noted significant impairments in jump height and power in response to military training (Merrigan, Stone, Martin, et al., 2021; Welsh et al., 2008), suggesting that this is not a global effect. Other metrics, such as eccentric peak and relative peak force, relative concentric peak force, followed a similar descriptive downward trend for both sexes through 48 hours; descriptively, the estimate did approach baseline values, suggesting that mean impairments could persist longer and potentially up to the previously noted 96 hours following similar military activities (Heilbronn et al., 2023). Interestingly, while jump height, and peak and relative peak power remained largely unchanged, IMTP peak force post-exercise increased immediately after the field exercise by 42 N and 187 N for males and females, respectively. This indicates a potentiation effect, particularly in males, whose force production continued to increase at each time point (pre: 1822 N, 48 h: 2402 N). This contrasts with reports of acute strength loss following intensive military tasks (Grenier et al., 2012; Heilbronn et al., 2023; O'Leary et al., 2018; Scales et al., 2021; Vaara et al., 2022), but it aligns with evidence that jump height and peak power may not necessarily capture some instances of neuromuscular fatigue (Bishop et al., 2023). Therefore, the field exercise's long-duration and varied-load profile may have elicited a response distinct from the high-intensity, short-duration carriage tasks typically studied.

The female-specific maintenance of concentric peak force observed in this study may reflect greater fatigue resistance, potentially due to a higher proportional area of Type I muscle fibres (Nuzzo, 2024) and the protective effects of estrogen against exercise-induced muscle damage, potentially enhancing the ability to maintain propulsive force-generating ability (Fitts, 1994; Kendall & Eston, 2002; Westerblad et al., 2010). While there does not appear to be any similar military research controlling for relative strength, one study of British Army recruits found that both males and females suffered a similar loss in vertical jump height following a load carriage task, but that females' knee extension strength experienced a smaller loss compared to males (O'Leary et al., 2018). While this does seem to suggest that females may possess greater resistance to neuromuscular fatigue, it is unclear the degree to which controlling for relative strength might have influenced their results. Nonetheless, differences between our findings and others should be interpreted with caution due to the low sample size. Notably, there was limited evidence that baseline relative strength affected the change over time when included with sex, suggesting that the unique demands of field exercises may override the typical advantages of superior relative strength seen in civilian populations (Behm & St-Pierre, 1998; Jurasz et al., 2022; Kotikangas et al., 2024).

Notable reductions of 0.11 a.u. for in the flight time:contraction time ratio and increases in concentric duration were observed across both sexes immediately after the field exercise, particularly within the male group (males: 64 ms, females: 17ms). While eccentric duration also appeared to increase over time for males (despite high uncertainty), females showed an immediate increase of 85 ms that largely returned to baseline by the 48-hour mark. These findings corroborate existing literature suggesting the effects may be observed past the 48-hour mark (Heilbronn et al., 2023) and that movement strategy is significantly altered in response to strenuous physical activity (Bishop et al., 2023; Hasegawa et al., 2024; Kennedy & Drake, 2017). Notably, flight time:contraction time is a key metric for detecting neuromuscular fatigue, where large changes have been observed following fatiguing activities (Cormack et al., 2008; Gathercole, Sporer, et al., 2015b, 2015a). This is largely driven by extended contraction times, which signifies a slower movement strategy in which both eccentric and concentric durations increase by large and small amounts, respectively (Gathercole, Stellingwerff, et al., 2015). This is of importance as these variables can help practitioners to understand compensatory shifts in movement strategy which may not always be observed in other, primarily output-based metrics.

The observed concurrent reduction in CMJ force production and increased contraction time is a compensatory shift, where recruits utilised a longer force application window to achieve the impulse necessary to maintain gross performance (Gathercole, Sporer, et al., 2015a; Kennedy & Drake, 2017; Kirby et al., 2011). Furthermore, countermovement depth was not controlled, with participants free to choose their own strategy (within the standardisation described in the methods section), it is possible this result may be explained by changes in countermovement depth. Countermovement depth is frequently standardised across trials to control for kinematic variations (Mandic et al., 2015), and in this case may clarified changes observed in our outcome variables. Generally, our data were compatible with quite broad ranges for each variable, and larger sample sizes may elucidate more precise estimates of change. Despite reduced power, moderate-to-large decreases in flight time:contraction time were observed across both groups, a proposed proxy of stretch-shortening cycle efficiency or ‘explosiveness’ (Ebben & Petushek, 2010; Suchomel et al., 2015), suggest reductions in neuromuscular readiness for at least two days post-field exercise.

While gross performance metrics like jump height and peak power remained largely preserved, the underlying mechanics of the movement were significantly altered. The most notable difference between sexes is that females appear to display a greater stability or return to baseline, albeit with a high degree of uncertainty in the results, suggesting a higher degree of resistance to neuromuscular change. However, the marked reduction in the flight time:contraction time ratio and the prolonged concentric duration suggest that recruits adopted a compensatory strategy. This was characterised by lower CMJ force expression, but increased contraction times in an effort to maintain impulse, which directly contributes to jump height (Kirby et al., 2011). This is observed in the wider literature (Bishop et al., 2023; Ladlow et al., 2025) and is similar between sexes. It has also been noted that primary output variables, such as jump height and peak power, may not be sensitive enough to detect changes in performance following fatiguing protocols (Bishop et al., 2023). These 'hidden' changes, characterised by a less efficient stretch-shortening cycle, persisted for at least 48 hours, aligning with recovery timelines observed in similar high-volume military contexts (Heilbronn et al., 2023). Collectively, these findings reveal dissociation between gross neuromuscular output and movement strategy following a military field exercise, with descriptively similar responses between sexes when adjusting for relative strength in most variables. Ultimately, these results underscore that relying solely on basic measures like jump height or power may risk missing neuromuscular changes; leveraging technology (e.g., force plates) to extract variables like jump strategy may be valuable for monitoring the physical toll of military field operations.

4.6 Limitations and Future Directions

The findings of this study should be interpreted alongside several inherent limitations. First, quantifying the specific training demands of the field exercise was complicated by incomplete access to the full training curriculum and inconsistent tracking of external loads. Consequently, our models could not account for individual variations in physical work performed during the field exercise. Future research should seek to better quantify these demands using GPS-derived metrics, heart rate, sleep, and nutritional data to provide a more granular understanding of the physiological strain experienced by recruits. Additionally, exploring further covariates, such as baseline cardiovascular fitness, would clarify the relationship between initial status and training adaptation.

Second, our sample size, notably the female cohort, was smaller than planned. Accordingly, our precision of estimates and statistical power was low. As such, while the results provide insight, notably on the broader effect of field exercises within basic, we caution readers when interpreting both between-sex comparisons and within-sex longitudinal trends (notably the female cohort). Future research should seek to employ a larger sample size to draw more robust conclusions. Further, some effects persisted at the 48-hour mark, where the study concluded, and feasibly were carried into later tasks the recruits were assigned. In this study, countermovement depth was not standardised due to project constraints and adhering to typical military assessment protocol; thus, a portion of the variance in jump metrics may be explained by individual shifts in range of motion. Future research should consider controlling or standardising countermovement depth across trials. Additionally, tracking countermovement depth as a key variable would provide deeper insight into strategy compensations. Therefore, a broader protocol of assessment, utilising key measurements, may be insightful. In this study, we aimed to control for a degree of physical capacity when comparing between sexes; while relative isometric strength is a defensible construct within the constraints of our design, other methods of adjustment (e.g., absolute or dynamic strength) may net different results. Additionally, lifting straps were not worn during IMTP data collection, which introduces grip strength as a potential limiting factor. Finally, given the heterogeneity of training protocols across different military branches and nations, these results may not be directly transferable. Practitioners should consider these branch-specific nuances when applying these findings to alternative cohorts. Because recruits with varying fitness levels likely experience divergent outcomes, future research should seek to understand individual response trajectories and nested data structures.

We attempted to control for strength and provide a more nuanced picture of differences between male and female recruits, using IMTP. Nonetheless, it is possible that other measures may be more insightful, such as dynamic measures of strength (e.g., 1RM) or indeed other physical capacities altogether. Finally, given the heterogeneity of training protocols across different military branches and nations, these results may not be directly transferable. Practitioners should consider these branch-specific nuances when applying these findings to alternative cohorts. Because recruits with varying fitness levels likely experience divergent outcomes, future research should seek to understand individual response trajectories and nested data structure.

4.7 Conclusion and Research Suggestions

In conclusion, the results of this study demonstrate that a week-long field exercise did impact a variety of measures, including those related to force output and movement strategies. While there was evidence suggesting males and females may diverge over time in their response to a field activity, even when adjusting for relative strength, the magnitude and direction of effects over time were comparable in many instances; ultimately, the limited sample size and accordingly imprecise estimates rendered many of the between-sex comparisons inconclusive. From a practical perspective, these results indicate that while the effects of this field exercise on power-related output variables were not necessarily detected, isometric and dynamic force production and movement strategies were altered. This highlights the need for more nuanced methods of monitoring performance and recovery during basic training, so that appropriate and individualised recovery strategies can be employed.

Chapter 5: Going Kinetic: A Soldier's Guide to Profiling and Monitoring Neuromuscular Performance During Initial Military Training with Force Plate Technology

5.0 Prelude

In Chapter 2, it was identified that most militaries tend to follow traditional assessments of neuromuscular fitness, such as push-ups, pull-ups, and sit-ups. These assessments are typically conducted to achieve a minimum standard and may not best capture key neuromuscular capabilities and markers of adaptation and fatigue. Chapter 3 sought to understand the effects of basic training on a simple and accessible measure of jump height from the CMJ. The primary analysis identified that jump height did not change over time, but secondary, single time course analyses showed differing trajectories between intakes, where one had decreased, and the other increased, highlighting the complexity in quantifying the effects of basic training using simple measures. Chapter 4 sought to build on this, providing a more nuanced assessment of neuromuscular strength and power over time, utilising a broader range of variables encompassing both output and movement strategy to understand group-level effects of a field exercise. Like Chapter 3, several primary output variables exhibited unclear or otherwise minor changes over time. However, several CMJ force production and movement strategy metrics differed from baseline up to 48-hours post-field exercise—potentially indicating utility for monitoring. There was relatively limited evidence for varying changes over time between the sexes when controlling for baseline strength, even if detection was limited by the design. This highlights the impacts of a specific portion of basic training and suggests that more granular assessments may provide greater insight into recruits' neuromuscular readiness. A key limitation of both chapters, in a practical sense, is the ability to detect individual-level responses and act accordingly. The purpose of this chapter is to combine the learnings of the preceding chapters and provide a commentary for implementing group and individual-level neuromuscular profiling and monitoring protocol within military personnel, to enable practitioners and researchers to optimise performance and reduce attrition.

5.1 Introduction

High injury rates among military recruits during basic training are a direct consequence of unmanaged load. Initial Military Training (i.e., ‘basic training’), is a high-stress environment, pushing recruits to their physical and cognitive limits (Ahn et al. 2020; Blacker et al. 2009; Bulmer, Drain, et al. 2022; Kyröläinen et al. 2018; Laroche et al. 2023). However, this compressed development often leads to sudden increases in load (Andersen et al. 2016), stress (Bulmer, Aisbett, et al. 2022), sleep deprivation (Larsen et al. 2022), and limited recovery, which is not always carefully managed (Kyröläinen et al. 2018; Michael et al. 2022). This results in high injury rates, where up to one-third of recruits sustain musculoskeletal injuries (Jones et al. 1993; Murphy et al. 2023), a rate significantly higher than in trained soldiers (Hall et al. 2022; Murphy et al. 2023), which creates a financial and readiness burden (Andersen et al. 2016; Molloy et al. 2020). Therefore, it is critical that militaries adopt testing protocols to profile and monitor neuromuscular performance to mitigate the costly effect of unmanaged load.

There is evidence that entry fitness levels are a primary risk factor for sustaining an injury during the course of basic training (Knapik et al., 2012; Kraemer & Szivak, 2012; Mala et al., 2015; Vaara et al., 2022). To assess entry fitness, militaries still tend to use traditional methodology, typically centred around muscular endurance (McCleary et al., 2026) (Chapter 2). However, strength and power have been shown to be important qualities to optimise soldiers performance (Knapik et al., 2012; Kraemer & Szivak, 2012; Mala et al., 2015; Vaara et al., 2022) and prevent injuries (B. H. Jones & Knapik, 1999; Kaufman, 2000; Orr et al., 2020). Furthermore, these traditional assessments may fail to capture subtle shifts in performance as a result of fatigue, which manifests as reduced voluntary activation and motor control (Akbar et al., 2022; Scott et al., 2006; Tornero-Aguilera et al., 2022). Although military tasks often cause an acute reduction in performance (Armstrong et al., 2023; G. E. Giles et al., 2019), fatigue accumulates when recovery is insufficient, resulting in overtraining (Bullock et al., 2010; Knapik et al., 2013; Maupin et al., 2019). A key limitation of more advanced testing protocols being used during recruit courses is the difficulty of testing large groups efficiently. This likely explains the focus on relatively simple measurement protocols used in the military characterising personnel over time (McCleary et al., 2026) (Chapter 2). Recent advances in technology have made testing neuromuscular performance significantly more accessible to profile and monitor recruits. Profiling can be defined as testing to understand the current neuromuscular capacities of a recruit, whereas monitoring is the ongoing use of these tests to understand a recruit's current state of readiness or adaptation to a training stimulus (Bishop et al., 2023).

Force plate technology is emerging as an affordable, portable, lightweight, non-invasive, and easy-to-operate method of testing. They can provide rapid insight into participants' performance (McMahon et al., 2018; Welsh et al., 2008) with exceptional reliability and validity (Cabarkapa et al., 2025; Collings et al., 2024; Grgic et al., 2022; McMahon et al., 2018; Plakoutsis et al., 2023). Additionally, they offer insight into a vast selection of metrics, which are important to understand not just how high a recruit can jump, but also the strategy that underpins how they move (Ladlow et al., 2025; Merrigan et al., 2020; Merrigan, Stone, Martin, et al., 2021; C. Williams et al., 2025). The use of force plates has been discussed in similar articles, notably by Ladlow et al. (2025) and Merrigan et al. (2021), who each provided reviews of the current methodology utilised in military settings. This chapter aims to build on and add to similar works by providing a practical commentary for implementation, specifically within recruit training.

While their use is still limited in recruit settings, the isometric mid-thigh pull (IMTP) and countermovement jump (CMJ) are common tests to quickly assess maximal isometric strength and dynamic lower body power, which are both critical for military-specific performance such as load carriage, manual material handling, and casualty evacuation (Knapik et al., 2012; Mala et al., 2015; Vaara et al., 2022). Popular for their ease of implementation, but also for their ability to detect changes in performance and monitor potential fatigue accumulation (Anicic et al., 2023; Bishop et al., 2023). The IMTP is a full-body maximal isometric test used to quantify maximal strength. The CMJ is widely considered one of the premier assessments of the stretch-shortening cycle (SSC) (Ladlow et al., 2025; McMahon et al., 2018; Merrigan et al., 2020; C. Williams et al., 2025), which is required for jumping over obstacles or manoeuvring during close-quarters combat, in addition to its preference as a tool for monitoring neuromuscular fatigue (Alba-Jiménez et al., 2022; Badby et al., 2025). Both can be quickly administered with minimal familiarisation and provide valid and reliable results (Collings et al., 2024; Hoffman & Kang, 2002; Ishida et al., 2023; Merrigan et al., 2020; Merrigan, Stone, Hornsby, et al., 2021). This positions them as an excellent option for understanding recruits' neuromuscular strength and power capabilities.

Given the lack of current guidance or standardisation of a neuromuscular profiling and monitoring protocol in recruit training and how previous literature has highlighted the importance of such protocols to avoid maladaptive training and musculoskeletal injury (Ladlow et al., 2026; Merrigan, Stone, Martin, et al., 2021), it seems pertinent to provide a practical commentary for implementing a system that allows for efficient and reliable assessment of performance in large groups of recruits for fast insights, allowing practitioners to make more informed and individualised decisions on recruit readiness. Accordingly, understanding sex-based nuances is particularly critical when evaluating fitness and training responses. Research indicates that females operate at a higher relative effort compared to males in military training (Armstrong et al., 2023; Schram et al., 2024; Vickery-Howe et al., 2024). This disparity likely contributes to the substantially higher injury rates in female cohorts (Bell, 2000; Hall et al., 2022). Nonetheless, the literature indicates that targeted improvements in strength may help to narrow this gap (Hunter et al., 2023). By contextualising force-plate derived neuromuscular performance metrics from the CMJ and IMTP, this chapter aims to provide an evidence-informed, profiling and monitoring guide to enhance decision making, reduce injury risk, and improve recruit readiness at both the group and individual level. It will provide an understanding of force-time data, procedures for testing, and data management and interpretation strategies.

5.2 Force Plates in Neuromuscular Performance Testing

5.2.1 Understanding force-time variables

Force plates measure ground reaction forces over time to calculate key biomechanical metrics like power, velocity, and momentum (Collings et al., 2024). These data points create force-time curves, visual maps of an individual's movement strategy. While insightful, the granularity of force-time curves lacks the scalability required for high-volume settings (Bishop et al., 2021). Rather than analysing full curves, practitioners typically streamline data into three key metric domains for a performance "snapshot", explained in Table 8.

Table 8. *Classification and Definition of Force Plate Metric Categories*

Category	Description
Output	Performance or task outcome metrics (e.g. jump height, peak force)
Strategy	Indicators of *how* an output was achieved, usually involving time, velocity or displacement (e.g. time to take off, countermovement depth)
Asymmetry	Inter-limb differences spanning both output and strategy metrics

During dynamic movements, these variables are often categorised by phases of the movement, such as eccentric, concentric and landing (McMahon et al., 2018). The goal is to avoid redundancy by selecting a battery of metrics that provide a holistic view of the participant's current state while avoiding strongly correlated variables which effectively give you the same information (Bishop et al., 2021).

This multifaceted approach is critical for ongoing monitoring. Research indicates that a participant's absolute output may remain stable, even under significant fatigue; however, their underlying movement strategy may shift (Bishop et al., 2023; Hasegawa et al., 2024; Kennedy & Drake, 2017; Ladlow et al., 2025), which may provide a more nuanced expression of changes in neuromuscular function. These compensatory changes typically manifest as reduced movement velocity, rate of force development, and/or increased contraction times (Bishop et al., 2021, 2023; Ladlow et al., 2025). Furthermore, asymmetry is often tracked to monitor training responses and can be quite easily measured with force-plate technology. Fatigue may increase inter-limb asymmetry due to a shift in loading to the dominant or less fatigued limb (Gao et al., 2022). Although asymmetry is often tracked to monitor training responses, it is excluded from this commentary. Research indicates that baseline asymmetry does not reliably predict injury risk (Merrigan et al., 2020) or unilateral CMJ performance (Bishop et al., 2022), unilateral tests may detect fatigue-induced imbalances (Janicijevic et al., 2023). Further, unilateral tests may be impractical for large-scale military testing. Moving forward, this commentary prioritises more robust, scalable markers of performance and readiness, while acknowledging that asymmetry could be interesting to monitor for changes over time, potentially as a maladaptive response.

5.2.2 Which variables to use

Modern force plates offer access to substantial data; this can lead to a form of "paralysis by analysis", and selecting appropriate variables is critical. Evidence specifically targeting neuromuscular testing using force plates in military recruits is scarce, with most available literature focused on graduated soldiers and draws upon research from civilian or athletic populations. However, Ladlow et al. (2025) present a scoping review of current methodologies used in global militaries for both the IMTP and CMJ. The discussed methodologies align with the metrics presented in Chapters 3 and 4. This section synthesises information from the preceding chapters paired with wider literature to provide a selection of appropriate metrics.

The IMTP is simple, regularly reported as reliable, and can be conducted using several technologies (e.g., strain gauges and portable dynamometers) (Comfort et al., 2019; Montoro-Bombú et al., 2023; Pichardo et al., 2024; Till et al., 2018). There is substantial guidance on the appropriate practical implementation and associated analysis of data from the test (Comfort et al., 2019). Notably, the

IMTP force-trace ideally follows a "tabletop" shape characterised by a weighing, pre-tension and rapid initiation of a maximal contraction, maintained for a predetermined period (Figure 6).

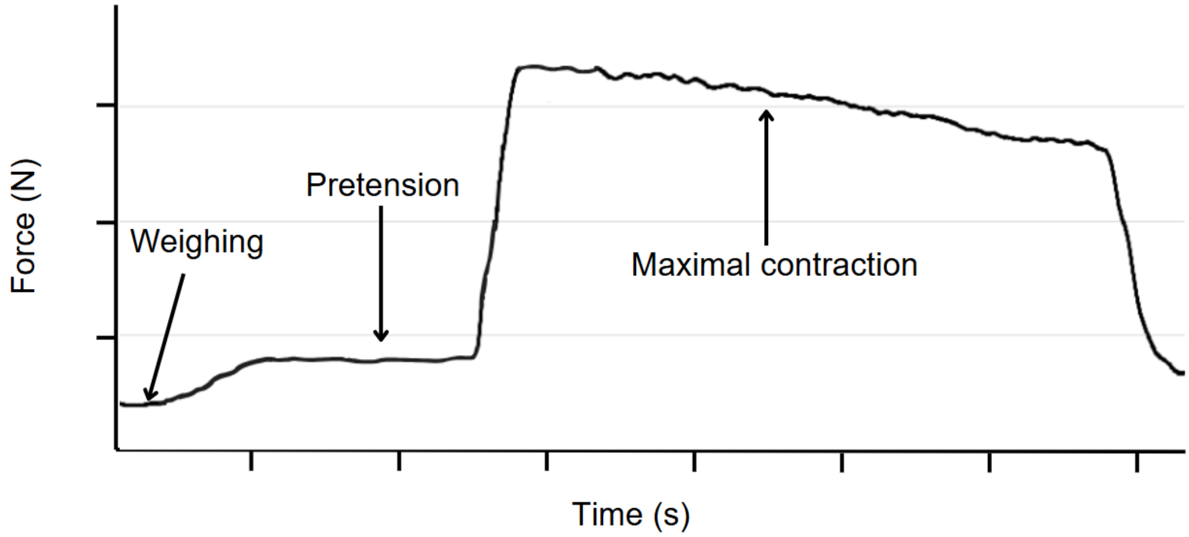

Figure 6. *Characteristic Force-Time Curve and Phases of the Isometric Mid-Thigh Pull for Illustrative Purposes (Recorded by the Author)*

Because the IMTP is primarily used to quantify maximal isometric strength output, peak force (absolute/gross force) is the most commonly used metric (G. Giles et al., 2022; Ladlow et al., 2025; McCormick et al., 2022; Merrigan et al., 2020). Net peak force (force above body weight) is also a common metric, typically used when practitioners want to eliminate the passive influence of body weight to isolate neuromuscular capacity, track changes is the presence of body composition change, or enhance reliability of rate of force development variables (Comfort et al., 2024). However, research shows that in a tactical context, using absolute measures may better reflect task performance when external loads are present (Maleček et al., 2026). Accordingly, for recruits it can be used to provide an understanding into maximal strength, which is important for injury prevention and directly correlated to enhanced performance in military-specific tasks (Knapik et al., 2012; Kraemer & Szivak, 2012; Lauersen et al., 2018; Vaara et al., 2022). However, to ensure the data is comparable across a diverse recruit cohort, including between sexes, these values may be normalised by body weight (N/kg). This allows practitioners to apply standardised benchmarks and identify those who may be lacking in strength, regardless of absolute output (Ladlow et al., 2025).

The CMJ is a complex dynamic movement used to understand lower-body power. Research has shown the importance of lower-body power in a military setting, as it may help soldiers manoeuvre around the battlefield, be more resilient to injury, and enhance performance in tasks such as load carriage (Knapik et al., 2012; Ladlow et al., 2025; Mala et al., 2015; Merrigan et al., 2020; Merrigan, Stone, Martin, et al., 2021; Vaara et al., 2022). Typically, it is analysed across six distinct phases: weighing, unweighting, braking, propulsion, flight and landing phases (McMahon et al., 2018), see Figure 7. While terminology may vary across force plate manufacturers, a precise understanding of these phases is required to differentiate between a participant's gross output and movement strategy. CMJs can be performed in both loaded and unloaded conditions. While unloaded jumps provide a baseline measure of explosive power, the inclusion of loaded variants allows for the development of load- or force-velocity profiles specific to conditions that soldiers may find themselves in (Merrigan et al., 2020). For standardisation, loads should remain constant using equipment like body armour (Merrigan, Stone, Martin, et al., 2021). This can offer greater insight into an individual's performance under load; however, in recruit environments, this may not always be feasible given expected time constraints.

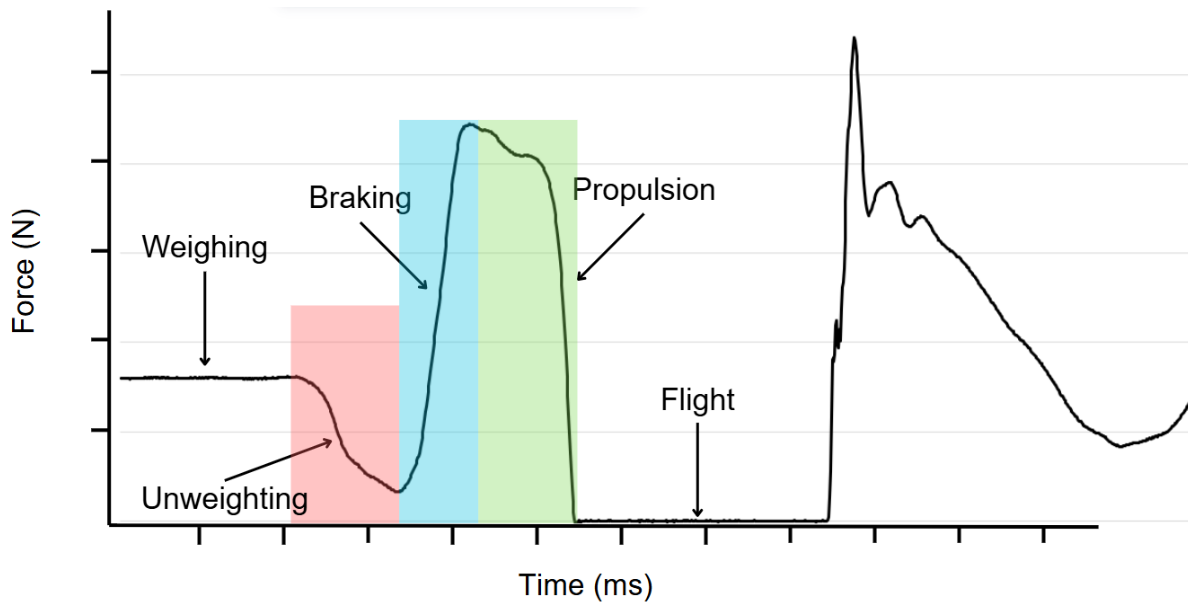

Figure 7. *Characteristic Force-Time Curve and Phases of the Countermovement Jump for Illustrative Purposes (Recorded by the Author)*

While the literature reports a wide array of CMJ metrics, there is a clear consensus on the importance of tracking both output and strategy, as presented in Chapter 4. Examples include jump height, phase-specific absolute and relative peak power, phase-specific peak or mean force, phase-specific absolute and relative impulse and strategy variables like flight time:contraction time (or similar e.g., RSI modified), phase-specific duration, countermovement depth, flight time, time to take off, and time to peak power (Bishop et al., 2023; Gathercole, Sporer, et al., 2015b; Ladlow et al., 2025; Merrigan et al., 2020; Merrigan, Stone, Martin, et al., 2021; C. Williams et al., 2025). An emerging metric of interest not discussed in previous chapters is eccentric peak velocity; it may provide an 'early warning' of neuromuscular fatigue during the braking phase and acts as a data hygiene marker to ensure recruits are performing the eccentric portion of the jump with intent, where values exceeding -1.2 m/s signify appropriate intent and valid trial data (Cohen et al., 2020). To ensure the guidelines are actionable for large cohorts, it is necessary to distil these variables into a concise battery that captures the most significant changes in performance and readiness. A summary of the metrics presented in Chapter 4 and their significance are included in Table 9.

Table 9. *Selected Force Plate Output and Strategy Variables Recommended for a Proposed Soldier's Guide*

Category	Recommended Metric	Practical Significance
Output	Jump height	A primary measure of explosive capacity.
	Relative peak power	Normalised explosive output to body mass; key for cohort benchmarking.
	Eccentric/concentric peak force	The maximum gross force achieved during the specific phase.
	Relative peak force (IMTP)	Peak force output normalised by bodyweight.
Strategy	FT:CT	A measure of movement efficiency and springiness.
	Eccentric/concentric duration	Time spent in the specific phase.
	Eccentric peak velocity	Evaluates the speed of the braking phase and intent in the movement.

Note. Jump Height uses the impulse momentum method. FT:CT = flight time:contraction time)

5.3 Methodology

5.3.1 Before you begin

Place force plates on a stable, non-slip surface. Ensure all load cells maintain full ground contact. Due to the sensitivity of some metrics, a sampling frequency of 1000Hz is recommended (Comfort et al., 2019; Haff et al., 2015; Owen et al., 2014). Conduct a standardised dynamic warm-up. This should include submaximal trials of the IMTP and CMJ (at 50, 70 and 90% effort). This improves reliability and prevents data misinterpretation (Brady et al., 2018; Merrigan, Stone, Martin, et al., 2021). Record body weight during a 2-3 second quiet stand. This "first line of defence" is essential for identifying movement phases and key metrics. The start of movement identification is also important. While many different methods exist, historically, the 5 SD threshold method was recommended for both the IMTP and CMJ (Comfort et al., 2019; Owen et al., 2014), but more recent literature suggests that the first derivative or "yank-time" method might be more accurate for the CMJ (Pinto & Callaghan, 2023; Sahrom et al., 2020) while the IMTP retains the 5 SD Threshold method.

5.3.2 Cuing and standardisation

Effective cuing and standardised motivation are essential for ensuring maximal participant intent and data reliability (Comfort et al., 2019). For the IMTP, instructing participants to "pull as hard and as fast as you can" optimises both peak force and rate of force development (McCormick et al., 2022), while the CMJ requires a similar "jump as hard and as fast as you can" cue to maximise height and velocity. To maintain consistency, practitioners should provide verbal encouragement and may use peer competition to increase buy-in (Lonergan et al., 2025). Although a self-selected depth is commonly used in practical settings, standardising range of motion across experimental trials is necessary to prevent artificial fluctuations in jump metrics driven by changes in displacement (Mandic et al., 2015).

5.3.3 Repetitions and rest

To maintain maximal, unfatigued performance, trial and rest protocols should balance practical time constraints with physiological recovery. Ideally, a minimum of 48 hours of rest is allowed prior to neuromuscular assessment to ensure peak performance and mitigate confounding fatigue (Comfort et al., 2019; Kennedy & Drake, 2017). However, in tactical populations, operational demands and training schedules often preclude ideal recovery timelines. While a standard rest window is recommended, the overriding priority must be protocol standardisation. If operational constraints dictate a compressed rest window, this exact timeframe must be consistently enforced across all subsequent testing sessions to maintain test-retest reliability. For the IMTP, rest periods of 2–3 minutes are recommended between trials (Brady et al., 2018; McCormick et al., 2022). However, in some cases, it may not be feasible due to time constraints (e.g., see Chapter 4, where rest of 1 min between trials was adopted). Alternatively, just 20 seconds is sufficient for the CMJ (Pereira et al., 2008; Rappelt et al., 2026). Across both assessments, performing three to six trials is preferred for ensuring both data reliability and peak performance (Brady et al., 2018; Gathercole, Sporer, et al., 2015a; Kennedy & Drake, 2017; McCormick et al., 2022; Rappelt et al., 2026). For both assessments, averaging across repetitions may be preferred to reduce error when monitoring longitudinal trends (Claudino et al., 2017; Kennedy & Drake, 2021; Keogh et al., 2020).

5.3.4 Frequency and timing

Testing frequency must balance access to equipment and availability with operational constraints. Ideally, profiling occurs in week one (Comfort et al., 2018), once recruits acclimate to intake stressors and before physiological and psychological stressors are added. Chapters 3 and 4 detail longitudinal and acute methods of monitoring, respectively. Longitudinal monitoring (weeks 1, 8, 14) was conducted at the start, middle and two weeks before the end. Aligning with another military study (Santtila et al., 2012). Historically, literature has not used intermediary data points to monitor performance throughout recruit courses (Merrigan et al., 2020; Merrigan, Stone, Martin, et al., 2021). This has been in part due to an over-reliance on simple pre-post measures collected during routine testing. Regular monitoring allows tracking of key performance indicators at the mid-point and toward the end of the course, or between blocks of different physical training. Given the differences in global regimen, these time courses should be adapted to suit the individual needs of the course in question.

Depending on the application of monitoring, the structure of testing will vary. For example, when applied around a specific intensive event, higher frequencies may be necessary as a means of judging time-course of fatigue. For example, in Chapter 4, recruits were measured before, then immediately, 24 and 48 hours after a field exercise. While the experimental nature of this study necessitated intensive testing in terms of characterising the impact of the field exercise, such testing is likely both infeasible and lacks practicality for decision making in a recruit training course. As Chapter 4 identified, adaptation, likely as a result of fatigue, persisted at the 48-hour mark, suggesting that recruits took longer to fully recover (Heilbronn et al., 2023). Therefore, follow-up testing designed to understand readiness may be conducted 48 – 96 hours post activity (Merrigan et al., 2020; C.

Williams et al., 2025). This method helps to understand pre-post activity recovery to ensure that training does not recommence with recruits under recovered (Merrigan, Stone, Martin, et al., 2021).

For routine monitoring, the CMJ is recommended on a weekly or intra-weekly basis (Badby et al., 2025; Merrigan, Stone, Martin, et al., 2021), allowing for the more time-intensive IMTP to be used less frequently and to coincide with the start and finish of training blocks (Comfort et al., 2018). To minimise data "noise," testing should follow a period of rest to allow reasonable recovery (C. Williams et al., 2025). Consistent scheduling (i.e., day, time, rest) is essential for longitudinal reliability (Ishida et al., 2023). Table 10 presents a sample strategy for basic training that balances practicality with evidence-based procedures.

Table 10. *Standardised Procedures for the Proposed Profiling and Monitoring Protocol*

Parameter	IMTP	CMJ
Sampling frequency	1000 Hz	1000 Hz
Warm-up	5-minute dynamic warm-up followed by submaximal warm-up repetitions at 50%, 70%, and 90%.	5-minute dynamic warm-up followed by submaximal warm-up repetitions at 50%, 70%, and 90%.
Rest interval	2 minutes	30 seconds
Trials	3 maximal repetitions.	3 maximal repetitions
Start of movement threshold	5 SD threshold method.	First derivative / “yank-time” method
Profiling frequency	Week 1 of basic training.	Week 1 of basic training.
Monitoring frequency	Every 4-8 weeks	Weekly, including 48 hours after high-load periods (e.g. field exercise)

5.4 Data Management and Interpretation Strategy

5.4.1 Establishing baselines

Most commercial force plate providers now synthesise raw force-time data into actionable insights, facilitating immediate oversight of individual and cohort performance without manual calculation. For longitudinal tracking, organisations may adopt custom dashboards using a variety of data management, analysis, and visualisation tools (e.g., Power BI, Tableau, or R) to integrate force data with injury records and training loads. Initial CMJ and IMTP testing establishes individual baselines for strategy variables (e.g., flight time:contraction time) and benchmarks output against normative data. These values must be captured before high-volume fatigue sets in to represent true neuromuscular capacity (Merrigan, Stone, Martin, et al., 2021).

While some literature exists for benchmarking, it remains scarce and is further complicated by heterogeneity, as shown in McCleary et al. (2026) (Chapter 2) and supported by Ladlow et al. (2025). Tables 3 and 4, presented in Chapter 4, provide the means for each sex and dependent variable in this Chapter (except eccentric peak velocity). While normative ranges in the wider literature for military recruits are not available for all variables, common measures of performance, CMJ jump height, relative peak power and IMTP relative peak force do have some data available. In Chapter 4, the means for each were: CMJ jump height, 30.69 ± 5.38 cm for males, 20.43 ± 3.51 cm for females; CMJ relative peak power, 48.61 ± 5.66 W/kg for males and 37.21 ± 3.78 W/kg for females; IMTP relative peak force, 29.57 ± 3.37 N/kg for males, 24.66 ± 4.5 N/kg for females. The values from Chapter 4 largely align with the available literature, albeit placing them comparatively lower, with jump heights ranging in recruit literature between 29.7 and 35.6 cm (Rosendal et al., 2003). In US Marine Corps recruits, relative peak power has been recorded at 49.9 ± 6.2 W/kg in males, and 37.6 ± 4.9 W/kg in females, while for relative peak force in the IMTP sits at 34.6 ± 5.3 N/kg and 27.5 ± 4.6 N/kg, respectively (Friedl, 2024). Recent evidence suggests that recruits achieving greater than 38.4 ± 3.62 N/kg (males) and 30.78 N/kg (females) for the IMTP and 52.52 ± 5.77 (males) and 39.61 W/kg (females) significantly outperformed all those in the lower performing group and had lower injury incidence (Peterson et al., 2024), similar to Lovalekar et al. (2024). Consequently, organisations should collect and benchmark data relative to their specific cohort (Ladlow et al., 2025). This data can then be used to identify if recruits are under- or overperforming and subsequently be used to inform group training. Additionally, recruits falling below intended thresholds can be flagged for targeted physical interventions or musculoskeletal screening to mitigate attrition risk.

5.4.2 Longitudinal trends

Once baselines are established, metrics can be monitored longitudinally to ensure physical adaptations align with program goals. This can be conducted at both group-level (per Chapters 3 and 4) to understand general trends, or at the individual-level to make more targeted interventions when recruits diverge from their expected trajectory. The preceding chapters utilised null hypothesis testing to understand the broad and more nuanced effects of basic training at the group-level (albeit shifting to a descriptive lens). While these methods are essential for characterising the global impact of basic training, and can inform the utility of potential measures, they are inherently limited in their ability to inform individualised interventions. To bridge the gap between group-level trends and individual-level responses, practitioners must adopt a framework that distinguishes the physiological “signal” from measurement “noise”.

Many methods exist for analysing data to track individual responses, and are detailed elsewhere (Andrade, 2021; Gustavo & Wyatt, 2026; Hopkins, 2004; Weir, 2005). Broadly, the collection of summary statistics for detecting individual change are concerned with whether any change is larger than measurement noise and enough to practically matter. One common approach is the consideration of the relationship between the standard error of measurement (SEM) and the minimal detectable change (MDC). This is important to consider when deciding on what “meaningful” changes to the data are. The SEM represents the precision of the measurement itself or the “noise”, while the MDC provides a threshold beyond which an observed change is unlikely to be attributed to measurement error alone (i.e., helping judge “signal”). These values will vary dependant on the specific system being used, cohort and protocol, with examples presented in the literature (Cabarkapa et al., 2025; Collings et al., 2024; Grgic et al., 2022; McMahon et al., 2018; Plakoutsis et al., 2023). A practical concept to track individual-level responses could utilise rolling or exponentially weighted moving averages (e.g., a 28-day window), which can be employed to smooth daily variation (Bourdon et al., 2017). Z-scores are another common means of assessing change, and allow practitioners to normalise disparate scales to facilitate easier comparison (Andrade, 2021; McElreath, 2020). The normalisation to group or individual variation gives insight into whether performance change represents a meaningful physiological shift rather than measurement error.

The Z-score is calculated as:

$$z = \frac{x - \mu}{\sigma}$$

Where:

- x is the current observed value.
- μ is the rolling mean (e.g., 28-day average).
- σ is the standard deviation of that period.

An example of how this can be applied in a practical context is a "traffic light" reporting system for easy communication of readiness (Robertson et al., 2017): Green (Ready) indicated by a $Z > -1.0$; Amber (Caution) between -1.0 and -1.5; and Red (At-Risk) at $Z < -1.5$ (Turner et al., 2019). In this context, negative values represent a decline in performance, potentially reflecting accumulated fatigue or maladaptation to the training stimulus. Conversely, recruits exhibiting a significant positive trend ($Z > 1.0$) are categorised as demonstrating a superior adaptation, which may represent a physiological gain. It should be noted that strategy metrics are likely to increase *or* decrease as a negative response or fatigue. Therefore, the use of Z scores for positive adaptation is best suited to output variables.

Figure 8 displays a decision matrix for this example, including potential actions based on data categorisation. Green represents recruits who are within their normal range or adapting well to training stimuli. Amber requires caution, where recruits may be beginning to exhibit signs of maladaptation. This can function as an early warning sign, where practitioners can make targeted interventions such as modified training load or recovery modalities for individual recruits. Red is where recruits may have been overexerted and are experiencing a significant decline in performance. At this stage, rest and recovery modalities are recommended, and if required, a medical/performance staff check-in where sleep, nutrition and psychological state can be assessed. However, it is important to note that objective data mustn't dictate decisions in isolation; subjective criteria must also be considered. This system is designed to create an easy way for military performance staff to communicate recruit readiness, simply to training staff directly overseeing recruits.

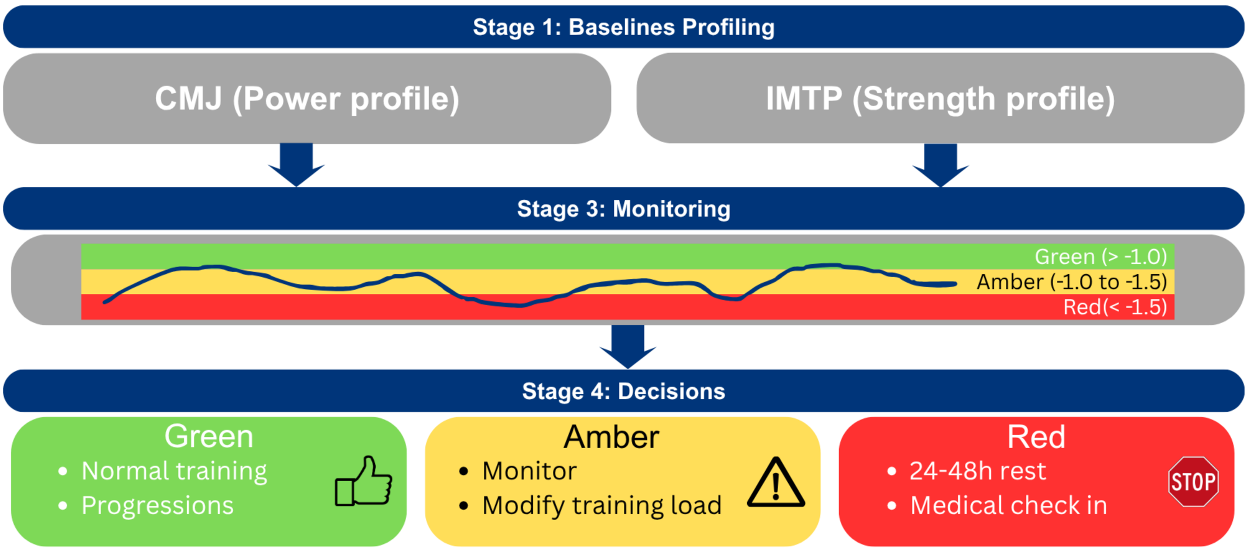

Figure 8. Proposed Decision Matrix for Optimising Recruit Monitoring Protocols during Basic Training

Note: BM = body mass, PF = peak force, Ecc = eccentric, Con = concentric, FT:CT = flight time:contraction time, EPV = eccentric peak velocity.

5.5 Limitations and Future Directions

Implementing a profiling and monitoring protocol provides objective insight into recruit readiness, yet several limitations persist. Both the CMJ and IMTP require maximal intent; while metrics like eccentric peak velocity act as a proxy for effort, they cannot fully account for the stressors unique to basic training. Furthermore, the learning effect is a concern in populations with particularly low training ages, where initial fluctuations may reflect movement “noise" rather than physiological adaptation (Moeskops et al., 2018; Moir et al., 2004). A current lack of specific normative data also complicates initial benchmarking.

Distinguishing a meaningful physiological "signal" from the "noise" of daily variation remains a significant challenge, with variability in nutrition, sleep, and training regimens affects results (Merrigan et al., 2020; O’Leary et al., 2020). Additionally, there is a secondary risk of overinterpretation, where practitioners might rely on a dashboard's data in isolation. To mitigate this, objective force plate data should be paired with other objective and/or subjective criteria. In practice, protocols should aim to intertwine performance metrics with subjective wellness markers. This may also include additional objective criteria such as GPS-derived internal load data. Overlaying these different streams creates a broad early warning system, allowing practitioners to identify when an individual may be at risk of injury. Developing such a multivariate model will allow for a more holistic understanding of readiness and precise training adjustments. Given the variation in stressors, each military branch should develop and validate its own specific framework.

5.6 Conclusion

Ultimately, the value of integrating CMJ and IMTP protocols lies in quantifying baseline neuromuscular qualities and the "invisible" physiological costs of basic training. Because global organisational practices differ significantly, strategies must be modified for specific cohorts. Furthermore, Chapter 2 demonstrated that while some physical qualities improve during extreme basic training loads, neuromuscular capacities like maximal strength and explosive power are often overlooked. This is supported by Chapters 3 and 4, where jump height and power did not change over time, but both CMJ force production and movement strategy were significantly altered following a field exercise. Each chapter underscores the necessity of a routine benchmarking and monitoring framework. By utilising initial profiling to identify high-risk recruits and longitudinal monitoring to detect the "tipping point" between functional adaptation and non-functional overreaching, military organisations can transition toward a data-driven model of performance. Implementing these objective markers within a structured decision matrix optimises recruit throughput and reduces the financial and operational burden of musculoskeletal attrition. This approach ensures soldiers are trained to the highest standard while remaining physically resilient enough for operational service.

Chapter 6: Summary

6.1 Summary

The purpose of this research was to answer the overarching question, “What are the effects of army basic training on neuromuscular performance in army recruits?”. This involved understanding the effects as reported in current literature, and how these effects align with New Zealand Army recruit basic training both acutely and longitudinally to inform the practical guide for soldiers to implement neuromuscular profiling and monitoring assessments.

At the beginning of this thesis, a narrative review (Chapter 2) was performed to better understand the effects of basic training on recruits during Initial Military Training. While this thesis focuses its attention on the Army, due to the sparsity in existing research, a broader lens was cast to encompass all primary military services. This identified substantial heterogeneity in global military practices, with courses differing in length, intensity and design, making collective quantification of the effects difficult. However, broadly, neuromuscular strength and power were shown to decrease immediately following activities core to initial military training, such as load carriage, manual material handling and casualty evacuation. During task effects raised maximal oxygen consumption and cardiovascular strain, notably amongst females who typically were required to carry greater relative load. Consequently, injury rates were highest amongst females, but overall injury rates, regardless of sex, remain high. The chronic effects of cardiorespiratory endurance, full-body strength, upper-body muscular endurance and power were reasonably documented and tend to improve from entry levels. However, these improvements seemed to occur largely in the first eight weeks of the course, and amongst those with lower levels of initial fitness.

The chronic and acute effects were investigated in Chapters 3 and 4, respectively. Chapter 3 applied a high-level overview of the effects of basic training on jump height during the CMJ, primarily following one intake with measures at baseline, mid-point and end of the course. No differences in jump height were observed between any time points ($F(2, 82) = 1.612$, $\omega^2p = 0.002$). Secondarily, a retrospective intake (Intake B) was used as a comparative and descriptive control, where it was identified that the intake had greater jump heights at baseline ($p < .001$, $d = 0.714$), which tended to decline at the mid-point ($p = .023$, $r_B = -0.406$). Intake A appeared to improve their jump performance ($p = .036$, $r_B = 0.228$). The apparent difference in adaptation between cohorts might be explained by lower baseline values, differences in training, and statistical phenomena—all of which complicate the interpretation of results. However, this does align with the findings in Chapter 2, supporting potential improvements in those with lower levels of baseline fitness.

Chapter 4 provided a more nuanced view of a week-long field exercise, a specific but highly demanding component of basic training, by testing recruits' CMJ and IMTP before, immediately after and 24 and 48 hours post field exercise. It sought to understand how neuromuscular strength and power change in response to a week-long field exercise and what influence sex and relative strength would have on those effects. Unforeseen changes resulted in lower recruitment, and accordingly the work suffered from lower sample size than planned and imbalanced groups. Interestingly, when adjusting for relative strength, IMTP peak force (as a measure of maximal strength) increased post activity. However, for the CMJ, dynamic force production was almost universally decreased immediately following the activity, most notably with a divergent sex trend identified for concentric peak force ($p = .009$, $\omega^2p = 0.011$) where the female group were able to largely maintain baseline output before a late improvement from 24 to 48 hours. Conversely, males experienced an immediate reduction that persisted at the 48-hour mark. Primary output variables (jump height, peak and relative peak power) remained largely unchanged for both sexes. Perhaps most prominently, though, flight time:contraction time and concentric duration were significantly altered, influenced by longer concentric durations. There was some evidence of this change in estimates for both sexes. This highlights the hidden impacts of the field training exercise, where primary physical outputs remain stable, while recruit movement strategy shifts to compensate, a mechanism noted within the literature to be indicative of fatigue and heightened injury risk. Given that these effects also persisted at 48 hours, it emphasised the need for a more nuanced approach to monitoring recruit readiness. Furthermore, this aligned with our hypothesis that there may be some differences between the sexes in the effects of basic training, but they are inconsistent when accounting for relative strength.

The focus of Chapter 5 was to reflect on the learnings in previous chapters and design a practical commentary for profiling and monitoring neuromuscular performance during recruit training. It emphasised a time and cost-effective method of easily testing large groups of recruits to gain immediate insight into recruits' current state of readiness, both on entry to the course and throughout. This commentary aimed to provide a framing of the practical applications of this thesis to assist personnel in the implementation of testing to improve recruit performance outcomes and potentially reduce injury-related attrition.

6.2 Limitations

The limitations of this research are outlined here:

Chapter 2: Elevated heterogeneity made direct comparisons between research challenging and accordingly complicates synthesis; further, it was unclear whether a maximal output was given to obtain fitness scores reported within the literature.

Chapter 3: The significant baseline differences between intakes make it difficult to understand the trajectory of change over time during NZ Army recruit training. This is further influenced by the lack of an end-of-course data collection point in intake two, in addition to the lack of demographic information, which rendered more detailed and insightful comparisons impossible.

Chapter 4: Unexpectedly reduced sample size for this study complicated aspects of our data interpretation, notably for the female cohort. While efforts were taken to more fully describe the training stimulus, the study was unable to more directly quantify training load data. Such data would increase the value of subsequent analyses, allowing for a degree of correction based on factors like individualised task involvement. In addition, unstandardised countermovement depth may account for variance in jump metrics. Future research should control this variable across trials. Furthermore, some effects were still present during the last data collection session. It is unclear what time course was required for a return to baseline.

Chapter 5: This chapter presented force plates as the focal point of the preceding work in the thesis and a relatively limited view of assessments and variables. While justified given their interest and practicality, it is worth noting there are other potentially interesting assessments and variables which could also be explored. In addition, given that these assessments acts as a proxy of fatigue, it is incapable of distinguishing between central and peripheral fatigue, which is ultimately affected by a significant range of stressors (nutrition, sleep, physical activity).

6.3 Future Research

This research has identified further opportunities for further understanding of the effects of basic training on recruits. The use of force plate technology in recruit training is currently limited, and further, more research is needed to understand the effects more specifically for each nation and/or branch of military. Opportunities arising from this research include:

- Large-scale, longitudinal studies with rigorous data collection methods to improve comparability and to develop a more cohesive understanding of how specific training modalities influence long-term health and readiness.

- Appropriately powered recovery time course investigations into the effects of specific components of basic training, with additional post-activity measurement time points, and more granular measurements.
- Exploring the relationship between neuromuscular performance data and injury risk.
- In line with the above, integration of training load data during basic training, the variability therein, and its impacts for characterising the effects of basic training and individual and group levels.

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Appendices

Appendix A: AUTEC Ethics Approval

Auckland University of Technology Ethics Committee (AUTEC)

16 September 2025

Aaron Uthoff
Faculty of Health and Environmental Sciences

Dear Aaron

Re: Ethics Application: **24/284 Neuromuscular fatigue in male and female New Zealand Army recruits: are the acute and chronic effects of basic training influenced by sex, body mass or relative strength?**

Thank you for your responses to the conditions for the amendment to your ethics application.

The following amendments are approved.

- Change the timing of specific measurements (either side of 3-day field exercise).
- Add grip strength measurement.
- Secondary use of data (for comparison).

Standard Conditions of Approval

1. The research is to be undertaken in accordance with the Auckland University of Technology Code of Conduct for Research and as approved by AUTEC.
2. All public facing documents must have the AUTEC approval number and be of a high standard of spelling and grammar. Dates on the Information Sheet(s) and Consent Form(s) must be consistent.
3. Any amendments to the project must be approved by AUTEC prior to being implemented.
4. A progress report is due annually on the anniversary of the approval date.
5. A final report is due at the expiration of the approval period, or, upon completion of project.
6. Any serious or adverse events must be reported to AUTEC, this includes unforeseen issues that might affect continued ethical acceptability of the project.
7. AUTEC grants ethical approval only. You are responsible for obtaining management permission for access from any institution or organisation at which your research is being conducted and you need to meet all ethical, legal, public health, and locality obligations or requirements for the jurisdictions in which the research is being undertaken.

The application number and title need to be referenced on all correspondence related to this project.

All forms are available online http://www.aut.ac.nz/research/researchethics

For any enquiries, please contact the Secretariat at ethics@aut.ac.nz

(This is a computer-generated letter for which no signature is required)

The AUTEC Secretariat
Auckland University of Technology Ethics Committee

Cc: sean.mccleary96@gmail.com; matthew.cross@aut.ac.nz

Auckland University of Technology, Private Bag 92006, Auckland 1142, New Zealand
ethics@aut.ac.nz; www.aut.ac.nz/researchethics

Appendix B: AUTEC Amended Ethics Approval

Auckland University of Technology Ethics Committee (AUTEC)

22 November 2024

Aaron Uthoff
Faculty of Health and Environmental Sciences

Dear Aaron

Re Ethics Application: **24/284 Neuromuscular fatigue in male and female New Zealand Army recruits: are the acute and chronic effects of basic training influenced by sex, body mass or relative strength?**

Thank you for your responses to AUTEC's conditions.

Your ethics application has been approved for three years until 21 November 2027.

Non-Standard Conditions of Approval

1. Include in the Information Sheet privacy section all the places that deidentified data will be stored indefinitely (VALD platform and open Science repository).
2. The 2 above should be reflected in the Consent Form also.

Non-standard conditions do not need to be submitted to or reviewed by AUTEC unless requested but must be completed before commencing your study.

Standard Conditions of Approval

1. The research is to be undertaken in accordance with the Auckland University of Technology Code of Conduct for Research and as approved by AUTEC.
2. All public facing documents must have the AUTEC approval number and be of a high standard of spelling and grammar. Dates on the Information Sheet(s) and Consent Form(s) must be consistent.
3. Any amendments to the project must be approved by AUTEC prior to being implemented.
4. A progress report is due annually on the anniversary of the approval date.
5. A final report is due at the expiration of the approval period, or, upon completion of project.
6. Any serious or adverse events must be reported to AUTEC, this includes unforeseen issues that might affect continued ethical acceptability of the project.
7. AUTEC grants ethical approval only. You are responsible for obtaining management permission for access from any institution or organisation at which your research is being conducted and you need to meet all ethical, legal, public health, and locality obligations or requirements for the jurisdictions in which the research is being undertaken.

The application number and title need to be referenced on all correspondence related to this project.

All forms are available online http://www.aut.ac.nz/research/researchethics

For any enquiries, please contact the Secretariat at ethics@aut.ac.nz
(This is a computer-generated letter for which no signature is required)

The AUTEC Secretariat
Auckland University of Technology Ethics Committee

Cc: sean.mccleary96@gmail.com; matthew.cross@aut.ac.nz

Auckland University of Technology, D-88, Private Bag 92006, Auckland 1142, New Zealand.
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Appendix C: Participant Information Sheet

Participant Sheet

Date Information Sheet Produced:
16th of September 2024

Project Title

Neuromuscular fatigue in male and female New Zealand Army recruits: are the acute and chronic effects of basic training influenced by sex, body mass or relative strength?

An Invitation

Kia Ora, my name is Sean McCleary, and I am a master's student at the Auckland University of Technology (AUT). You have received this information sheet as part of an invitation to participate in a research project aiming to investigate the effects of army basic training on measures of physical fatigue. This research will be part of my master's Degree and will be conducted in collaboration with the NZDF with Maj. (Dr.) Jacques Rousseau of the A9 Human Performance Cell. This study will utilise force plate platforms to measure vertical forces during performance testing with a vertical jump and static pull. These platforms are produced by VALD Performance of which I am an employee.

What is the purpose of this research?

The purpose of this study is to develop a better understanding of both the short- and long- term effects of basic training on measures of physical performance and fatigue. The research will also explore how these effects may differ based on sex (male vs female), body mass, and relative strength.

A summary of the de-identified findings of this research may be published in accredited academic publication and presentations.

How was I identified and why am I being invited to participate in this research?

You were identified as being a part of Recruit Regular Force 417. And as such, you are invited to participate. We welcome your participation in this study if you are currently healthy and free from injury. Those who are medically downgraded or injured will not be able to participate.

How do I agree to participate in this research?

Your participation in this research is voluntary (it is your choice) and whether or not you choose to participate will neither advantage nor disadvantage you.

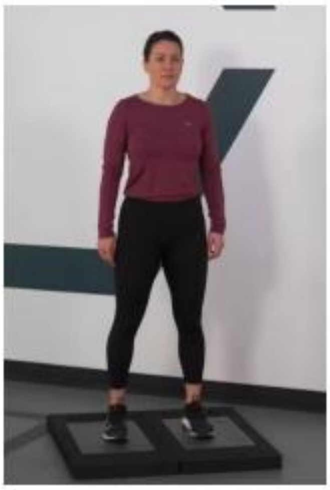
If you are interested in participating in this study, you can agree to voluntarily participate by completing and signing the consent form accompanying this information sheet. By signing the consent form, you will be agreeing to participation in both studies.

You are able to withdraw from the study at any time. If you choose to withdraw from the study, then you will be offered the choice between having any data that is identifiable as belonging to you removed or allowing it to continue to be used. However, once the findings have been produced, removal of your data may not be possible.

What will happen in this research?

If you decide to participate in this study, you will take part in a study which will fit around your normal schedule and take place within the Waiouru Military Camp itself and surrounding training area. You will complete some performance testing on four different occasions either side of a field exercise. There will be testing conducted prior, immediately after and then 24 and 48 hours afterward.

The tests involved in each session will be a maximal countermovement jump and an isometric mid-thigh pull and grip strength test – similar in exertion to your training and as shown in the below images. You should not complete any strenuous activity within 48 hours of the start and finish of the field exercise; this will be established with your instructors. The combined total of all testing across this session will be approximately 5 hours.



Countermovement Jump

Isometric Mid-thigh Pull

Grip Strength

What are the discomforts and risks?

The likelihood of discomfort or risk associtated with participating in this study is minimal. Each tests requires no more effort than what would normally be exerted during a gym training session and/or during normal basic training routines. There is a small chance that you could expierience some slight discomfort in the form of low levels of delayed onset muscle soreness post testing again, similar to your habitual training (and that occuring within basic).

How will these discomforts and risks be alleviated?

As a recruit actively involved in basic training the tests and field exercise are designed to be like tasks which will be completed in a standard physical training session or during your regular training. However, we will attempt to limit the likelihood discomfort or risk by ensuring you are properly warmed up as part of the testing procedure.

If a high level of discomfort is experienced during the testing process, please inform the researcher as soon as possible. The primary researcher aims to ensure you are as comfortable as possible throughout the research process.

If you have questions regarding any risk or comfort that you anticipate, please feel free to address these concerns to the researcher so that you always feel comfortable throughout the process. Recruit medical assistance is available through the Waiouru Military Camp Medical Treatment Centre at any stage, should you require it.

What are the benefits?

While it is unlikely that participation in this study will directly impact you, the aim of the study is to better understand the effects of basic training on recruits. It is intended that this understanding may help to guide future practices within the NZDF to assist with maintaining the wellbeing of recruits. As such this may benefit future recruits. However, if you opt in on the consent form, you will receive an indiviudalised summary of your neuromuscular performance data which help you to learn about your performance.

The results from this study will benefit me as they will be used to write my masters thesis, of which some or all components may be published as scientific literature. This will also benefit those who assist in the study such as Maj. Rousseau and my supervisors as they will be mentioned as co-authors.

What compensation is available for injury or negligence?

In the unlikely event of a physical injury as a result of your participation in this study, rehabilitation and compensation for injury by accident may be available from the Accident Compensation Corporation, providing the incident details satisfy the requirements of the law and the Corporation's regulations. This can be accessed through the MTC services available on camp.

How will my privacy be protected?

All data collected will be de-identified which means that no one will be able to identify you from your data alone. Any identifying information will be securely held with Maj. Rousseau at the A9 Human Performance Cell in Waiouru and the deidentified data will be held on the NZDF VALD Hub (online cloud storage) and with the research team and Auckland University of Technology. Furthermore, any publications that result as a part of the research will report group means to further ensure that no data can be attributed to you.

Any identifying documents such as consent forms will only be able to be identified by Maj. Rousseau. All deidentified data collected from this research will be held securely with both the NZDF and the research team at Auckland University of Technology. It may also be uploaded onto online repositories. You may opt against having your data stored indefinitely on the accompanying consent form.

What are the costs of participating in this research?

There will be no financial cost to participate in this research. You will only be asked to volunteer approximately 5 hours of your time spread across seven different sessions.

What opportunity do I have to consider this invitation?

You will be given the duration of a physical training session to consider participation.

Will I receive feedback on the results of this research?

Any published articles as a result of this study will be made available to you. You can opt to receive an individual report of your results on the accompanying consent form.

What do I do if I have concerns about this research?

Any concerns regarding the nature of this project should be notified in the first instance to the Project Supervisor,

Concerns regarding the conduct of the research should be notified to either the Executive Secretary Dr Carina Meares of AUTEC (*ethics@aut.ac.nz*, (+649) 921 9999 ext 6038) or the Chair of the NZDF Research Ethics Committee, Jo Hughes (OrgResearch@nzdf.mil.nz).

Whom do I contact for further information about this research?

Please keep this Information Sheet for your future reference. You are also able to contact the research team as follows:

Researcher Contact Details:

Sean McCleary,

Maj. (Dr.) Jacques Rousseau,

Project Supervisor Contact Details:

Dr. Aaron Uthoff,

Approved by the Auckland University of Technology Ethics Committee on *21/11/24*, AUTEC Reference number 24/284

Appendix D: Consent Form

Consent Form

Project title: *Neuromuscular fatigue in male and female New Zealand Army recruits: are the acute and chronic effects of basic training influenced by sex, body mass or relative strength?*

Project Supervisors: *Dr Aaron Uthoff & Dr Matthew Cross*

Researcher: *Sean McCleary*

By signing this form, you agree to the following statements:

- I have read and understood the information provided about this research project in the Information Sheet dated September 2024.
- I have had an opportunity to ask questions and to have them answered.
- I understand that taking part in this study is voluntary (my choice) and that I may withdraw myself or any information I have provided for this project at any time without being disadvantaged in any way.
- I am not suffering from any current injury, illness, or disorder that may impair my ability to perform the required tasks.
- I agree to provide physical effort to the best of my ability throughout testing.
- I understand that participation in this research will in no way benefit or disadvantage my assessment of performance during basic training.
- I agree to deidentified performance data being collected and stored.
- I agree to take part in this research.
- I wish to receive a copy of my individual results (please tick one): Yes O No O
- I consent to the indefinite storage of my anonymised data, for future (similar) research purposes: (please tick one): Yes O No O

Participant's signature: ....

Participant's name: ....

Date:

Approved by the Auckland University of Technology Ethics Committee on 21/11/24, AUTEC Reference number 24/284

Note: The Participant should retain a copy of this form.

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Appendix E: Chapter 2 Abstract

Initial Military Training (IMT) is designed to physically and mentally transition recruits from civilian to military personnel, typically lasting six to fourteen weeks. Accordingly, the content and focus of IMT appear variable, and it is important to understand what effects this training has on recruits. This study reviewed existing literature regarding the acute and chronic effects of IMT on physiological and neuromuscular performance. Using a systematic style search strategy (Google Scholar, EBSCO, PubMed, Medline), 28 relevant studies were identified, focusing on longitudinal (n=26) and acute (n=6) effects. The included studies were performed in various branches of the military, but primarily the army, across nations, and rarely disclosed the nature of activities involved, but tended to follow a progressive structure, culminating in scenario-based training specific to their respective branch, to emphasise skills learned earlier in the course. Findings indicate that training causes an acute decrease in strength and power, along with increased cardiovascular strain and maximal oxygen consumption, with these effects more pronounced in females. Longitudinally, recruits demonstrated improvements in cardiorespiratory endurance, full-body strength, and upper-body muscular endurance; however, performance gains typically plateaued by the eighth week. This plateau, most evident in recruits with higher baseline fitness, suggests potential fatigue accumulation from sleep restriction and high physical activity, or a late-stage shift in training focus that provides insufficient stimulus. These results underscore a critical need for standardised assessment protocols to address literature heterogeneity and enhance the comparability of training outcomes across military populations.

Key points:

- Initial military training organisational practices vary widely in duration, intensity, and design. In addition, inconsistent outcome measures complicate interpretation; for example, changes may reflect true gains in maximal capacity or improvements driven by test-specific thresholds (e.g., clustering around minimum passing standards).

- Broadly, neuromuscular strength and power appear to decrease immediately following activities core to initial military training (i.e., load carriage). Cardiovascular strain and VO2 consumption increase significantly during physical activity and are more prevalent in females.
- IMT training appears to improve cardiorespiratory endurance, full body strength, upper body muscular endurance and power. Improvements seem largely to occur during the first eight weeks, and in females and those with lower initial fitness levels.
- Future research should prioritise the establishment of standardised physical assessment protocols across military cohorts. Large-scale, longitudinal studies with similar data collection methods are essential to improve comparability and to develop a more cohesive understanding of how specific training modalities influence long-term health and readiness.