Combatting the War on Sleep: Investigating Sleep and Recovery in the Military

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Abstract

The military setting often includes continuous operations, whether in training or deployed environments. These often-stressful environments present unique challenges for service members to achieve both intra-day and inter-day recovery. This thesis aimed to investigate the physical fitness levels, sleep, and recovery of military personnel (Army, Navy, and Air Force), which have been deemed as essential for daily task completion and safe operation during military training and deployment.

The physical fitness levels of trainees entering military service are of major interest internationally. In Study One, 116 participants were assessed for 2.4 km run times, muscular endurance (press-ups and curl-ups), body mass, and Y-balance musculoskeletal screening, before and after a 6-week Joint Officer Induction Course. In general, fitness levels were poor compared to entry-level standards over the last 4–5 years, and it was shown that significant improvements could be made over 6 weeks in aerobic fitness and upper-body and core muscular endurance across all services. Of note, Army personnel performed better in the 2.4 km run and press-ups compared to other services ($p < 0.05$), and Navy personnel performed better in curls-ups. At completion of the course, there were significant improvements in 2.4 km run time ($p = 0.02$), press-ups ($p = 0.04$), and curl-ups ($p = 0.01$) across all services. However, it was evident that there were poor levels of perceived recovery and sleep over the duration of the 6-week course.

In an attempt to improve day-to-day recovery, Study Two investigated the influence of wearing lower-body compression garments (CG) on changes in physical performance, subjective soreness, and sleep quality over 6 weeks of military training. Twenty-seven participants wore CG every evening for 4–6 h, and 28 wore standard military attire (CON), over a 6-week period. Subjective questionnaires (soreness and sleep quality) were completed weekly, while 2.4 km run times, maximum press-ups, and curl-ups were tested before and after 6 weeks of military training. There were *small* benefits in favour of CG over CON for improvements in 2.4 km run times ($d = -0.24$) and press-ups ($d = 0.36$). While not statistically significant, CG provided *small* to *moderate* benefits to perceived muscle soreness. Study Two again highlighted that poor sleep was a concern during the initial military training courses.

In Study Three, 22 officer-trainees wore wrist actigraphs for 36 nights to monitor sleep, completed subjective well-being questionnaires weekly, and were tested for: 2.4 km run times, and maximum press-ups and curl-ups before and after 6 weeks of training. The sleep mid-point of 6:15 h:min was used to stratify the trainees into two quantile groups, UNDERS (5:51 ± 0:29 h:min [mean ± SD], n = 11) and OVERS (6:27 ± 0:09 h:min, n = 11). Subjective wellbeing scores demonstrated a significant group × time interaction ($p < .05$), with *large* effect sizes in favour of the OVERS group for fatigue and soreness at various time points. Sleeping more than 6:15 h:min per night over 6 weeks was associated with *small* benefits to aspects of physical performance when compared with sleeping less than 6:15 h:min. Given these results in relation to physical performance and well-being with increased sleep, we conducted a follow-up study to investigate interventions to enhance sleep in the military setting.

In Study Four, before investigating a sleep intervention (Study Five), we compared manually-scored with automatic-scoring actigraphy devices. Sixty nights of sleep data from 20 healthy adult participants were assessed by concomitantly wearing an automatic scoring device (Fatigue Science Readiband™) and a manually-scored device (Micro Motionlogger®). Sleep indices including total sleep time (TST), total time in bed (TIB), sleep onset latency (SOL), sleep efficiency (SE%), wake after sleep onset (WASO), wake episodes per night (WE), sleep onset time (SOT), and wake time (WT) were assessed between the two devices. There were no significant differences between devices for any of the measured sleep variables ($p > 0.05$). All sleep indices resulted in *very-strong* correlations (*r's* >0.84) between devices. A mean difference between devices of <1 min for TST was associated with a typical error of measurement TEM of 15.5 mins (95% CI, 12.3–17.7 min). Given there were no significant differences between devices in the current study, we identified that these two devices could be used concurrently for the interventional study (Study Five).

In the final study, Study Five, 64 officer-trainees wore wrist actigraphs for 6 weeks during initial military training to quantify sleep metrics. Participants were randomly allocated to either: a low-temperature lighting group (LOW, n = 19), standard-temperature lighting with no adjustment to lights but with a placebo 'sleep-enhancing' device placed in the barrack room (PLA, n = 17), or a control group of standard-temperature lighting (CON, n = 28). The lighting environments referred to their living quarters, where they resided from 1800h each night during the 6-week training camp. A significant group x time interaction was observed for the 2.4 km run, with the improvement in LOW (Δ92.3 s) associated with a *large* improvement when compared to CON (Δ35.9 s; $p = 0.003$; $d = 0.95$), but not PLA (Δ68.6 s). Similarly, curl-up improvement resulted in a *moderate* effect in favour of LOW (Δ14 repetitions) compared to CON (Δ6; $p = 0.063$; $d = 0.68$). Chronic exposure to low-temperature lighting was associated with benefits to aerobic fitness across a 6-week training period, with minimal effects on sleep measures.

In summary, the series of studies in this thesis provides a foundation for better understanding the physical fitness characteristics, as well as sleep and recovery considerations in the military setting. Although trainees present to initial training with low levels of fitness, significant improvements can be made over a 6-week training period. It was also identified that recovery and sleep are generally poor during these initial military training courses. However, the use of recovery interventions, such as CG, can provide some benefits to perceived muscle soreness, physical performance, and improvements in sleep over the duration of these courses that translated into benefits to physical adaptation to training. Results from this thesis enhance our understanding of sleep and recovery in military trainees. This work may help to inform decision-making in the design and implementation of intensive military courses, highlighting the need for a greater emphasis on sleep and recovery practices to enhance both the physical adaptation to training and the overall well-being of recruits.

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List of Abbreviations

ASVAB	Armed services vocational aptitude battery
CG	Compression garments
CK	Creatine kinase
CWI	Cold-water immersion
ESS	Epworth sleepiness scale
HREC	Human research ethics committee
HRV	Heart rate variability
JOIC	Joint officer induction course
MANOVA	Multivariate analysis of variance
NREM	Non-rapid eye movement
NZDF	New Zealand Defence Force
PQSI	Pittsburgh sleep quality index
PSG	Polysomnography
PT	Physical training
PTI	Physical training instructors
RB	Readiband
REM	Rapid eye movement
SCN	Suprachiasmatic nucleus
SE	Sleep efficiency
SOL	Sleep onset latency
SOT	Sleep onset time
SOV	Sleep onset variance
TEM	Typical error of measurement
TIB	Total time in bed
TST	Total sleep time
WASO	Wake after sleep onset
WE	Wake episodes
WT	Wake time
WV	Wake variance
YBT	Y-Balance musculoskeletal screening test
YBT-LQ	Y-Balance musculoskeletal screening test lower-quartile
YTB-UQ	Y-Balance musculoskeletal screening test upper-quartile

CHAPTER ONE

Thesis Overview

Thesis Outline

The thesis comprises five experimental studies, inserted as separate chapters in this thesis, structured to address the following aims:

1) Assess changes in the physical characteristics of New Zealand Army, Navy and Airforce officer trainees’ over the 6-weeks of a Joint Officer Induction Course (**Study One**, Chapter Three).
2) Investigate the chronic effects of lower-body CG wear (over 6-weeks) on performance adaptations and subjective soreness and sleep quality in officer trainees (**Study Two**, Chapter Four).
3) Investigate the relationship between sleep duration and changes in physical performance in recruits during 6-weeks of military training (**Study Three**, Chapter Five).
4) Compare automatic-scoring and manual-scoring actigraphy for sleep measurement in healthy adults (**Study Four**, Chapter Six).
5) Investigate the longitudinal effect of altered light exposure in military barracks on subsequent sleep, well-being, and physical performance (**Study Five**, Chapter Seven).

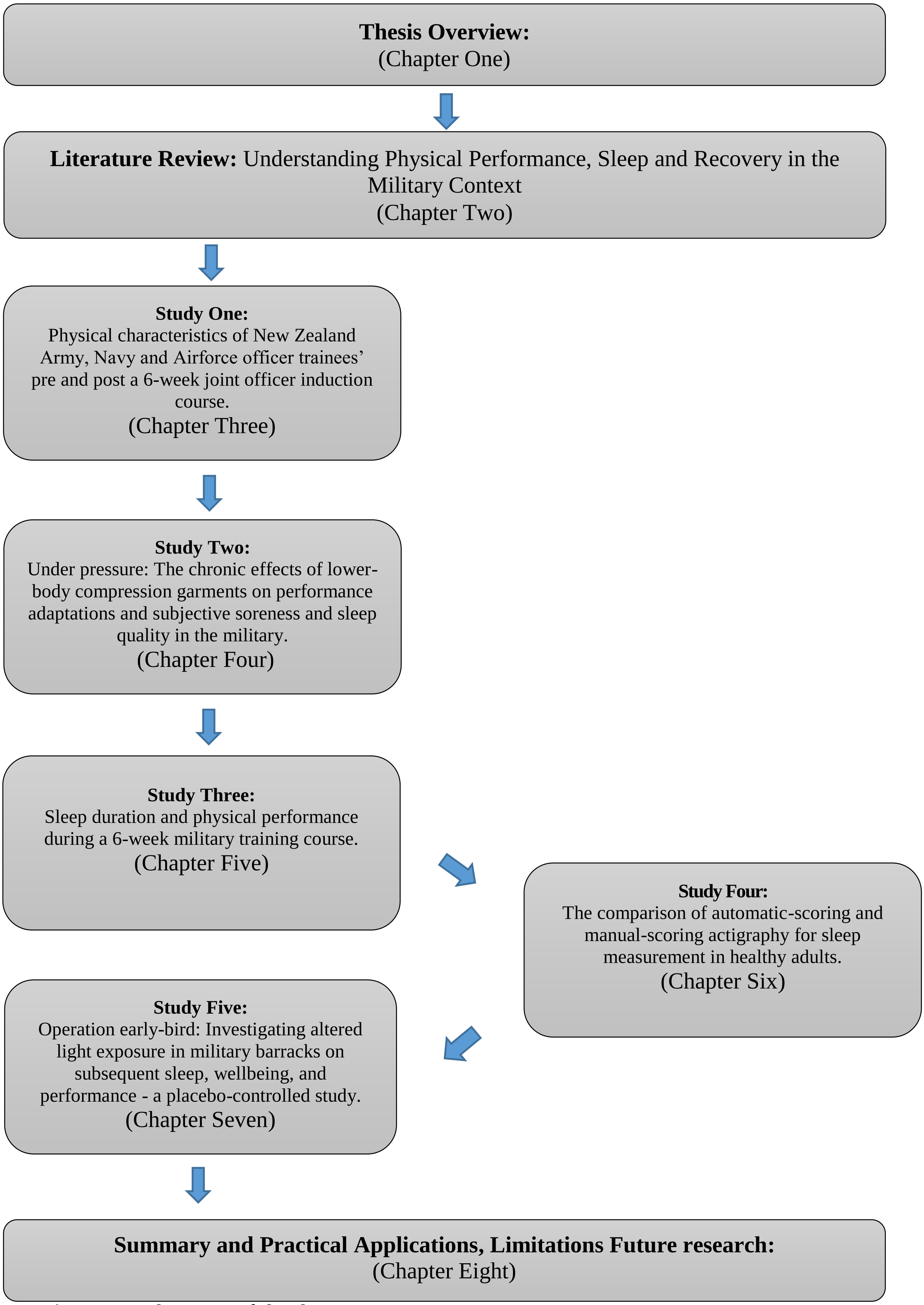

Figure 1. Schematic of the thesis structure

Chapter Organisation

The thesis comprises eight chapters. Chapter Two comprises a literature review, which provides a background to understanding physical performance in a military context, highlighting the importance of sleep and recovery in modern war fighters. Each of the experimental chapters (Three to Seven) are written as stand-alone chapters that are either published or accepted for publication in journals, and incorporate a standard paper format (Abstract, Introduction, Methodology, Results, and Discussion). Chapters Three to Seven appear in the same format for consistency, but note that these articles were formatted to the specific journal specifications when published. It is acknowledged that, due to the structure of the thesis, there is a degree of repetition throughout. A single reference list of citations is included at the end of the thesis for consistency and readability.

Research Outputs Arising from this Doctoral Thesis

Peer-reviewed Journal Publications

Chapter Three

Edgar, D., Gill, N., & Driller, M. (2020). Physical characteristics of New Zealand Army, Navy and Airforce officer trainees' over a 6-week joint officer induction course. *The Journal of Sport and Exercise Science,* 4, (2), 63-71. doi: 10.36905/jses.2020.02.01

Chapter Four

Edgar, D., Gill, N., Beaven, C., & Driller, M. (2022). Under pressure: The chronic effects of lower-body compression garment use during a 6-week military training course. *International Journal of Environmental Research and Public Health*, 19 (7), 3912. doi: 10.3390/ijerph19073912

Chapter Five

Edgar, D., Gill, N., Beaven, C., Zaslona, J., & Driller, M. (2021). Sleep duration and physical performance during a 6-week military training course. *Journal of Sleep Research*, 30 (6), e13393. doi: 10.1111/jsr.13393

Chapter Six

Edgar, D., Gill, N., Beaven, C., Zaslona, J., & Driller, M. (2022). Automatic-scoring actigraph compares favourably to a manually-scored actigraph for sleep measurement in healthy adults. *Sleep Science*. (Accepted 30th August 2022).

Chapter Seven

Edgar, D., Beaven, C., Gill, N., Zaslona, J., & Driller, M (2022). Operation early-bird: Investigating altered light exposure in military barracks on subsequent sleep, wellbeing, and performance - a placebo-controlled study. *Journal of Sleep Research.* (Accepted 5th October 2022).

Conference Presentations Arising from this Thesis

Edgar, D., Gill, N., & Driller, M. Physical characteristics of New Zealand Army, Navy and Airforce officer trainees' over a 6-week joint officer induction course. Sport and Exercise Science New Zealand Conference, Dunedin, New Zealand. 2018. (Oral Presentation)

***Edgar, D.,** Gill, N., & Driller, M. Physical characteristics of New Zealand Army, Navy and Airforce officer trainees' over a 6-week joint officer induction course. International Congress on Soldiers Physical Performance Conference, Adelaide, Australia. 2019. (Oral Presentation)

* Winner of best presentation by a junior officer.

Edgar, D., Rousseau, J. Physical performance monitoring of infantry soldiers during a 24-hour tactical resilience exercise in the New Zealand Army. Sport and Exercise Science New Zealand Conference, Palmerston North, New Zealand. 2019. (Oral Presentation).

Edgar, D., Rousseau, J. Embedded physiological monitoring program to enhance physical performance, sleep and reduce injuries in the New Zealand Defence Force. New Zealand Defence Force Research Organisation, Human Factors Conference. Wellington, New Zealand. 2019. (Oral Presentation).

Edgar, D., Gill, N., Beaven, C., Zaslona, J., & Driller, M. Sleep duration and physical performance during a 6-week military training course. Sport and Exercise Science New Zealand Conference, Christchurch, New Zealand. 2020. (Oral Presentation).

Industry Presentations Arising from this Thesis

Edgar, D. Sleep, recovery, hydration and physical performance; for the corporate athlete. New Zealand Defence Force, Defence College, Institute of Leader Development. 2020 & 2021. NZDF lead integrated capability course, Wellington, New Zealand. (Oral Presentation).

Edgar, D. Sleep, recovery, nutrition and physical performance preparation; for New Zealand Air Force officer cadets and recruits. New Zealand Airforce Base Woodbourne, Blenheim New Zealand, 2021 & 2022. New Zealand Airforce initial training course. (Oral Presentation).

Edgar, D. Recovery, sleep, training preparation and nutrition for the aging athlete. Marlborough Masters Swimming and Athletic Association. Blenheim, New Zealand. 2022. (Oral Presentation).

Edgar, D. Sleep hygiene and resistance training for continued health and wellbeing. New Zealand Defence Force Directorate of Psychology NZDF, Wellness Week, Wellington, New Zealand, June 2022. (Oral Presentation).

Media Articles Arising from this Thesis

Military precision: the never-ending battle to get a good night's sleep. Stuff national news website, 27th December 2020.

Manu Samoa's NZ army recruit bridges culture and science of sport. Stuff national news website, 18th July 2021.

Thesis Introduction

Physical training (PT) approaches for the modern war fighter need to focus on a flexible integration of strength, power, movement-reaction, and aerobic performance training (Kraemer & Szivak, 2012), as well as integrated physical recovery. The physical demands and conditions under which military personnel perform are unique (Lovalekar et al., 2018). Therefore, human performance programs in the military must facilitate and support fitness and conditioning improvement from recruitment onwards (Rudzki & Cunningham, 1999), in conjunction with recovery and sleep initiatives (Lovalekar et al., 2018).

Military forces need to be ready physically for operational deployment and it is widely accepted that military personnel are required to achieve a specified level of fitness. This fitness level is determined by individual service, individual ability to effectively undertake required tasks, and more importantly, the capacity to remain in a state of mission-essential fitness (Heinrich, Spencer, Fehl, & Carlos Poston, 2012). Activities such as running, jumping, crawling, rolling, accelerating, decelerating, climbing, bounding, lifting, pushing, and sprinting are all components of everyday operation. Furthermore, long periods of carrying heavy loads are normal and expected, as are long periods of working under extreme stress and in extreme environments (Heinrich et al., 2012).

Military PT can vary depending on the operational level of the service person, or in relation to the stage of the soldier's career. Although all service personnel need to maintain an adequate level of fitness and conditioning, individual tracking is the most effective method to ensure the improvement and maintenance of physical performance (Kyröläinen, Pihlainen, Vaara, Ojanen, & Santtila, 2017). In a military environment, physical fitness and training not only provide positive benefits toward operational enhancement of physical condition, but also prove essential in promoting and/or conferring resilience (Deuster & Silverman, 2013). Resilience can be categorised as an individual's ability to deal with hardship, stress, physical fatigue and cognitive strain (Bhattacharyya, Pal, Chatterjee, & Majumdar, 2017). The importance of aerobic physical condition when dealing with intense physiological stressors such as tactical tempo, increased cognitive demand in a military environment (Bhattacharyya et al., 2017; Deuster & Silverman, 2013; Szivak et al., 2018), and reduction of injuries is evident in the literature (Andersen, Grimshaw, Kelso, & Bentley, 2016). However, what has also now been accepted as an essential component of optimal physical performance, is well-timed and effective recovery (Brown et al., 2020; Nindl, 2012a) and sleep (Charest & Grandner, 2020; Good, Brager, Capaldi, & Mysliwiec, 2020).

Previous research investigating military recruit physical performance, recovery, and injury occurrence has generally focused on load carriage and physical preparedness. A consensus paper developed following the International Congress on Military Research in 2018, (Lovalekar et al., 2018) outlined the main priorities for human performance military research worldwide. This paper ranked sleep, physical performance, fitness, and physical demands in the training environment in the top 10 of 44 priority research areas. Eighteen out of 44 key areas were associated with physical performance, with sleep and recovery highlighted as priority areas. As a result, this thesis aimed to investigate physical performance, recovery and sleep in the military setting. We start with a literature review that is divided into two parts, Part A initially focuses on physical performance and characteristics in the military, and Part B focuses on sleep and recovery in the military setting.

CHAPTER TWO

Literature Review:

Understanding Physical Performance, Sleep and Recovery in the Military Context.

PART A:

Physical Training in the Military Context

In contrast to civilian professions, PT in a military environment is not solely focused on health and fitness. Within a military profession, physical ability is essential to undertake daily work tasks (Orr & Pope, 2015). Physical tasks can be diverse and varied and orientated toward either tactical (military job) or technical output (trade/occupational). Tasks can include working on a mechanical or aircraft shop floor, on a heavy gun line lifting heavy rounds, patrolling various distances of changing terrain, negotiating challenging obstacles, running and explosive movements, and ultimately engaging with the enemy in unpredictable and extreme environments (Kyröläinen et al., 2017; Orr, Pope, Johnston, & Coyle, 2010).

Targeted PT has been classified as a 'military occupational specialty' whereby service personnel must maintain physical capabilities to execute tasks with minimal risk to health and injury (Boye et al., 2017; Heinrich et al., 2012; Jones et al., 2017). In a military context, PT can be delivered in varying environments with changing environmental conditions and regularly altering requirements dependent on operational demands and task output (Friedl et al., 2015; Kyröläinen et al., 2017; O'Hara et al., 2012). Internationally, military PT can be prescribed for varying sized groups of service personnel including; Regiment (300+), Battalion (300–500), Company (60+), and Platoon (20–30). Single-service PT instructors from the Army, Navy, and Airforce customarily deliver PT in a class format tailored toward group needs. When required, 'advanced' or 'elite' physical training will be provided for specialised units such as Special Forces Operators (Lovalekar et al., 2017; Nindl, 2012b).

The Operational Environment

In a military context, the operational environment is the combination of conditions and circumstances, and will influence the use of military forces and command decisions regarding the best use of troops to support an intended line of operation (Deuster & Silverman, 2013). There are varying examples of an operational environment, and in most cases, they describe troops, human personnel, equipment, vehicles, and supplies when deployed in another country to either a permissive friendly or a non-friendly environment. The most widely used term, but perhaps the most unsettling one for soldiers, troops, and families is a 'hostile' environment (Deuster & Silverman, 2013).

Many contributing factors will be evident for a commanding officer in a hostile environment when making decisions about tasks such as troop manoeuvres, intelligence gathering, mission sign-off, and successful task execution. A significant consideration is the physical and mental fatigue state of troops being repetitively exposed to operational missions and tasking (Lovalekar et al., 2018; Szivak et al., 2018). Due to an increased demand placed on the body, the relevance of physical fitness and resilience is substantially accentuated in hostile environments where the sustainment of human life is paramount (Deuster & Silverman, 2013). Not only will demanding operational tasks be more physically challenging in a hostile environment, but they will often be required to be repeated on multiple days for an ongoing duration in states of fatigue and sleep deprivation (Farina et al., 2017; Lentino, Purvis, Murphy, & Deuster, 2013; Wesensten & Balkin, 2013).

Physical Training Program Delivery and Approach

Program delivery can be highly diverse depending on culture, country, military, and service (Lovalekar et al., 2018). Although the approach may differ, it is accepted that physical preparation needs to be shaped toward the working environment (Boye et al., 2017; Kyröläinen et al., 2017), and include the facilitation of recovery (Cortis, Tessitore, D'Artibale, Meeusen, & Capranica, 2010; Vartanian et al., 2018).

Drain, Groeller, Burley, and Nindl (2017) suggested that training needs to be specific to the demographic (recruit, officer, experienced service person or Special Forces), as the response patterns from the physical conditioning and recovery will be different and affect operational field training. In relation to this, it has been demonstrated that decrements in aerobic fitness, muscular endurance, and power are a negative outcome of military field training, and are further influenced by a lack of recovery (Ojanen, Häkkinen, Vasankari, & Kyröläinen, 2018). Therefore, it is advantageous that military personnel, and specifically the war fighter, have an adequate fitness level before field training and combat (Ojanen et al., 2018). This requirement highlights the necessity for targeted recovery strategies and sleep protocols in a normal living environment, both pre- and post-field training, to facilitate physical and cognitive regeneration (Andrews, 2004).

The Australian Army has evaluated the effect of a modified physical training program to enhance performance and reduce injury by being more adaptive, incremental, and incorporating individualised recovery (Rudzki & Cunningham, 1999). This program identified that the key risk factors that contribute to poor outcomes in military PT programs include: low levels of past activity, low levels of physical fitness, previous history of injury, high running mileage, smoking, age, and poor recovery (Rudzki & Cunningham, 1999). Further to this, it has been shown that injury risk can be higher when the stated risk factors are not considered methodically in the program prescription phase, (Jones et al., 2017; Lovalekar et al., 2017; Molloy, 2016; Robinson et al., 2016; Rosendal, Langberg, Skov-Jensen, & Kjær, 2003).

The popularity and influence of non-traditional training modalities on physical performance in the military were investigated by O'Hara et al. (2012), with several forms of non-traditional training including: heavy lower extremity strength training, cross-fit training, kettlebell training, and agility training. These authors identified that beneficial adaptations were observed with Airforce personnel improving fitness scores (O'Hara et al., 2012). However, O'Hara et al. (2012) also stated that more research and investigation is needed to accurately quantify non-traditional training modalities in the military. In a study by Bergeron et al. (2011), the emerging problem of extreme conditioning programs in the military was discussed and outlined how this training paradigm is often conducted with little recovery time between high-volume training sessions. This training model increases fatigue, oxidative stress, muscular strain, and unsafe movement patterns, leading to acute injury (Bergeron et al., 2011). Although improvements in fitness were evident, an apparent disproportionate musculoskeletal injury risk from these types of demanding programs has been observed (Bergeron et al., 2011; Heinrich et al., 2012).

It is of paramount importance that new physical training modalities will enhance performance and recovery while minimising injuries (Nindl, 2012a). Extreme conditioning programs were investigated in the US Army by Grier, Canham-Chervak, McNulty, and Jones (2013), where an advanced tactical athlete conditioning program and extreme conditioning program were compared to standard military and individual PT. Similar injury rates of 12% were observed for the advanced tactical and extreme conditioning formats when compared with standard military and individual PT formats at 14% (Grier et al., 2013). Those participating in the alternate programs covered more mileage in a training week on-feet but displayed slower 2-mile run performance (Grier et al., 2013).

In a study by Heinrich et al. (2012), 8-weeks of Military Essential Fitness (circuit-style training), and standard Army readiness training were compared in the US Army. These authors reported that Military Essential Fitness participants significantly increased their push-ups, bench press, and flexibility and significantly decreased their 2-mile run and step test heart rate (p's < 0.05) compared to participants doing Army readiness training. Both groups maintained their body composition and reported no injuries. The Military Essential Fitness group safely improved their muscular strength and endurance, cardiovascular endurance, and flexibility, supporting functional fitness circuit-style exercise training for military personnel (Heinrich et al., 2012). These findings were further supported by Anderson et al. (2017), when looking at the mandatory unit and individual physical training in relation to fitness in military men ($n = 6290$) and women ($n = 558$) in US Army light infantry brigades. In this research, it was evident that circuit-styled unit PT and running resulted in improved 2-mile run times, sit-ups, and push-ups (Anderson et al., 2017).

Aerobic Conditioning in the Military

Aerobic conditioning often involves the specific and targeted training of the cardiovascular system, leading to improvements in the maximal volume of oxygen uptake (VO_{2max}) and oxygen utilisation (Brock & Legg, 1997; Friedl et al., 2015; Koury, 2016; Santtila, Keijo, Laura, & Heikki, 2008). Knapik et al. (2006) and Simpson et al. (2013) discussed how aerobic fitness is a vital requirement for military trainees, as deficiencies have been attributed to a higher risk of musculoskeletal injuries, in conjunction with increased attrition rates during basic training and the initial stages of military service (Knapik et al., 2001; Knapik et al., 2006; Molloy, 2016; Orr & Pope, 2015). Friedl et al. (2015) and Santtila et al. (2008), also outlined how sound exercise training principles, such as progression, overload, and recovery must underpin the PT program to elicit cardiovascular adaptation.

Sound exercise prescription allows for effective physiological stimulation (Friedl et al., 2015; Gibala, Gagnon, & Nindl, 2015). Brock and Legg (1997), found that 6-weeks of basic training in the British Army was sufficient to induce significant increases in VO_{2max} from 45.7 ml/min/kg to 46.7 ml/min/kg (~2.2%). In the New Zealand Army, it was found that the 2.4 km run distance used for fitness testing has shown to be an accurate predictor of aerobic capacity (VO_{2max}) for military personnel when assessed using a regression equation (Burger, Bertram, & Stewart, 1990). In a wider PT context, Santtila et al. (2008) found that when specifically-prescribed training programs were implemented, 8-week of endurance or strength-focused training improved VO_{2max} by 10.5%.

Resistance Training in the Military

The daily occupational environment for military personnel is one that is loaded and dynamic (Friedl et al., 2015). Strength is important to the everyday undertaking of equipment handling requirements and tactical operational tasks (Bullock, Jones, Gilchrist, & Marshall, 2010; Friedl et al., 2015; Hendrickson et al., 2010; Orr & Pope, 2015; Williams, Rayson, &. Jones, 2002). Manual handling and load carriage over prolonged distances are critical tasks within a military environment and essential for the success of combat performance for the war fighter (Friedl et al., 2015; Orr & Pope, 2015). The primary objective of resistance training in a military context is to improve physical performance and prevent injury by strengthening muscles and associated connective tissue (Knapik et al., 2003; Kraemer & Szivak, 2012), and to ensure muscle response is effective and adaptive (Vera-Garcia, Grenier, & McGill, 2000). When Hendrickson et al. (2010) implemented a targeted strength training program for 8-

weeks in the military, strength increased in; squat 1RM by 48.3%, bench press 1RM by 23.8%, and the operational 3.2 km load carriage run by 11.5%.

Although not always traditional in its modality of delivery, strength and power training in a military context can still be beneficial (Hofstetter, Mäder, & Wyss, 2012; O'Hara et al., 2012; Orr & Pope, 2015; Orr, Pope, Johnston, & Coyle, 2011). To support this, increasing evidence in the literature advocates the use of mixed modalities in military PT (Friedl et al., 2015; Hendrickson et al., 2010; Hofstetter et al., 2012). For example, current modalities and cross training adopted in military settings include: resistance and endurance contrast and compound training (O'Hara et al., 2012), mixed circuits (Heinrich et al., 2012; Hofstetter et al., 2012), progressive and mixed load carriage (Orr et al., 2010, 2011), running and obstacle course training (Hendrickson et al., 2010), and gym-based training (weights, boxing, static cycling, swimming and stretch/mobility) (Rudzki & Cunningham, 1999). Cross-training offers variety during long military courses, and has been effective in increasing leg strength and aerobic fitness in those who struggle with running (O'Hara et al., 2012). Cross-training has also been effective in improving push-ups, decreasing 2-mile run time (Heinrich et al., 2012), and improving squat strength by up to 15%, bench press strength by 20% and VO_{2PEAK} by 7.6% (Hendrickson et al., 2010).

Balance and Functional Movement in the Military

To determine the musculoskeletal deficiency and potential injury risk of military personnel, dynamic balance and musculoskeletal movement screening has been widely used in many countries around the world including Britain, USA, Canada, and Korea (Kazman, Galecki, Lisman, Deuster, & O'Connor, 2014; Lee, Kang, Lee, & Oh, 2015; Robinson et al., 2016; Shaffer et al., 2013). Although there are several screening tests available, the Y-Balance musculoskeletal screening test (YBT) for both the Lower (YBT-LQ) and Upper Quartiles (YBT-UQ) is used extensively in sporting and performance populations (Chimera, Smith, & Warren, 2015; Lee et al., 2015; Shaffer et al., 2013), but only sparingly in the military. The YTB-LQ test observes the lower extremity reach of the contralateral leg while maintaining a unilateral stance. The YBT-LQ examines unilateral reach in three directions: the anterior, the posteromedial, and the posterolateral (Smith, Chimera, & Warren, 2015). The YBT-LQ has been shown to be a reliable test for injury prediction (Lee et al., 2015; Plisky, Rauh, Kaminski, & Underwood, 2006; Shaffer et al., 2013) and research has identified that individuals with asymmetries greater than 4 cm are more likely to sustain a lower extremity injury (Plisky et al., 2006).

The YBT-UQ test is designed to obtain a quantitative measure of trunk and upper extremity functional symmetry, core stability, strength and mobility. The YTB-UQ test observes upper the limb reach of the contralateral arm/shoulder while maintaining a unilateral prone stance with feet shoulder-width apart. The YBT is shown to be a valid, time-efficient, and cost-effective initial screening tool to reliably predict upper body musculoskeletal injuries, particularly in the shoulder girdle (Butler, Arms, et al., 2014; Butler et al., 2014b; Gorman, Butler, Plisky, & Kiesel, 2012). The YBT has previously been utilised with first responders (Cosio-Lima et al., 2016; Vaulerin, Chorin, Emile, d'Arripe-Longueville, & Colson, 2019), which share some characteristics with the military in regard to extreme environments and high-stress work situations (McGillis et al., 2017).

The composite YBT score gives an indication of upper body strength and core instability (de la Motte et al., 2016). For upper limb injury risk, a composite score of less than or equal to 88% for males and less than or equal to 85% for females are strong indicators that the participant is at risk of injury (Butler, Myers, et al., 2014; Gorman et al., 2012) due to inadequate core stability and strength. For lower limb injury risk, a composite score of less than or equal to 98% for males and less than or equal to 92% for females are strong indicators that the participant is at risk of injury (Plisky et al., 2006). Right and left reach direction scores are compared to determine functional symmetry levels. Differences between left and right reach distances of more than 4 cm are an indicator of asymmetry and risk for injury (Butler et al., 2014b).

Load Carriage

There is a general requirement for military personnel to be capable of carrying a load in excess of their body weight (Orr & Pope, 2015). The load carried will be dependent on service tasking requirements and operational threats. Loads can differ, but will generally include: clothing, protective gear (such as body armour and helmet), combat equipment, webbing, weapon systems, ammunition, batteries and radios, and logistical stores such as food, water, and first-aid packs (Orr et al., 2010). Further to this, the operational environment often requires the 'foot-solider' to carry mission-specific tactical equipment of varying loads for excessive periods of time in extreme conditions over challenging terrain. However, a key underpinning consideration is dependent upon factors such as expected task outcome, mission requirement, and enemy threat (Drain, Orr, Attwells, & Billing, 2012).

While the equipment carried is often crucial for mission success and sustainment of life, there is an increasing body of literature indicating the adverse effect heavy load carriage has on a soldier's physical performance both acutely and chronically (Birrell & Hooper, 2007). Evidence suggests that loads are increasing due to the advancements in technology in the military environment, for example: body armour, radios, batteries, cameras, tracking devices, and personnel global positioning satellite units (Drain et al., 2012; Treloar & Billing, 2011). During recent Afghanistan operations, reports suggest that carrying loads in excess of 50 kg was common when patrolling (Orr et al., 2011). It is accepted that excessive external load can unfavourably affect an individual's physical performance and operational viability (Knapik, Harman, Steelman, & Graham, 2012). Factors such as fatigue and injury, as well as jeopardised cognitive function, thermoregulation, and general health will compromise operational intent (Orr et al., 2011).

Load carriage capacity can be influenced by a multitude of individual factors that can either regress or progress performance. Comparable to aerobic conditioning and strength training, load carriage training needs to be prescribed in a specific format with detailed incremental loading, recovery and periodisation (Knapik et al., 2012; Treloar & Billing, 2011). The dynamic interaction between all components of the training program, training modalities, and pre-deployment phases need to be factored in to develop an individual's load carriage capacity (Knapik et al., 2012; Orr et al., 2010).

In regard to individualised physical performance training, it is important to remember that load carriage training (as per other training modalities) should not be generically applied to all load carriage scenarios (Birrell & Hooper, 2007). Factors such as the extent of military training and operational history should be considered when carrying heavy loads, and even more so in situations of extreme stress and fatigue, and/or difficult operational and environmental conditions (Orr et al., 2011). The physiological energy cost for a load carriage needs to be considered during all stages of training and operation to support operational intent and safety. Drain et al. (2012), defined the energy cost of a 10 kg increase in external load as being equivalent to an increase in walking speed of 0.5 km/h or a change in terrain gradient from 0 to 1%. Drain et al. (2012) also predicted that if an average soldier can carry 40 kg at 5.5 km/h over hard flat terrain for approximately 14 km; if that external load is increased to 50 kg, the distance decreases to 9 km. If the walking speed is increased to 6.5 km/h (from 5.5 km/h), the calculated distance the task could be sustained for decreased to approximately 6 km (Drain et al., 2012; Knapik, Reynolds, & Harman, 2004).

Physical Characteristics of Trainees Entering the Military

On entry into the military, trainees are exposed to both programmed physical activity, and informal and unfamiliar physical demands such as walking and marching for long periods while carrying a load, and traversing challenging ground and obstacles (Orr & Pope, 2015). New trainees are typically recruited from the general public, from differing cultures and communities, and can struggle with the required on-feet load (Knapik et al., 2006). Therefore, varying levels of physical condition and fitness are observed on initial entry during physical training and fitness testing (Orr & Pope, 2015).

Both the formal and informal activity requirements required will often exceed a trainee's previous training load and capability (Orr & Pope, 2015). Although entry-level fitness standards are outlined as part of the recruiting process for military around the world, the declining rate of recruit fitness levels are impacting the overall recruitment potential, with many applicants struggling to pass entry fitness assessments or meet the standards of the required medical screening Robinson et al., 2016). As a result of the increase in training and physical activity load required in the military, fatigue, overtraining, and injury are common (Warfe, Jones, & Prigg, 2011). Specifically, it has been shown that new trainees are at a heightened risk of injury on entry to the military when compared with their trained counterparts (Robinson et al., 2016). Indeed, in a paper by Reis, Trone, Macera, and Rauh (2007), it was reported that the leading cause of release from the Marine Corp's basic training was medical discharge (53.4%). A paper by Talcott, Haddock, Klesges, Lando, and Fiedler (1999) similarly discussed how medical discharge was also found to be the leading cause of dismissal (33%) from U.S. Air Force basic training.

Literature has identified four key factors that play a role in characterising trainees entering the military: 1) increased time and distance on feet (Knapik et al., 2006); 2) poor entry-level fitness (Molloy, Feltwell, Scott, & Niebuhr, 2012); 3) poor lower-limb strength (Bullock, Jones, Gilchrist, & Marshall, 2010); and 4) pre-existing injuries (Knapik et al., 2001). Research by Kyröläinen et al. (2017) also suggests poor recovery can result in an increased risk of overtraining, with initial poor fitness a major contributor to a lack of poor progress in the PT program and increased attrition (Davidson, Chalmers, Wilson, & McBride, 2008). Knapik et al. (2003) found that a key characteristic of trainees who sustained an injury during basic training was that they were less aerobically fit.

Conclusion

As outlined by Deuster and Silverman (2013), physical fitness is associated with many attributes required for recovery, military performance, and operational resilience. As such, improving physical fitness is an important pathway toward enhancing daily work performance and operational outputs (Bergeron et al., 2011; Orr & Pope, 2015). Promoting physical fitness and recovery should be underpinned by scientific practice-based evidence and be specific to the required work output. Current literature demonstrates an important relationship between conditioning benefits in the military and reductions in injury (Anderson et al., 2017; Friedl et al., 2015). Further to this, the enhanced physical fitness of military recruits modulated the overall stress response and enhances physiological adaptation (Hofstetter et al., 2012; Rudzki & Cunningham, 1999). The role of performance training is critical to physical improvement and incremental development in the military setting. The key components of aerobic conditioning, strength training, and load carriage are all vital to overall tactical performance and are essential to optimal physical performance (Hendrickson et al., 2010; Orr & Pope, 2015). However, excessive physical activity in the absence of adequate periodisation and planning can lead to overtraining and musculoskeletal injuries (Deuster & Silverman, 2013; Halson, 2013a).

PART B:

Sleep and Recovery in the Military Setting

Maximising the performance capacity of active service personnel is not only a matter of training, it also depends on the careful consideration of the balance between training and recovery in order to prevent maladaptation to accumulated psychological and physiological stresses (Dupuy, Douzi, Theurot, Bosquet, & Dugué, 2018; Good et al., 2020). However, specific recovery from PT in the military setting has historically been a low priority. Research has tended to focus more on changes in fatigue levels and cognitive function (Vartanian et al., 2018), mental health (Gehrman et al., 2013), illness, and task performance (Wentz et al., 2018), as well as the implications of lack of sleep on task completion (Grandou, Wallace, Fullagar, Duffield, & Burley, 2019; Troxel et al., 2015; Williams, Collen, Wickwire, Lettieri, & Mysliwiec, 2014). Sleep is regarded as essential in the military, with both the quantity and quality of sleep influencing optimal physical performance (Good et al., 2020). Lack of sleep is considered to be of significant concern in the military (Grandou et al., 2019; Moore et al., 2020), potentially effecting physical fitness levels of recruits and officers entering training (Knapik et al., 2006; Knapik, Redmond, et al., 2018; Wentz et al., 2018). The need for consolidated quality sleep in conjunction with optimal levels of fitness is essential firstly, for daily task completion and for safe operation during military deployment (Kyröläinen et al., 2017), and secondly, to improve recovery during all stages of military training (Molloy, 2016; Vartanian et al., 2018).

The Physiology of Sleep

Biological Rhythms

Human physiology is centred upon rhythmic biological functions, with circadian rhythmicity detected in many physiological variables (Vetter, 2018). One such fundamental rhythm is the day-night/sleep-wakefulness cycle (Roky, Herrera, & Ahmed, 2012). The biological timing of the natural day-night cycle is used as a surrogate marker of the circadian rhythm of our 'master clock', the suprachiasmatic nuclei in the brain regulates core body temperature and melatonin rhythms (Vetter, 2018). In an article by Miller, Matsangas, and Kenney (2012), investigating the role of sleep in the military, the importance of sleep on overall human function was emphasised in alignment with sleep rhythms. The circadian system enables a consolidated nocturnal sleep phase which is stimulated by ambient darkness, where increased circulating levels of the pineal hormone, melatonin, are released (Shechter, Kim, St-Onge, & Westwood, 2018). Melatonin acts as the hormonal signal for the onset of the biological night and has been described as imperative to maintaining the sleep-wake cycle. A delay in melatonin onset (or suppressed release) can contribute to subsequent delays in the sleep initiation mechanisms (Shechter et al., 2018).

The Two Process Model of Sleep

Borbely and Achermann (1992) and Achermann (2004) outlined the two-process model of sleep regulation that includes the interaction of these two constituent processes (Figure 1). Firstly, the homeostatic sleep/wake dependent "Process S" occurs: essentially the longer you are awake, the more pressure or drive for sleep builds. When sleep is obtained and the sleep process occurs, this pressure dissipates. Secondly, the circadian "Process C", which generates the timing of sleep and wakefulness. The circadian rhythm (approximately 24 h) tells the body whether it is day (and you should be awake), or night (and you should be asleep). Further to the timing of sleep, changes in daytime vigilance are also components of the two processes. The two-process model also led to the establishment of other models of neurobehavioral functions (Borbely & Achermann, 1992).

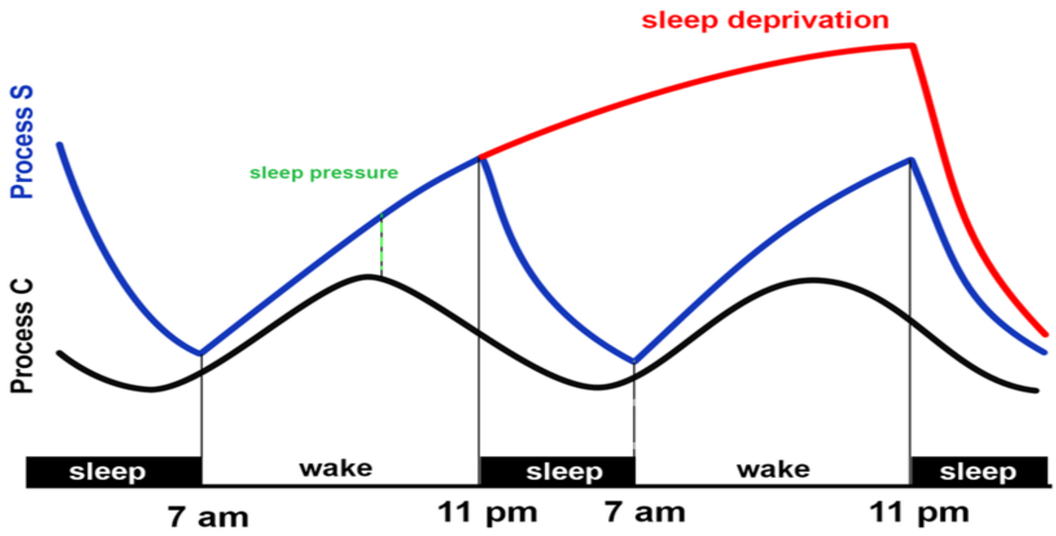

Figure 2. The two-process model of sleep regulation (Borbely & Achermann, 1992) and (Achermann, 2004). Process S indicates the homeostatic build-up of sleep pressure and Process C represents the circadian rhythm. The difference between the two processes quantifies the sleep pressure.

Sleep States

Sleep is categorised into two states, non-rapid eye movement sleep (NREM) and rapid eye movement sleep (REM) (Carskadon & Dement, 2005). According to the sleep staging criteria developed by the American Academy of Sleep Medicine (Good et al., 2020), NREM sleep can be separated into three stages (N1, N2 and N3) and can be considered a continuum of sleep depth. N1 and N2 stages of NREM are considered light sleep and last on average for 1–7 min and 10–20 min, respectively (Venter, 2012) in healthy people free of sleep disorders (Figure 2). Stage N3 is considered “deep sleep” or “slow wave sleep”, and lasts for approximately 20–40 min. REM sleep typically follows NREM sleep in the sleep cycle and is characterised by a brain activity that resembles wakefulness with low amplitude high-frequency electroencephalogram waves, bursts of rapid eye movements, and muscle atonia that prevents the sleeper from physically acting out their dreams. It is during REM sleep that dreaming is most commonly observed. The NREM and REM sleep cycles occur within an 80–100 min period on average throughout the night (Carskadon & Dement, 2005) and allow the various sleep functions to take place (Venter, 2012; Vetter, 2018).

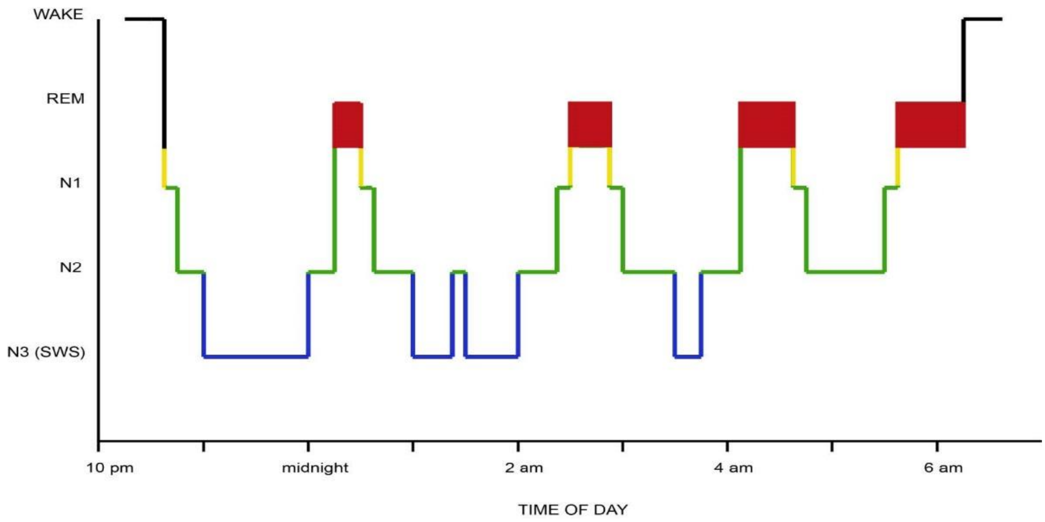

Figure 3. The human sleep cycle (Carskadon & Dement, 2005). WAKE; indicated being awake, REM; represents rapid eye movement, N1; sleep stage one, N2 sleep stage two, N3 (SWS); represents sleep stage three, slow wave sleep.

Important hormonal biorhythms take place in the body in the lead up to bedtime and continue during sleep. Vital to physical recovery and regeneration, growth hormone is released during N3 sleep and is important for muscle growth, repair, and bone building (Davenne, 2009; Halson, 2008). Venter (2012), described that 95% of the daily production of growth hormone occurs during NREM, therefore it is considered the optimal time in which the body can regenerate, repair, and restore. Tissue and structural repair are vital for recovery following strenuous physical activity and load carriage in the military (Orr et al., 2010); therefore, adequate recovery is heavily reliant on sufficient sleep (Grandner, 2017; Wesensten & Balkin, 2013). Additionally, N3 sleep is considered a proxy for the need for physical recovery, with increases in N3 sleep observed following exercise (Torsvall 1984; Baekland & Lasky 1966; Shapiro 1981; and Shapiro 1975).

Measuring Sleep

A number of objective and subjective methods of measuring sleep have been described in literature. Although there are several methods available, the most common objective measures include polysomnography (PSG) and actigraphy, while subjective measures include sleep questionnaires, sleep logs, and diaries. Historically in the military, commanders have been required to manage the sleep of their soldiers based primarily on their experience and assessment of the need for sleep relative to other mission requirements (Fletcher, Wesensten, Kandelaars, & Balkin, 2012). This requirement generally occurred as no objective measure of sleep was obtained over previous days or weeks, and no means of measuring the relative amounts of sleep state versus the wake state were available to predict sustained readiness (Fletcher et al., 2012; Good et al., 2020). In the modern military environment, sleep monitoring and assessment is more common and accepted as a beneficial component of optimal physical performance and operational preparation (Grandou et al., 2019).

Sleep Monitoring with Polysomnography

Polysomnography is considered the gold standard for sleep measurement (Sadeh, 2011) (Dunican et al., 2018). Body functions are measured through the scalp and skin surface electrodes, which record brain activity electroencephalogram (EEG), eye movements (electrooculogram), muscle activity (electromyogram), cardiac activity (electrocardiogram), oxygen levels, and leg movements (Chaudhry et al., 2020; Van de Water, Holmes, & Hurley, 2011). Polysomnography is the preferred method for accurate sleep staging due to the direct measures of brain activity. Polysomnography is also the principal procedure used to analyse and evaluate the treatment of sleep disorders and provides the most comprehensive measurement of sleep indices (Kushida et al., 2005). Other measures of sleep are often validated against PSG due to its accuracy and face validity of sleep assessment (Kushida et al., 2005). Although possible, this type of method is generally not practical in a military environment, due to the logistical constraints, cost, need for facilities/equipment, and the requirement of a specialised practitioner to perform and oversee the testing (Kushida et al., 2005; Scott, McNaughton, & Polman, 2006).

Sleep Monitoring with Wearable Actigraphy Devices

Actigraphy is becoming a well-accepted alternative method of sleep monitoring that has been validated against PSG (Chinoy et al., 2021) and used in a number of different populations. These include: the general population (Arendt, 2010; Maisey, Cattani, Devine, Lo, & Dunican, 2021; Tremaine et al., 2013), the military (Adler, Gunia, Bliese, Kim, & LoPresti, 2017; Ancoli-Israel et al., 2003; Sadeh, 2011), and elite athletes (Fowler, Duffield, & Vaile, 2015;

Fuller, Juliff, Gore, Peiffer, & Halson, 2017; Sargent, Lastella, Halson, & Roach, 2016). Actigraphy is used to objectively assess sleep through the use wrist-worn device containing an accelerometer (Chinoy et al., 2021). The actigraphy device monitors movement for extended periods of time (commonly in 1-minute data segments, known as epochs).

Actigraphy has been validated against PSG with positive relationships observed (Kushida et al., 2001; Sadeh, 2011). Specifically, when comparing sleep metrics attained from actigraphy and PSG, Sadeh (2011) showed a significant and very high (>90%) agreement in healthy individuals for sleep and wakefulness. In addition, a study by Chinoy et al. (2021) showed that the sensitivity was high between PSG and actigraphy at >0.93 in healthy adults aged 24-32 years. Actigraphy provides a sleep assessment tool that can be utilised in an applied setting due to being non-invasive, and thus, practical in sporting and military environments (Kushida et al., 2001).

Research by Chow et al. (2016), investigated the development of a standardised scoring methodology to ensure the accuracy of independent scoring and subsequent data processing and analysis. Follesø, Austad, Olsen, and Saksvik-Lehouillier (2021), also investigated inter-rater agreement rate and the performance of a hierarchical procedure to improve the accuracy of actigraphy sleep file scoring. These research groups concluded that the use of more consistent methods, such as a standardised procedure for setting the rest interval, would improve transparency and reproducibility of actigraphy research. In a validation study of commercially available wrist-worn actigraphy devices by Dunican et al. (2018), it was found that there were some differences between automatically scored and manually scored devices in comparison to PSG, but concluded that an automated scoring algorithm may be used in the same capacity as a manually scored device for the collection of sleep measures including time at sleep onset, total sleep time, and time at awakening.

Sleep Monitoring with Questionnaires and Diaries

Sleep-related questionnaires are frequently used to evaluate and monitor sleep, and to gauge potential sleep disorders in both the general population and athletes. Sleep questionnaires are widely undertaken in conjunction with sleep diaries to evaluate both sleep quality and quantity, as well as the prevalence of wider sleep problems. Administration of these tools is quick, non-intrusive, easy to complete, and additionally they are quick and easy to score and cost effective. Questionnaires are subjective measures based on an individual's perception of sleeping time and quality.

Commonly used sleep questionnaires include, the Insomnia Severity Index for insomnia (Bastien, Vallières, & Morin, 2001); the Berlin Questionnaire for sleep apnea (Sharma et al., 2006); the Morning-Evening Questionnaire for diurnal preference (Beşoluk, Önder, & Deveci, 2011); the Pittsburg Sleep Quality Index (PSQI) (Buysse, Reynolds III, Monk, Berman, & Kupfer, 1989), and the Epworth Sleepiness Scale (ESS) (Johns, 1991).

The Insomnia Severity Index for insomnia comprises seven items assessing the severity of sleep-onset and sleep maintenance difficulties with both nocturnal and early morning awakenings, and satisfaction with sleep pattern, interference with daily functioning, noticeability of impairment attributed to the sleep problem, and degree of distress or concern caused by the sleep problem. Each item is rated on a 0 ± 4 scale and the total score ranges from 0 to 28. A higher score indicates a more likely occurrence of severe insomnia. The insomnia severity index takes less than 5 minutes to complete and can be scored in less than 1 min. The insomnia severity index has shown to be a valuable clinical instrument for use as a screening tool for patients complaining of insomnia and as an outcome measure in treatment research (Bastien et al., 2001).

The Berlin Questionnaire for sleep apnea is a validated instrument for use in the western population to determine the occurrence of risk factors for obstructive sleep apnoea/hypopnoea syndrome. Factors include snoring behaviour, wake-time sleepiness or fatigue, and the presence of obesity or hypertension. Questions have been compiled from literature to elicit factors or behaviours that, consistently predicted and indicate the presence of sleep-disordered breathing. The Berlin questionnaire was evaluated in the population of Cleveland, Ohio USA with a sensitivity of 86% and specificity of 77%, and has emerged as a reliable independent predictor of both mild and moderate obstructive sleep apnea (Sharma et al., 2006).

The Morning-Evening questionnaire for diurnal preference is the most frequently used to determine when learning, particularly in students, is more likely to take place. This diurnal preference is also referred to as morningness or eveningness, or preferred chronotype. The questionnaire was validated in a population mainly comprising young students, where a 4-

choice indicated corresponding to a likely morning type, moderate morning type, moderate evening type, and definite evening type. This questionnaire is used to identify diurnal preference, and in-turn, an indication as to the optimal time to facilitate learning and performance (Taillard, Philip, Chastang, & Bioulac, 2004)

The Pittsburg Sleep Quality Index is a self-reported assessment of sleep quality, which can indicate individuals with clinical sleep disturbances (Buysse et al., 1989). Furthermore, the PSQI can provide a brief clinical valuation of a variety of sleep disturbances that may affect sleep quality (Buysse et al., 1989). The PQSI comprises 19 questions centred around: sleep quality, sleep duration, sleep latency, sleep disturbances, sleep efficiency, the use of sleep medications, and any daytime dysfunction. A high PSQI score (≥ 5) indicates poor sleep/poor sleep quality (Buysse et al., 1989).

The ESS is also a commonly used questionnaire developed to measure sleep propensity and daytime sleepiness in usual daytime situations (Johns, 1991). As outlined by Johns (1991), there is a correlation between adults who suffer from sleep disorders and adults who have associated daytime sleepiness, therefore the ESS can be an important measure. The ESS is based around eight situations, where the individual is asked on a scale of 0–3 how likely they would be to doze off or fall asleep in the set situation, for example; sitting and reading (0 - never doze, 3 - high chance of dozing) (Johns, 1991). The score from the eight situations is added together, to give a total number between 0 and 24. The ESS-validated questionnaire can accurately detect measures of sleep propensity from healthy control populations and a clinically sleep disturbed population (Johns, 1991). In a clinically sleep disturbed population, results showed a significant correlation between ESS score and sleep latency when tested using PSG.

In addition to the above, the McLean's subjective wellbeing questionnaire is also commonly utilised, especially in elite sport settings, however, it is designed to subjectively monitor both sleep and changes in fatigue, soreness, stress and mood. The questionnaire assesses an individual's sleep quality and quantity, fatigue, general muscle soreness, stress levels, and mood on a five-point scale of 1 to 5 with 0.5 point increments (5 = very-good, 4 = good , 3 = normal, 2 = poor, 1 = very-poor). The questionnaire takes no more than 1-2 minutes to complete and is quick to score (McLean et al., 2010).

Sleep diaries allow individuals to self-report sleep occurrences such as the time they go to bed and get up, the time that lights are actually turned out, estimations of time taken to fall asleep, and time at the end of the sleep period (Hooper & Mackinnon, 1995). Sleep diaries provide considerably more benefit when used in conjunction with objective sleep measures such as wearable actigraphy, as previous research has showed that athletes often over estimate sleep duration by up to 30–60 min when compared to validated wearable devices (Caia et al., 2018).

Effects of Sleep Deficit

Short-term insufficient sleep (days to weeks), may cause decrements in mental efficiency and physical performance that can place an individual in the military at augmented risk of committing errors, triggering accidents, and becoming injured (Wesensten & Balkin, 2013). More recently, it has been acknowledged that chronic insufficient sleep (over years) is associated with a variety of negative health outcomes such as cardiovascular, metabolic, mental, immune conditions (Watson et al., 2015), and weight gain (Patel & Hu, 2008). In a review paper by Griggs, Harper, and Hickman (2021), it was concluded that acute sleep deprivation can degrade dimensions of neurobehavioral function including psychomotor vigilance performance in young adults. In a review paper, Hale, Troxel, and Buysse (2020) discussed how there is a strong overlap between sleep problems and other mental and physical health morbidities. This overlap has led to a common misconception that sleep problems are merely an epiphenomenon of other conditions.

Interestingly, Knufinke, Fittkau-Koch, Møst, Kompier, and Nieuwenhuys (2019) discussed how athletes have recently shown markers of poor sleep quality and sleep efficacy despite having sufficient opportunity to sleep. Banks and Dinges (2007), studied the effects of sleep restriction on behavioural and physiological consequences. Of note, the negative effects on physical performance, daytime cognitive dysfunction, as well as reduced attention and working memory can be observed even after severe acute one-night sleep restriction (Banks & Dinges, 2007). However, what should also be considered, is that the impact of disrupted sleep patterns, and subsequent negative effects on physiological performance can vary significantly between individuals (Dennis, Dawson, Heasman, Rogalski, & Robey, 2016). Despite evidence validating the importance of restorative sleep (Tuomilehto et al., 2017), athletes appear to experience more sleep disturbances than the general population (Gratwicke, Miles, Pyne, Pumpa, & Clark, 2021), with even further potential difference between males and females due to physical demand and stress on the body (Miles, Clark, Fowler, Miller, & Pumpa, 2022). Previous military studies have also found that female stress fracture risk and overuse injury risk are greater than those of males doing the same training (Finestone et al., 2014).

Sleep problems have been linked to short sleep duration occurrence in the military (Mysliwiec et al., 2013). Evidence shows that sleep is not adequate in the initial stages of military training (Larsen et al., 2022), as well as in other high tempo occupational roles, such as fire fighters who are required to work long periods in extremely challenging and dangerous environmental conditions (McGillis et al. (2017). Given high physical training loads and injury rates, more focus has recently been given to the use of recovery strategies in the military (Orr & Pope, 2015; Wesensten & T. Balkin, 2013) in conjunction with the importance of sleep (Good et al., 2020).

Sleep as a Recovery Tool

Research regarding sleep as a recovery tool in the military is varied, with multiple strategies being investigated, such as sleep hygiene education (Wesensten & Balkin, 2013), manipulation of bed and wake timings (Baldus, 2002), and objective sleep monitoring to promote healthy sleep behaviours (Troxel et al., 2015). Further studies have investigated subjective sleep monitoring questionnaires with diary implementation to teach and educate (Aloba, Adewuya, Ola, & Mapayi, 2007; Richmond, Dawson, Hillman, & Eastwood, 2004), and the use of pharmacological aids (Miller, Matsangas, & Shattuck, 2008). Increased focus has also been given to reduced blue light emissions from electronic devices prior to bedtime (Sasseville & Hébert, 2010), due to the increased reporting of sleep disorders that effect up to 50% of the general population on an occasional basis, but up to 10% on a more serious chronic basis (Zimmerman et al., 2019).

As stated by Williams et al. (2014), sleep management in the military has long been complicated by the nature of the tactical work performed by active duty service members. Sleep quantity and quality are now being more accepted as critical variables in military readiness and essential prior to operational deployment (Moore et al., 2020). Many military tasks can be adversely impacted by reduced sleep and poor sleep quality (Wesensten & Balkin, 2013). More specifically, the number of problems arising from sleep deficiency following military deployment, and general service have increased (Gehrman et al., 2013). These include: insomnia, obstructive sleep apnea, incidence of post-traumatic stress disorder, and degraded cardiovascular health (Good et al., 2020).

Sleep Deficits in the Military

In a military context, it has been reported that 69% of service members, sleep less than 6 h per night, with only 30% obtaining the recommended 7–8 h of sleep per night (Luxton et al., 2011; Mysliwiec et al., 2013). These sleep deficiency problems should be considered alongside observations of a decline in hand-eye motor-sequence reactions, (Appleman, Albouy, Doyon, Cronin-Golomb, & King, 2016), high risk behaviours (Luxton et al., 2011), and impairments to driving performance as discussed by Fairclough and Graham (1999). Complex mental tasks such as planning and executing military operations/orders are particularly vulnerable to poor sleep (Good et al., 2020; Grandou et al., 2019). Additionally, the ability to maintain alertness in situations with little mental or physical stimulation, such as surveillance, guard duty, piloting, driving, and equipment maintenance, can be severely compromised (Pedersen et al., 2015). Specialised populations such as those in aviation, the Special Forces, and medical personnel have established procedures for dealing with sleep management as a vital component of operational planning; however, in reality these policies are often not able to be enforced due to operational demand (Pedersen et al., 2015). Given that sleep deprivation is associated with impaired cognitive function in higher-order executive processes, this area is worthy of due diligence in the training and operational space.

While sleep loss is a growing concern for the both the general population (Owens, 2014) and elite athletes (O'Donnell, Beaven, & Driller, 2018), military personnel can experience even greater challenges with sleep due to the dynamic changing nature of daily operation (Brown, Berry, & Schmidt, 2013). Inadequate sleep not only occurs in basic military training, but also during academic training at officer academies (Miller & Shattuck, 2005). Cadets at the United States Military Academy had their sleep monitored with actigraphy during their first year. The average weekday sleep duration was 4 h and 58 min and the average weekend sleep duration was 6 h and 31 min (Miller & Shattuck, 2005). The cadets were then followed as part of a 4-year longitudinal study, which showed that their average weekday sleep duration remained less than 5 h and 30 min on school nights (Miller, Shattuck, & Mateangas, 2010). These findings led the authors to conclude that military cadets have a chronic sleep debt and are indoctrinated into a cultural norm of sleep deprivation. Sleep deficit can affect a variety of performance measures including: strength, strength-endurance, aerobic-capacity, and power, and reduce cognitive function and recovery.

Chronic poor sleep not only negatively affects physical performance, it can also have catastrophic consequences in daily military operations (Williams et al., 2014). High risk behaviour such as short sleep duration is manifesting not only in newly deployed military personnel but during resettlement back home and on subsequent redeployments (Luxton et al., 2011). Luxton et al. (2011), discussed how persistent short sleep duration can be a factor in increasing the onset of post-traumatic stress disorder (PTSD), and it should be screened for prior to redeployment, in conjunction with additional education. In addition, it has also been proposed that military-wide policy change may be required to reduce occurrence of real-world high-risk behaviours (Mantua et al., 2021). Chronic sleep decifict can lead to negative emotional reaction (Motomura et al., 2013; Scullin, Hebl, Corrington, & Nguyen, 2020; Simon, Vallat, Barnes, & Walker, 2020), elevating the risk insomnia occuring (Gehrman et al., 2013). Predeployment symptioms of insomnia have also been significatluy associated with a higher risk of developing PTSD, depression, and anxiety post-deployment (Gehrman et al., 2013). Therefore, the purpose of this section is to provide a background on the importance of sleep and its role in recovery and enhancing physical and cognitive performance in the military.

The Importance of Sleep to Physical Performance in the Military

Sleep plays a vital role in optimising the physical performance of an individual (Larsen et al., 2022). Seven to nine hours of sleep per night is the standard recommendation for the general population (Mysliwiec et al., 2013); however, recent research has shown that a growing segment of the general population may obtain well below the recommended 8-h target (Good et al., 2020). Traditionally, sleep research has been focused on the effects of partial and total sleep deprivation, and the accumulation of sleep debt on cognitive function, mood levels, and daytime sleepiness. More recently there has been a growing interest in the impacts of sleep and sleep loss on physical performance (Mah, Mah, Kezirian, & Dement, 2011; Samuels, 2008) and the effects of short sleep duration in athletes (Miles et al., 2022; Miles et al., 2021), and the military (Luxton et al., 2011).

Numerous studies have identified the negative effect of poor sleep on a wide range of human cognitive and physical functions (Broughton & Ogilvie, 1992; Dinges & Kribbs, 1991; Dinges et al., 1997). These studies were well-controlled trials that provide convincing results of impairments that occur with sleep restriction in a laboratory setting, such as decrements to visual psychomotor vigilance, cognitive processing ability, and memory. Of some concern, in the military there can be a reluctance to accept laboratory research due to the notion that motivation and determination will allow individuals to perform optimally in real-world situations despite physical fatigue and sleep deprivation (Shay, 1998). Sleep debt seems ubiquitous in the military, despite documented incidents and policies that emphasise the importance of sleep and sleep management for occupational trades and operational readiness (Grandou et al., 2019).

A key goal of effective sleep education in the military is to ensure commanders understand the importance of sleep and its consequence on continued operational physical performance (Wesensten & Balkin, 2013). In a study by Miller, Tvaryanas, and Shattuck (2012), the manipulation of sleep timing was investigated in two groups of Army trainees. Physical performance (push-ups, sit-ups, and timed 2-mile run), basic rifle marksmanship (target shooting), and a 65-question profile mood state (tension-anxiety, depression-dejection, anger-hostility, vigour-activity, fatigue-inertia, and confusion-bewilderment) were assessed before and after 10-weeks of basic Army training. A control-group (n = 183) with a ‘normal’ sleep period of 20:30 to 04:30, and an intervention-group (n = 209) with a sleep period scheduled between 23:00 and 07:00, to better align with the habitual sleep pattern of the young recruits, were studied. Sleep recorded via actigraphy indicated intervention group obtained significantly more sleep than the control group (31 min more sleep per 24 h). However, the intervention group sleeping 6 h and 5 min per night was still noticeably less than the suggested 7–9 h for young adults. Of note, the intervention group showed significantly improved rifle marksmanship scores over the 10-week basic training compared to control, as well as decreased fatigue, increased vigour, and a trend towards improved overall sleep quality. In regard to physical performance in the Army physical fitness test, no significant difference was observed between the two groups following a sleep schedule intervention, but Miller et al. (2012), did highlight that the intervention group displayed a lower mean fitness composite scores of ~197 compared to the control group of ~221 for push-ups, sit-ups, and the timed 2-mile run. Trainees had to earn a score of ≥ 150 points at the completion of training, with ≥ 50 points in each event to graduate from basic training. In a similar military training environment with Army officer trainees, Ritland (2019) discussed how the ability to sleep longer produced better physical performance for distance jumped (cm) in standing broad jump, and increased motivation levels.

The Importance of Sleep to Cognitive Function in the Military

Rapid eye movement sleep is essential in memory and learning consolidation (Venter, 2012; Walker & Stickgold, 2005). During REM sleep the brain is very active, similar to wakefulness, with relatively high neural activity. It has been proposed that the high neural activity during REM sleep is connected with learning of motor skills (Davenne, 2009; Halson, 2008; Venter, 2012) and memory consolidation (Stickgold, 2005). The quantity and quality of sleep the night succeeding a specific memory task has been positively associated with the extent of retention and recall the following day (Zerouali, Jemel, & Godbout, 2010). Kuriyama, Stickgold, and Walker (2004), also noted that the sleep-dependent learning process provides maximum benefit to motor-skill procedures that proved to be most difficult prior to sleep.

A large body of research has examined the effect of both partial and total sleep deprivation on cognitive performance, and a substantial amount of evidence advocates that sleep deprivation unfavourably affects cognitive performance in the military (Good et al., 2020). In a study by Ritland (2019), it was found that cognitive function significantly improved in trainee officers when more sleep was allocated for four consecutive nights. Trainees significantly increased baseline scores in a psychomotor vigilance test reaction time and speed in a trail making test (Ritland, 2019).

When sleep extension was investigated in US Naval recruits, Andrews (2004) found that increasing the allocated sleep period from 6–8 h significantly improved academic performance in the vocational aptitudes test (ASVAB) of trainees. One full year of data (2003) from the 8-h per night routine was compared to two individual separate years where only 6 h of sleep per night was scheduled (2000 and 2001, respectively). Average academic test scores of 2,597 recruits were then compared by division and month of training (Andrews, 2004). Standardised test scores for each recruit and the year they were trained were entered into a regression model, adjusting for ASVAB score and month of entry administration to adjust for seasonal variation and differences in individual recruit aptitude. Results showed that recruits who received 6 h of sleep per night scored significantly lower than the recruits who received 8 h of sleep per night, with the average test score increasing by 11% for those who received additional sleep (Andrews, 2004). Given that sleep deprivation is associated with impaired cognition, vocational aptitude, and physical function, this area is worthy of due diligence in the training and operational space. Of note, the challenge remains that there is no one optimal coping strategy for poor sleep and work-rest cycles (Andrews, 2004).

Common Interventions to Combat Sleep Deficit

Caffeine

Caffeine is often utilised during extended work periods to both enhance physical performance and to stay awake (Cook, Beaven, Kilduff, & Drawer, 2012). Consequently, caffeine is one of the most widely abused substances in the military (Czeisler, 2006). When used as a neural stimulant, the minimum effective dose should be ingested only when adequate sleep cannot be obtained and only for a brief period. Czeisler (2006) outlined that what is often miscalculated is that when in a state of sleep deprivation, even with caffeine use, physical performance is decreased.

The daily physical demands of the military exceed those of the general population (Knapik et al., 2016). Early morning starts, late finishes, physical training, limited sleep during training, operations, and deployments all lead toward an increased consumption of caffeinated substances, more so than that of the general population (Knapik et al., 2016). Research has shown that even large amounts of caffeine cannot overcome the need to sleep, and fatal sleep-related accidents exceeded fatalities due to alcohol and illicit drug use combined (Czeisler, 2006). Even though alertness and vigilance can be temporarily boosted by caffeine consumption, studies in the military have found that it does not improve fine motor skills, such as marksmanship (Lieberman, Tharion, Shukitt-Hale, Speckman, & Tulley, 2002; Stephens, Attipoe, Jones, Ledford, & Deuster, 2014; Tharion, Shukitt-Hale, & Lieberman, 2003).

In a study by Stephens et al. (2014), the effects of a caffeine-containing energy drink and energy shot consumption was investigated in the military. Those who reported using energy drinks and energy shots indicated that the most common reasons for consumption were to improve mental alertness (61%), improve mental endurance (29%), and to improve physical endurance (20%). Sixty-five percent of users reported side effects, with the most commonly reported being increased pulse rate/palpitations, restlessness, and difficulty sleeping (Stephens et al., 2014). Although caffeine may provide an acute benefit to mental and physical performance, the chronic effect on sleep has been shown to be a negative in short sleeping populations (Knapik, Steelman, Trone, Farina, & Lieberman, 2022), and impacts on both TIB and SE (O'Callaghan, Muurlink, & Reid, 2018).

Sleep Banking and Sleep Extension

A strategy that could potentially have a positive benefit for the military is sleep banking, where extra sleep is allocated prior to a subsequent sleep restriction period, such as a continuous high tempo operation (Wesensten & Balkin, 2013). In a study by Rupp, Wesensten, Bliese, and Balkin (2009), 12 volunteers who were allocated 10 h total time in bed (TIB) per night for 7 nights, performed better during a subsequent sleep restriction challenge of 3 h TIB than 12 volunteers who were allowed 7 h TIB for 7 nights prior to the same 3-h TIB challenge. In essence, if there is a high tempo situation or an upcoming mission that is going to result in a lack of sleep, a targeted period of increased sleep prior to the mission may improve overall physical performance and cognitive function.

A similar strategy to sleep banking, referred to as sleep extension, was investigated by Mah et al. (2011), with athletic performance of university basketball players. During a baseline period of 4 weeks, 6–9 h of sleep per night was obtained. Then for a further 3 weeks, sleep was extended to as much as possible with a minimum goal of 10 h per night. The measures taken throughout the baseline and testing period were sleep duration, athletic performance (sprints and shooting tasks), reaction time, daytime sleepiness (ESS), and mood (Mah et al., 2011). Total sleep time duration showed a significant increase of 110 min from baseline as a result of the sleep extension period, with the average sleep period greater than 10h target. Athletic performance in all three variables measured (282 foot sprint, 10 free-throws, and three-point field goals made out of 15) all significantly improved following the sleep extension period (16.2 ± 2 to 15.5 ± 0.54s sprint; 7.9 ± 0.99 to 8.8 ± 0.97 shots; and 10.2 ± 2.14 to 11.6 ± 1.5

shots, respectively). Further to this, the reaction times recorded in both the morning and evening significantly decreased over the sleep extension period and daytime sleepiness and mood levels improved (Mah et al., 2011).

In another sleep extension study by Swinbourne, Miller, Smart, Dulson, and Gill (2018), 25 highly trained rugby players, participated in a 6-week, pre-post control-trial intervention study. During the final 3-week intervention period, participants were instructed to aim for 10 h sleep per night. Participants were educated about sleep scheduling, strategic napping, as well as controlling for sleep environment factors such as light, noise, and temperature. Sleep extension resulted in a moderate improvement in sleep quality scores (24.8%), small to moderate increases in total sleep time (6.3%) and greater time in bed (7.3%) Additionally, small decreases in cortisol and reaction times were observed following the intervention, compared to the control. It was concluded that professional rugby players were at risk of experiencing poor sleep during intense pre-season training, with concomitant rises in physical stress. Implementing a sleep extension program was recommended to not only improve sleep, but to support beneficial changes in stress hormone expression and reaction time performance.

Taking the available information into account, a decision was made by the United States Navy at the recruit training command to change the amount of sleep allowed by Navy recruits during 63-days of basic training from 6 to 7 h of sleep per night (e.g., mandatory bedtime was from 2100 h to 0400 h). Recruits were under a closely controlled daily schedule and prior to December 2001, received only 6 h of sleep per night. In early 2002, the sleep routine was revamped further to allow recruits 8 h of sleep per night, sleeping from 2100 h to 0500 h. Then in May 2002, the Navy recruit sleep formula was finalised at 8 h per night, with a bedtime at 2200 h and wakeup at 0600 h. This final alteration was selected to coincide with recognised sleep requirements and naturally occurring circadian rhythms of adolescents and young adults in line with the age of recruits (Miller et al., 2012). Studies were then conducted by the Naval Post Graduate School on recruits at Recruit Training Command to assess the effect of these decisions. The first study by Baldus (2002), assessed the quantity and quality of sleep received by recruits in two 8-h sleep conditions: 1). 2100 h to 0500 h and 2). 2200 h to 0600 h. Sleep data and activity were evaluated using wrist-worn activity monitors and individual activity logs were recorded. Data was collected during one full rotation of recruit training from April to June 2002. Thirty-one recruits were observed (20 males and 11 females), from five different recruit divisions (Baldus, 2002). Based on sleep patterns, sleep was defined as non-disrupted (an 8-h continuous night time interval) or disrupted (any night having at least a 30-min period of wakefulness after sleep onset or more than 45 min of wakefulness from bedtime until sleep onset). Disruptions in sleep were usually caused by guard duty, personal administration, and bathroom visits (Baldus, 2002). Results from this study indicated that although recruits were allocated 8 h of sleep per night, the overall average sleep for all recruits was still only 6.1 h per night (Baldus, 2002). Interestingly, recruits tended to receive more sleep when following the 2200 h to 0600 h routine than those following the 2100 h to 0500 h routine. On average, the 2200 h bedtime resulted in 22 min more sleep per night. These findings mirrored those outlined by Miller et al. (2012), where the change in timing matched the shift in adolescent and young adult circadian rhythm (in line with the age of recruits).

Circadian Lighting

Light contributes considerably to the regulation of biological functions in most species on earth (Figueiro, Rea, & Bullough, 2006b). In mammals, circadian rhythms are generated endogenously by neurons in the suprachiasmatic nucleus (SCN) in the anterior hypothalamus. Exposure to light in the daily environment resets the phase of clock neurons in the SCN, which in turn send multi-synaptic projections to sleep-wake centres in the brain to regulate the timing of sleep and wake (Figueiro, 2008a; Gooley et al., 2008).

The daily configuration of the consolidated sleep-wake cycle in humans is strongly influenced by the timing of exposure to light and darkness (Gooley et al., 2008) and the circadian system has a much higher threshold for activation than the visual system and has a peak spectral sensitivity at shorter wavelengths. In the absence of environmental time cues, the sleep/wake cycle continues to exhibit a near-24-h circadian rhythm (Gooley et al., 2008), albeit with a certain amount of drift resulting from the average human circadian period being longer than 24 h. Exposure to the 24 h solar cycle normally ensures that we remain entrained to the 24 h light/dark cycle with peak performance and alertness during daytime hours, and a consolidated bout of sleep during the night (Booth, Probert, Forbes-Ewan, & Coad, 2006; Figueiro et al., 2006b). In a study by Gooley et al. (2011), it was established that when compared with dim light, exposure to bright room light in the evening prior to bedtime suppressed melatonin. This exposure resulted in a later melatonin onset in 99% of individuals and shortened nightly

melatonin exposure duration by ~90 min. Exposure to bright room light during the usual hours of sleep also showed suppression in melatonin by greater than 50% in most individuals.
In a study by Kozaki, Koga, Toda, Noguchi, and Yasukouchi (2008) investigating the effects of different light exposure and reducing short wavelength, it was found that lowering the light from a 3000 K lamp to 2300 K lamp appeared to decrease melatonin suppression. Individual effects have previously been observed in sensitivity levels to light and corresponding effects on sleep and circadian rhythms (Chellappa, 2020). Literature indicates that the application of bright light during the day (between 1000 lux [Illuminance; luminous flux per unit area] and 8000 lux at the cornea) and dim light at night is a means of resetting natural circadian rhythm affected by light (Figueiro, 2008; Rahman, Hilaire, & Lockley, 2017). This approach was also supported by Knufinke et al. (2019) who found that blocking short-wavelength light in the evening through the use of amber-lens glasses is a cost-efficient and promising means to improve subjective sleep estimates among recreational athletes in their habitual home environment. Depending upon the timing, duration, illuminance at the eye, and spectrum of the light (Munch et al., 2006), indications are that circadian rhythms can be synchronised, phase advanced, or phase delayed with respect to the solar day (Figueiro et al., 2008).

Light interventions can be characterised in five dimensions: quantity, spectrum, distribution, timing, and duration (Rea, Figueiro, & Bullough, 2002). Light provides high levels of stimulation even at night when asleep, and Zeitzer, Fisicaro, Ruby, and Heller (2014) have shown that exposing individuals to a series of 0.002 ms flashes of bright light (totalling 0.24 s) during sleep delayed the timing of circadian salivary melatonin rhythm. Although the eyelid can attenuate roughly 90% of light stimulation (Moseley, Bayliss, & Fielder, 1988; Robinson, Bayliss, & Fielder, 1991), Zeitzer et al. (2014) still found the flash of light changed circadian stimulation. This finding was also supported by Figueiro, Bierman, and Rea (2013), who also found that when delivering flashing light through closed eyelids while people were asleep, a light-stimulus condition compared to no light, significantly delayed circadian phase and significantly suppressed nocturnal melatonin.

As outlined by Hebert (2002) and Figueiro (2008a), the internal clock can be reset forward (phase advance) or backward (phase delay) depending on the timing of light exposure. The sensitivity of the circadian system to light appears to change depending on previous light exposures. For example, an office worker who stayed in a dim room all day will suppress more melatonin when exposed to a given light at night than would a farmer, who had experienced very high outdoor light levels during the day. In this respect, the circadian system appears to be more concerned with contrasting (night versus day) than absolute light levels (Brooks, Fuller, Kemp, & Reddin, 2008).

In a study by Figueiro (2008a), it was proposed that a dual lighting scheme that maximises circadian stimulation during the day and minimises it at night, while maintaining good visibility at any time is ideal to enhance sleep. Evidence suggests that stimulation during daytime waking hours can be achieved by about 400 lux at the cornea of a 6500 K cool-white light source (Figure 4). During evening waking hours, the lighting system should provide no more than 100 lux at the cornea from a white light with low energy in the short-wavelength region of the spectrum. Relatively dim ambient evening light can be provided by light sources such as a 2700 K (warm-white) compact fluorescent lamp. The dual lighting system provided a day/night light ratio of about 16:1 (Figueiro, 2008a). Further studies by Gooley et al. (2008), Figueiro et al. (2006b), and Figueiro et al. (2014), suggest that ambient light levels reduced to 80–100 lux at the cornea from a neutral light source of 3000–4100 K (Figure 4) can passively stimulate the circadian rhythm enhancing sleep and the sleep-wake cycle. To our knowledge the use of altered lighting as a sleep intervention has not been reported in the literature previously in a military setting.

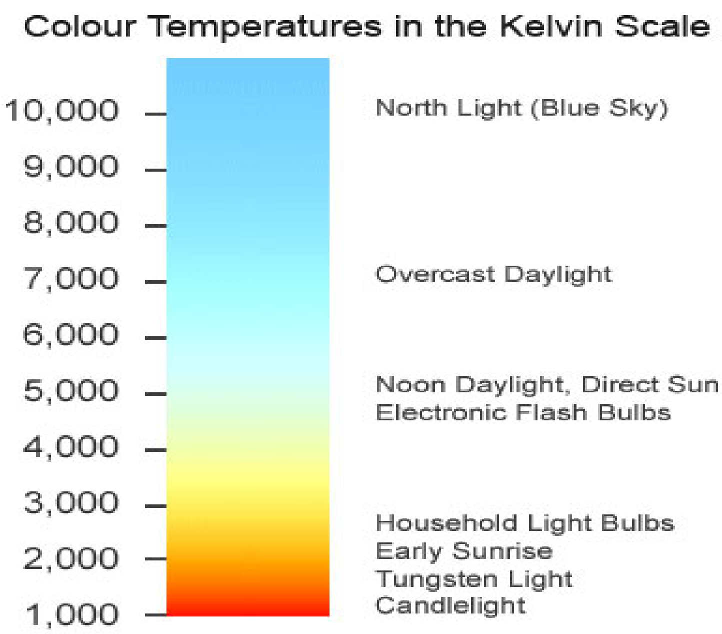

Figure 4. The Kelvin colour temperature chart for lighting. (Mariana Figueiro, Lighting Research Centre (LRC), Rensselaer Polytechnic Institute, Troy, N.Y., USA).

Modern technology now ensures florescent tubes and light-emitting diodes are significantly more efficient to run (lower Watts required) and emit brighter light for less power than a standard incandescent bulb. However, although florescent tubes and light-emitting diodes are more efficient and produce superior light, they also operate at a significantly higher Kelvin colour temperature and emit elevated levels of blue light (Boyce, 2010). Although generally becoming less popular, incandescent bulbs potentially still have a place in positively enhancing lighting in sleep interventions and health care in the hours before bedtime due to limited negative circadian stimulation (Figueiro & Rea, 2006a).

Compression Garments as a Recovery Tool

While numerous recovery interventions have been investigated in the literature, the use of CG is one practical option that could be utilised in the military environment. Compression garments are used widely in various physical performance environments (Hettchen et al., 2019) and may potentially enhance the recovery processes allowing faster cellular repair from structural damage to the skeletal muscle following intensive exercise (Kraemer et al., 2010). Repeated isometric or concentric muscle contractions result in fatigue and damage to working skeletal structures that quickly recover without any long-term loss of function (Smith, Kruger, Smith, & Myburgh, 2008). In contrast, unaccustomed eccentric muscle contraction (common in the military) frequently results in a greater loss of acute function which can take several days to recover (Harty, Cottet, Malloy, & Kerksick, 2019; Proske & Allen, 2005). Muscle soreness can often occur in the days following eccentric exercise, or more commonly known as delayed onset muscle soreness, or DOMS (Howatson, Van Someren, & Hortobagyi, 2007).

Compression stockings have been shown to promote blood flow from superficial veins into deep veins (Herzog, 1993), and previous studies have suggested the wearing of CG can act to increase venous blood flow (Broatch, Bishop, Halson, 2018; Lee, Law, et al., 2020; O’Riordan, Bishop, Halson, & Broatch, 2022). Bochmann et al. (2005), found increased arterial blood flow after 3 h of constant application of GC at interface pressures of 13-23 mmHg. When elite junior basketball players were assigned to a CG group of either socks, shorts or full-length CG tights, the tights displayed the most benefit to venous blood flow when measured using Doppler ultrasound at the popliteal and femoral vein, and in the gastrocnemius medialis and vastus lateralis using near-infrared spectroscopy (O'Riordan, McGregor, Halson, Bishop, & Broatch, 2021). Full length CG tights were concluded as providing the most benefit to blood flow venous return due to potentially providing a larger body area to be compressed (O'Riordan et al., 2021).

In an additional study by Broatch et al. (2020) it was also found that wearing CG during treadmill running proved effective in reducing thigh and calf muscle displacement. In the short term these displacements and vibrations may prove to be beneficial to attenuating impact forces that potentially cause injury, however, repeated or chronic exposure to vibrations can have injurious effects. Therefore, CGs ability to reduce muscle displacements may prove beneficial to performance in the long term (Broatch et al., 2020). It is also speculated that compression garments aide the muscle pump associated with blood flow (Lovell, Mason, Delphinus, & McLellan, 2011), and the wearing of CG supports active recovery and some of the underlying benefits seen in athletic populations (Brown, Gissane, Howatson, Van Someren, et al., 2017; Hettchen et al., 2019). Although the use of compression is often advocated for improved recovery from exercise induced muscle damage in the sports environment (Leabeater, James, & Driller, 2022; Weakley et al., 2021; Gill, Beaven, & Cook, 2003), there is little information regarding the effect of compression on recovery in the military setting.

Studies by Davies, Thompson, and Cooper (2009) and Kraemer, Bush, Wickham, Denegar, Gomez, et al. (2001) have shown that CG maintained muscle function and reduced perceived muscle soreness following eccentric exercise. These studies also showed that compression garments attenuate creatine kinase (CK) release from skeletal muscle into circulation following eccentric exercise. The attenuated CK release and maintenance of muscle function were attributed to the effect of the CG preventing oedema within the muscle (Davies et al., 2009; Kraemer, Bush, Wickham, Denegar, Gómez, et al., 2001; D. Lee, Law, et al., 2020). However, despite these functional and biochemical adaptations, the effects of CG on intra-cellular metabolism are not fully understood (Kraemer, Bush, Wickham, Denegar, Gómez, et al., 2001).

Many studies have examined the benefits of CG in regard to diverse exercise regimens; however, the relationship between compression and the autonomic nervous system has not been fully explored. Hu et al. (2020), aimed to examine Heart Rate Variability (HRV) trends in relation to the wearing CG. During a two-week intervention period, it was concluded that in novice runners, compression was effective in counteracting some deleterious effects from overtraining. Brown et al. (2020) investigated the benefit of CG in rugby players after lower-limb strength and sprint training, when worn for a 48 h period post activity. Marqués-Jiménez et al. (2017), explored the benefit of CG when worn for 7 h each day for 7-days post soccer match competition; however, no studies to date have investigated the effect of CG on physical performance and recovery in a chronic long duration setting. Although Hu et al. (2020), did examine CG in a medium duration setting, physical performance variables were not investigated.

The prevalent approach to CG research has been to investigate outcomes in the acute setting. Previous studies have shown benefit of CG wear to fatigue and muscle soreness in basketball after 15 h of CG wear post competition (Atkins, Lam, Scanlan, Beaven, & Driller, 2020,), during free-throw shooting accuracy (Wong et al., 2020), and in sprint cyclists muscle blood flow and exercise performance, when worn during exercise (Broatch, Petersen, & Bishop, 2018). In a high intensity training environment, a study by Argus et al. (2013), investigated the efficacy of different recovery strategies in highly trained cyclists following maximal sprints. Three sets of 30 s sprints were interspersed with 20-min recovery periods where compression garments were worn. When compared to a control group the CG group showed a higher mean power output, with authors concluding that CG may be an effective tool for recovery to enhance repeated sprint performance.

Although reviews and meta-analyses on the use and benefit of CG have returned varied conclusions (Brown, Gissane, Howatson, Van Someren, et al., 2017; da Silva et al., 2018; Lee, Ali, Sheridan, Chan, & Wong, 2020; Leabeater et al. 2022; MacRae, Cotter, & Laing, 2011; Marqués-Jiménez, Calleja-González, Arratibel, Delextrat, & Terrados, 2016), the majority of literature supports the use of CGs following exercise as an acute recovery strategy. A meta-analysis by Brown, Gissane, Howatson, Van Someren, et al. (2017), reported that CGs may aid in recovery following resistance training eccentric load, for following day aerobic activities. A study by Redolfi et al. (2011), exhibited potential benefits to enhanced sleep and reducing obstructive sleep apnea when CG were worn during the day to reduce apneas and hypopneas per hour of sleep. The study concluded that findings provide proof-of-principle that overnight fluid displacement into the neck plays causative role in obstructive sleep apnea (Redolfi et al., 2011). However, as noted, while the acute use of CGs has been well studied, an area that requires future research is the long-term/chronic use of CGs as a recovery strategy.

Conclusion

Based on the current literature, it can be concluded that recovery and sleep are influenced and affected by many variables such as physical training load (Orr & Pope, 2015), injury (Wesensten & Balkin, 2013), general health (Nedeltcheva, Kilkus, Imperial, Schoeller, & Penev, 2010; Redline, 2012), and circadian rhythms/the 24 h day-night cycle (Figueiro et al., 2014; Figueiro et al., 2006b). The dynamic nature of military operations (Wesensten & Balkin, 2013) and lighting (Figueiro et al., 2014; Gooley et al., 2008; Rea et al., 2002) also further influence these environments and outcomes. This review highlights the importance of sleep on recovery and performance and outlines the need for further research in the military population.

A common thread in operational militaries worldwide are high cases of accumulating sleep disorders and poor physical recovery (Miller et al., 2012). Critical examination of the fundamental approach to physical performance, recovery, and sleep in the modern military environment is needed (Knapik, Redmond, Grier, & Sharp, 2018), and will add to the body of knowledge about physical performance and operational effectiveness (Lovalekar et al., 2018; Miller et al., 2012). Physical training is essential amongst military forces, and like athletes, the need to recover and adapt is vital; however, very little research has been undertaken in this space, particularly in the area of sleep (Lovalekar et al., 2018). Given sleep is one of the most important recovery strategies we have following exercise (Wentz et al., 2018), the need for more research in this area is vital in understanding the impact that both poor sleep and good quality sleep have on military personnel (Vartanian et al., 2018).

The application and use of light manipulation as a passive strategy to enhance sleep has been utilised in sport and health literature (Boyce, 2010; Rahman et al., 2017; Sasseville & Hébert, 2010) and may show to be beneficial in the military environment. As outlined in this review, the link between recovery and sleep in the military is evident (Brown et al., 2013; Ojanen et al., 2018), as are the links between sleep and physical performance, and, sleep and cognitive function (Friedl, 2018). However, topics of recovery, sleep, and the use of light are yet to be studied in depth in the New Zealand Defence Force (NZDF). Research in the area of sleep and recovery will provide important information to the NZDF and the global military population, and future research in a military setting may yield performance and recovery gains for personnel across multiple service, training, and operational roles.

Although literature on the benefit of CG is mixed (Brown et al., 2017; da Silva et al., 2018; Lee, et al., 2020), research generally supports the use of CG's as an effective acute recovery strategy. Recovery implemented early has been shown to reduce inflammation and the occurrence of secondary muscle damage and can support performance (Chazaud, 2020). However, despite an abundance of research on the acute use of CG as a recovery strategy in athlete settings, there is no research on the benefit of CG in either the acute or chronic setting in the military.

CHAPTER THREE

Physical characteristics of New Zealand Army, Navy and Airforce officer trainees' pre and post a 6-week joint officer induction course.

Edgar, D., Gill, N., & Driller, M. (2020). Physical characteristics of New Zealand Army, Navy and Airforce officer trainees' over a 6-week joint officer induction course. *The Journal of Sport and Exercise Science*, Vol 4, Issue 2, 63-71.

Prelude: Study One was designed to focus on characterising the levels of fitness in new recruits on a 6-week Joint Officer Induction Course (JOIC) in the New Zealand military. A secondary aim of the study was to compare differences across groups from Army, Navy, and Air Force. Furthermore, we also wanted to collect information on the perceived recovery and sleep metrics during the JOIC to identify any issues for further examination.

Abstract

Background: Fitness levels of military personnel has been well researched around the world, however limited data exists on the New Zealand Defence Force (NZDF). This study identifies NZDF officer trainees' physical characteristics during a Joint Officer Induction Course (JOIC) and compares differences across groups. **Methods:** 116 participants (Army n = 75; Navy n = 25; Airforce n =16) were tested over 2.4km run, muscular-endurance (press-ups and curl-ups), body-mass and Y-balance musculoskeletal screening, pre and post a 6-week JOIC. **Results:** Army performed better in the 2.4km run and press-ups compared to other services ($p < 0.05$), Navy performed better in curls-ups. At completion, there were significant improvements in 2.4km run ($p = 0.02$), press-ups ($p = 0.04$) and curl-ups ($p = 0.01$) across all services. **Conclusion:** Army officers performed better when compared to Navy and Airforce. Significant improvements were found for aerobic fitness, upper-body and core muscular-endurance across all services, following a 6-week JOIC.

Introduction

The physical fitness levels of recruits and officers entering military service is a major area of interest for defence forces worldwide (Knapik et al., 2006; Knapik, Sharp, & Montain, 2018; Robinson et al., 2016; Rosendal et al., 2003; Rudzki & Cunningham, 1999). Optimal levels of fitness are essential for daily task completion and for safe operation during military deployment (Kyröläinen et al., 2017) as there is still an essential need for physically capable men and women to deploy and fight on ground, sea and air spaces in the modern military world (Friedl et al., 2015). This has been illustrated by Lovalekar et al. (2018) when measuring physical performance/fitness was ranked in the top five of 44 priority research areas identified via surrey at the 2018 International Congress on Soldiers Physical Performance in Melbourne Australia; with eight of the top ten ranked topics focused on physical demands in operational environments and measuring physical performance adaptation (Lovalekar et al., 2018).

While there is research on other forces in the world in relation to physical training and fitness assessment, including the USA (Deuster & Silverman, 2013), Finland (Kyröläinen et al., 2017), Australia (Rudzki & Cunningham, 1999), and Britain (Brock & Legg, 1997), there is limited research on the New Zealand Defence Force (NZDF) and especially new officer trainees. Although it is clear that physical fitness is vital for military forces, the physical characteristics of recruits and officers entering the NZDF has not been fully understood, and as a result an unwanted outcome of certain forms of training is high injury rates (Davidson et al., 2008). Such rates have been revealed both internationally (Andersen et al., 2016) and in New Zealand (Brooks et al., 2008). Previous research suggests military recruit physical performance has generally focused on load carriage and physical preparedness, and its effect on the body. Literature has established that four key factors play a major role in contributing to poor physical-condition and physical-state in military recruits: 1) time and distance on feet (Knapik et al., 2006); 2) entry level fitness (Molloy, Feltwell, Scott, & Niebuhr, 2012); 3) lower-limb strength (Bullock et al., 2010); and 4) pre-existing injuries (Knapik et al., 2001). These four defined areas combined with a lack of research and data in New Zealand has impacted adversely on the success of the NZDF joint officer induction course (JOIC). Furthermore, research suggests physical training approaches for the modern military service person need to focus on a flexible integration of strength, power and aerobic performance training programs (Kraemer & Szivak, 2012). It is of the utmost importance that forces are physically ready for deployment and physical assessments play vital role in ensuring this occurs. It is also internationally accepted that military personnel need to be physically fit to perform their normal duties, which are likely to be more physically demanding than that of the normal civilian population a (Lovalekar et al., 2018), and as previously indicated, will substantially vary within the NZDF. Therefore, it is essential that physical training in the military positively facilitates fitness and conditioning improvement from the on-set of recruit and officer training.

Successful completion of the JOIC, which is the initial training phase for all new officers joining the NZDF, has been compromised by trainees entering the course at low levels of fitness. These low levels have contributed to a lack of ability to progress in the physical training program (Davidson et al., 2008). However, if initial military training is well structured, fitness can be improved with concurrent reductions in injury (Rudzki & Cunningham, 1999). Although an important wider topic injury is not the focus of this paper. Brock and Legg (1997), investigated the effects of 6-weeks of physical fitness training in female British Army recruits and found 6-weeks was effective for recruits to respond with significant increases ($p < 0.05$) in mean VO_2 max (45.7 $ml.kg.min^{-1}$ to 46.7 $ml.kg.min^{-1}$). This study showed that aerobic fitness can increase effectively over a 6-week military training period. Also observed in the same 6-week period was a significant reduction in mean percentage body fat by 3.3% ($p < 0.001$), indicating that the training period also influences energy balance.

de la Motte et al. (2016) Suggested that in order to effectively quantify and characterise progressive loading and improvements in physical conditioning across a given course, physical trainers will benefit from baseline fitness and musculoskeletal data prior to finalising and planning the physical training. Pre and post fitness testing and musculoskeletal functional screening data needs to be used to enhance physical training and should be accepted as standard operating procedure (de la Motte et al., 2016; Simpson et al., 2013).

The purpose of the current study was to characterize the trainee officers and assess the effectiveness of the physical training program prescribed within the NZDF JOIC. A further aim of this study was to compare the entry level physical characteristics of the recruits from different services and differences between males and females.

Methods

Participants

A total of 116 newly recruited healthy officer trainees (n = 95 male, n = 21 female, age 24 ± 12 years [mean ± SD]) from the NZDF participated in the current study. Participant demographics for each sex and area of service (Army, Navy and Airforce) are displayed in Table 1. Participation in the study was voluntary and ethical approval for the study was obtained from the institution's Human Research Ethics Committee and the NZDF. Volunteers were all from the same course and no trainees declined to be involved. Volunteers were explained the procedures and requirements, and signed consent was provided.

Experimental Design

The experimental design included a single-group longitudinal study, whereby all participants were tested for physical characteristics and performance pre and post a 6-week JOIC. Fitness and musculoskeletal data were collected in weeks one and six of the JOIC across two 90-minute sessions. These tests were selected as they were standard NZDF protocols in place.

Table 1. Participant demographics. Data shown as means ± standard deviations.

	n	**Age (y)**	**Height (cm)**	**Body Mass (kg)**
Male				
Army	65	25 ± 7.2	181 ± 5.5	78 ± 12.6
Navy	18	26 ± 2.6	179 ± 6.5	82 ± 13.2
Airforce	12	24 ± 2.8	178 ± 7.5	74 ± 17.4
Male Mean	**95**	**25 ± 2.8**	**179 ± 7.5**	**78 ± 14.6**
Female				
Army	10	24 ± 12	173 ± 7.5	73 ± 10.3
Navy	7	25 ± 5.2	168 ± 9	72 ± 13.8
Airforce	4	21 ± 2.6	174 ± 7.5	74 ± 5.2
Female Mean	**21**	**23 ± 13**	**171 ± 8**	**73 ± 9.8**
Total Mean	**116**	**24 ± 12**	**175 ± 8**	**75 ± 12.1**

Physical Training Program

Physical training (PT) comprised a controlled two-week introduction phase of body weight exercises and aerobic conditioning. In weeks three and four, the intensity of PT increased to challenge individuals. Weeks five and six then focused on functional fitness and conditioning. This included increased load carriage with a combination of field packs, day packs, webbing (military load-carrying vest with pouches for ammunition and water bottles), and weapons. There was a specified 10-minute warm-up and 5-minute cool-down period for all PT sessions. A total of 18, 90-minute periods were allocated to physical training over the 6-week period and included a combination of aerobic interval running, strength training, circuits, swimming, and bike-boxing-rowing intervals as outlined in Table 2.

Table 2. Joint Officer Induction Course Physical Training Program.

Note: A ten minute 6am early morning activity (EMA) was also conducted daily including stretching, mobility and cognitive reaction games.

Day	Physical Training Class (PT)	Military Activity	Total Time On-Feet
		WEEK 1	**Intensity:** High, Med, Low (H-M-L)
Monday	**Arrival-** Walking		4hr - L
Tuesday	Walking		5hr - L
Wednesday	Introduction to physical training	50min Basic Drill	5hr - M
Thursday	**(Pre) Fitness Evaluation**	50min Basic Drill	5hr - H
Friday	30 min Running + 30 min Body weight standing exercises	Class work	4hr - M
Saturday		Class work	6hr - L
Sunday	60min Circuit: Lift / Push / Pull / Lift	Class work	6hr - H
		WEEK 2	
Monday	60min 200m swim test & water tread + body weight exercises	Class work	6hr - M
Tuesday	60min Interval running 6x800m	3hr Survival training workshop	6hr - H
Wednesday	90min Aerobic Intervals (Off feet): Bike / Row / Box / Core	Class work	4hr - H
Thursday		16hr Endurance Activity: Leader building, marching, load carrying, problem solving, PT Circuits, Running.	18hr - M
Friday	40min Pool Recovery & Stretch	Class work	3hr - L
Saturday		7hr Weapons training	5hr - M
Sunday	OFF	OFF	
		WEEK 3	
Monday	90min Interval training: Bike / Row / Box / Core (Off-feet)	4hr Weapons training	5hr - M
Tuesday	90min Interval Run 6x 400-800m & body weight standing exercise	4hr Weapons training	5hr - H
Wednesday		4hr Weapons training	5hr - M
Thursday		4hr Weapons range activity	2hr - L
Friday		9hr Weapons range activity	6hr - M
Saturday		9hr Weapons range activity	6hr - M
Sunday		4hr Weapons range activity	2hr - L
		WEEK 4	
Monday	90min Interval Run 8x 400-800m & body weight standing exercise	3hr Land navigation	4hr - H
Tuesday	90min Interval training : Bike / Row / Box / Core (Off Feet)	6hr Land navigation	10hr - M
Wednesday	60min Circuit: Lift / Push / Pull / Lift	4hr Sea survival workshop (pool)	6hr - M
Thursday		4hr Land navigation	6hr - L
Friday	60min Interval running 4x800m	Class work	3hr - H
Saturday		8hr Bush craft skills	10hr - L
Sunday	OFF	OFF	
		WEEK 5	
Monday		24hr Sea & bush survival activity	18hr - M
Tuesday		Class work	3hr - L
Wednesday	60min Strength & Mobility + 6x 50 'stride outs'	60min Basic drill	4hr - M
Thursday	60min Pool + body weight exercise	60min Basic drill	4hr - M
Friday	**(Post) Fitness Evaluation**	Class work	4hr - H
Saturday		Tactical field exercise living outdoors: Patrolling, Vehicle checkpoints, obstacle building, navigation	18hr - M
Sunday		Tactical field exercise living outdoors: (As above)	18hr - M
		WEEK 6	
Monday		Tactical field exercise living outdoors: (As above)	18hr - M
Tuesday		Tactical field exercise living outdoors: (As above & Including 12km pack march)	14hr -M/H
Wednesday		60min Basic drill	5hr - L
Thursday		60min Basic drill	5hr - M
Friday	Course End	Course End	

Fitness Testing

The standard NZDF JOIC fitness evaluation was conducted by the same NZDF Physical Training Instructors (PTIs), at 0800 both pre and post course. This evaluation consisted of three key components, 1) 2.4km road run, 2) maximum curl-ups, and 3) maximum press-ups. The 2.4km road run, which has been shown to provide an effective evaluation of aerobic fitness (Booth et al., 2006; Burger et al., 1990), was completed on a sealed flat road in two groups of 58. The run was conducted in a similar fashion to that described by Knapik et al. (2006), where participants started together, but individual effort was assessed by participants completing the distance in the quickest time possible. Run times were measured via stopwatch to the nearest second by a designated PTI.

The Curl-up protocol as used by Vera-Garcia et al. (2000) provided an evaluation of local muscular-endurance of the core where repetitions were completed until failure (inability to continue). The curl-up was performed with participants in a supine position with knees bent at 90º and feet flat on the floor. Hands were held in a fist with arms straight. Hands slid up the thigh until the wrist met the apex of the knee. Hands then slid back down the thigh until the shoulder blades and shoulders touched the ground. A repetition was counted by a PTI every time the wrist reached the apex of the knee until failure. There was no time limit on repetitions, but they were completed in a continuous fashion with a pause of only 1-2 seconds between reps.

Press-ups were used to assess upper-body muscular-endurance similar to the protocol outlined by Booth et al. (2006) and Knapik et al. (2006). They were performed on a flat wooden gymnasium surface. Hands were placed on a line in the prone press position just slightly wider than shoulder width. A 'ready' cue was then given where the body position was adjusted up to the start position of arms straight, feet shoulder width apart and the head looking downward. From the start position the body was lowered eccentrically with a straight-line maintained between the shoulders and heels, until the elbows were at 90º or until the chest was approximately 3-5cm from the ground. During the concentric phase arms were extended until straight while maintaining the back and head positions. A repetition was counted by a PTI every time the full range of motion was completed until failure. For both the press-ups and curl-ups, one warning was given for an incomplete repetition, prior to participants being stopped by the PTI.

Body mass was recorded at 0800hr prior to the fitness assessments on a set of digital scales (SOEHNLE, Style Sense Safe 200, Germany) to the nearest 100g, while participants wore a t-shirt and shorts with shoes removed.

The Y-Balance Musculoskeletal Screening Test

To determine musculoskeletal asymmetry, the Y-balance test (YBT) was used for both the Lower (YBT-LQ) and Upper Quartiles (YBT-UQ) (Shaffer, 2013). The YBT-LQ examines unilateral reach in three different directions, anterior, posteromedial, and posterolateral. Differences in the maximum reach distance for left and right leg were compared to examine reach asymmetry for each direction, with lower limb reach normalised to leg length (anterior superior iliac spine to the most distal portion of the medial malleolus). The YBT-UQ test is designed to obtain a quantitative measure of trunk and upper extremity functional symmetry, core stability, strength and mobility. It is shown to be a reliable predictor of upper body musculoskeletal injuries, particularly in the shoulder girdle (Butler et al., 2014a; Butler et al., 2014b; Gorman et al., 2012). For YBT-UQ participants reach in three directions; medial, inferomedial, and superomedial to determine percentage of functional symmetry and potential injury risk. Scores are also normalised to participant's arm length (spinous process of the cervical vertebrae C7 to the tip of the longest finger of the right arm). Individuals with asymmetries greater than 4cm are more likely to sustain injury (Plisky et al., 2006).

Reach scores and limb measurements are used to determine a composite score: a YBT-UQ score less than or equal to 88% for males and 85% for females, is a strong indicator that the participant is at risk of injury (Butler et al., 2014a; Butler et al., 2014b; Gorman et al., 2012), due to inadequate core stability and strength. A YBT-LQ score less than or equal to 98% for males and 92% for females, is a strong indicator that the participant is at risk of injury (Plisky et al., 2006). Differences between left and right reach distances more than 4cm are also an indicator of asymmetry and a risk for injury (Butler et al., 2014b).

Statistical Analysis

Simple group scores are shown as mean ± SD values unless stated otherwise. All statistical analyses were performed using the Statistical Package for Social Science (V. 22.0, SPSS Inc., Chicago, IL), with statistical significance set at $p \leq 0.05$. A Student's paired T-test was used to compare pre to post performance measures for the entire group, for each sex (male, female), for each service (Army, Navy, Airforce). To examine whether there were any differences between subgroups, Group (e.g., male vs female, service comparisons) x Time (pre and post) two-way multivariate analysis of variance (MANOVA's) were performed. A Bonferroni adjustment was applied if significant main effects were detected. Analysis of the distribution of residuals was verified visually with histograms and also using the Shapiro-Wilk test of normality. Magnitudes of the standardized effects between pre and post were calculated using Cohen's *d* (Cohen, 1988) and interpreted using thresholds of 0.2, 0.5, and 0.8 for *small, moderate and large*, respectively.

Results

A total of 119 officer trainees started the JOIC with 116 completing the course, representing a drop-out rate of 2.5%. Those that dropped out were not injured but left due to personal choice. At baseline, Army trainees performed significantly better in the 2.4km run and press-ups than their Navy and Army counterparts ($p < 0.05$) (table 3), however Navy trainees at baseline performed significantly better in curls ups than both Army and Airforce ($p = 0.01$).

Following 6-weeks of JOIC training, there was statistically significant decreases in body mass for Army males (78 ± 10.1 to 76.1 ± 9.2, $p < 0.01$, $d = -0.18$), Navy males (81.1 ± 13.8 to 79.3 ± 12.4, $p < 0.01$, $d = -0.20$), and all females collectively (73 ± 13.0 to 71.4 ± 11.8, $p < 0.01$, $d = -0.120$, Table 10). The total mean across all groups also showed a decrease in body mass from (75.5 ± 11 to 73.7 ± 10, $p < 0.01$, $d = -0.20$).

Performance improvement was evident (Table 3, Figure 5 over the duration of the JOIC with statistically significant decreases in 2.4km run time for all males (644 ± 83 to 589 ± 82, $p < 0.01$, $d = -0.57$), all females (708 ± 48 to 661 ± 42, $p < 0.01$, $d = -0.86$), and for all JOIC participants collectively (676 ± 83 to 625 ± 82, $p < 0.0$, $d = -0.57$). Following the 6-weeks of training there were also significant increases in maximum repetitions for press-ups (26 ± 12 to 33 ± 11, $p < 0.01$, $d = 0.48$), and curl-ups (42 ± 21 to 56 ± 39, $p < 0.0$, $d = 0.67$) for all JOIC participants (Table 3).

The MANOVA resulted in a significant difference when comparing gender for pre-post 2.4km run time ($p < 0.01$), and press-ups ($p < 0.01$). However, there were no significant differences found for curl-ups ($p > 0.05$). There was a significant group interaction for service pre press-ups for Army vs Navy ($p < 0.01$) and Army vs Airforce ($p = 0.01$). There was a significant interaction for post press-ups for Navy vs Army ($p = 0.01$). No significant interaction was found for any other measures.

YBT musculoskeletal screening following 6-weeks of JOIC showed no significant mean improvement, with only *small* to *moderate* improvements in some limb scores (Table 4).

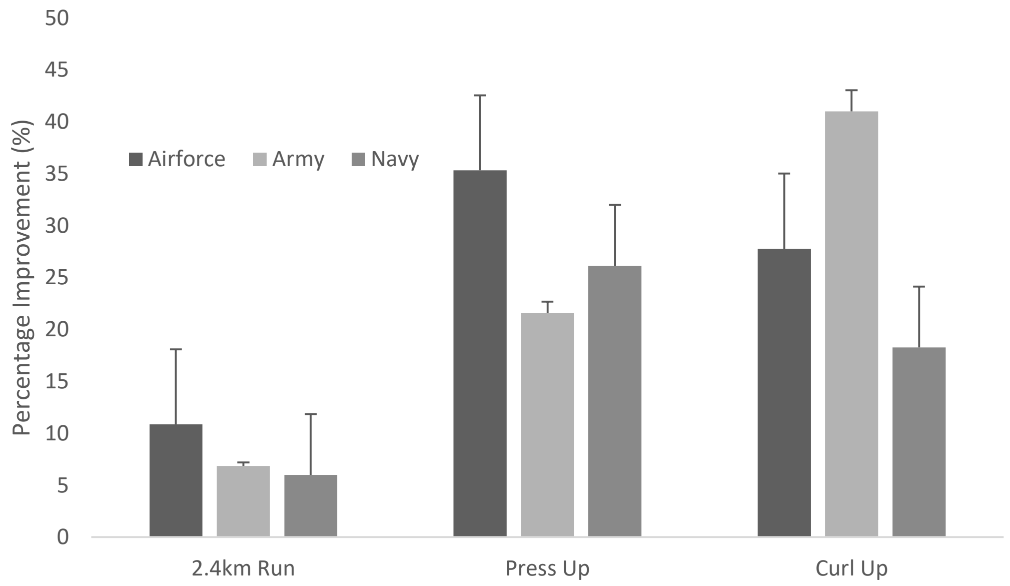

Figure 5. Percentage improvement pre to post for fitness testing scores for 2.4km run, press-ups and curl-ups for all trainee officers of the 6-week JOIC.

Discussion

The purpose of the current study was to compare and characterize New Zealand Army, Navy and Airforce officer trainees' pre and post a 6-week joint officer induction course. The 6-weeks of military training resulted in improved physical fitness markers as seen by significant improvements ($p < 0.01$) in all three measures; 2.4km run, press-ups and curl-ups. Although Army and Navy trainees performed better at baseline, Airforce percentage improvement for 2.4km run (11%) and press-ups (36%) was better than both other services. For curl-ups, the greatest improvement was seen in the Army trainee's (41%). Other international military studies have also shown comparable changes in aerobic fitness and strength-endurance over similar durations (Brock & Legg, 1997; Hendrickson et al., 2010; Hoffman, Chapnik, Shamis, Givon, & Davidson, 1999; Hofstetter et al., 2012).

Table 3. Joint Officer Induction Course Pre-Post Scores.

	Body Mass (kg)				**2.4km Run (sec)**				**Press-Ups (Repetitions)**				**Curl-Ups (Repetitions)**			
	Pre	**Post**	**p-value**	**Effect Size**	**Pre**	**Post**	**p-value**	**Effect Size**	**Pre**	**Post**	**p-value**	**Effect Size**	**Pre**	**Post**	**p-value**	**Effect Size**
Male																
Army	78 ± 10.1	76.1 ± 9.2	<0.01*	-0.18	681 ± 68	567 ± 82	<0.01*	-0.71○	39 ± 9	43 ± 10	<0.01*	0.31■	43 ± 16	76 ± 40	<0.01*	1.02+
Navy	81.1 ± 13.8	79.3 ± 12.4	<0.01*	-0.20■	648 ± 76	623 ± 70	0.14	-0.32■	30 ± 10	35 ± 10	<0.01*	0.51○	36 ± 14	42 ± 10	0.04*	0.56○
Airforce	74 ± 5.2	72.8 ± 4.3	0.08	-0.32■	667 ± 157	577 ± 79	0.08	-0.69○	32 ± 10	39 ± 10	<0.01*	0.78○	42 ± 36	49 ± 33	0.02*	0.18
Male Mean	**77.9 ± 10.6**	**76.1 ± 9.6**	**0.08**	**-0.23■**	**644 ± 83**	**589 ± 82**	**<0.01***	**-0.57○**	**34 ± 10**	**39 ± 11**	**<0.01***	**0.53○**	**40 ± 19**	**56 ± 38**	**<0.01***	**0.02**
Female																
Army	72.8 ± 12.6	71.3 ± 11.3	0.06	-0.13	694 ± 30	655 ± 24	<0.01*	-1.09+	21 ± 6	30 ± 7	0.05*	0.68○	32 ± 9	44 ± 15	0.02*	0.77○
Navy	71.9 ± 13.1	70.5 ± 12.8	0.18	-0.11	681 ± 45	642 ± 28	0.15	-0.88+	21 ± 9	29 ± 7	<0.01*	0.95+	58 ± 46	69 ± 7	0.17	0.26■
Airforce	74.4 ± 17.4	72.5 ± 15.0	0.22	-0.13	750 ± 118	686 ± 127	0.06	-0.60○	12 ± 5	21 ± 8	0.02*	1.12+	40 ± 25	56 ± 30	0.38	0.15
Female Mean	**73 ± 13.0**	**71.4 ± 11.8**	**<0.01***	**-0.12**	**708 ± 48**	**661 ± 42**	**<0.01***	**-0.86+**	**18 ± 7**	**27 ± 7**	**<0.01***	**0.91+**	**43 ± 28**	**56 ± 41**	**0.01***	**0.39■**
Service Mean																
Army	74.5 ± 13	73.7 ± 10	<0.01*	-0.17	656 ± 49^	611 ± 54	<0.01*	-0.68○	30 ± 8^	37 ± 9	<0.01*	0.32■	37 ± 13^	60 ± 27	<0.01*	0.89+
Navy	76.8 ± 13	74.9 ± 13	<0.01*	-0.17	665 ± 61#	633 ± 50	0.07	-0.37■	25 ± 9#	32 ± 9	<0.01*	0.54○	47 ± 30#	56 ± 43	0.01*	0.28■
Airforce	74.2 ± 11	72.6 ± 10	0.02*	-0.27■	708 ± 138	631 ± 104	0.04*	-0.66○	22 ± 8	30 ± 9	<0.01*	0.58○	41 ± 31	52 ± 31	0.01*	0.17
Total Mean	**75.5 ± 11**	**73.7 ± 10**	**<0.01***	**-0.20■**	**676 ± 83**	**625 ± 82**	**<0.01***	**-0.57○**	**26 ± 12**	**33 ± 11**	**<0.01***	**0.48■**	**42 ± 21**	**56 ± 39**	**<0.01***	**0.67○**

* Significant difference between pre and post values (p<0.05). # Significant difference between Airforce and Navy at baseline.
^ Significant difference between Army and Navy at baseline.
■ Small effect size, ○ Moderate effect size, + Large effect size

Table 4. Joint Officer Induction Course Pre-Post Y-Balance Musculoskeletal Screen Scores.

	Right Upper Limb				Left Upper Limb				Right Lower Limb				Left Lower Limb			
	Pre	**Post**	**p-values**	**Effect Size**	**Pre**	**Post**	**p-values**	**Effect Size**	**Pre**	**Post**	**p-values**	**Effect Size**	**Pre**	**Post**	**p-values**	**Effect Size**
Male																
Army	93 ± 6	95 ± 7	0.80	-0.05	93 ± 4	96 ± 6	0.04*	0.17	96 ± 11	96 ± 11	0.52	-0.08	95 ± 6	96 ± 7	0.80	-0.05
Navy	92 ± 7	94 ± 7	0.09	0.35■	92 ± 8	95 ± 7	0.12	0.23■	94 ± 6	96 ± 7	0.29	0.16	94 ± 10	97 ± 10	0.09	0.35■
Airforce	92 ± 7	94 ± 10	0.07	0.55○	94 ± 4	94 ± 7	0.09	-0.44■	98 ± 11	96 ± 9	0.45	-0.11	99 ± 10	96 ± 11	0.07	0.55○
Male Mean	**92 ± 6**	**94 ± 8**	**0.32**	**0.29■**	**93 ± 7**	**95 ± 7**	**0.08**	**-0.01**	**96 ± 8**	**96 ± 8**	**0.42**	**-0.01**	**95 ± 8**	**96 ± 8**	**0.32**	**0.29■**
Female																
Army	95 ± 6	99 ± 5	0.04*	1.11^{+}	97 ± 4	100 ± 6	0.13	0.22■	98 ± 6	98 ± 10	0.49	0.17	96 ± 8	97 ± 7	0.04*	1.11^{+}
Navy	90 ± 12	93 ± 9	0.48	0.93^{+}	87 ± 8	95 ± 6	0.79	-0.10	98 ± 9	97 ± 7	0.19	0.44■	97 ± 8	98 ± 7	0.48	0.93^{+}
Airforce	88 ± 3	88 ± 9	0.82	-1.37^{+}	90 ± 4	90 ± 6	0.21	0.72○	90 ± 9	96 ± 7	0.15	0.98^{+}	88 ± 5	91 ± 7	0.82	-1.37^{+}
Female Mean	**92 ± 9**	**95 ± 8**	**0.45**	**0.22■**	**92 ± 7**	**96 ± 6**	**0.38**	**0.28■**	**97 ± 8**	**97 ± 7**	**0.28**	**0.53○**	**95 ± 8**	**96 ± 7**	**0.45**	**0.22■**
Service Mean																
Army	94 ± 6	97 ± 6	0.38	0.16	95 ± 4	98 ± 6	0.01*	0.19	97 ± 9	97 ± 11	0.88	0.02	96 ± 7	97 ± 7	0.38	0.16
Navy	91 ± 10	94 ± 8	0.15	0.34■	90 ± 8	95 ± 7	0.15	0.19	96 ± 8	96 ± 7	0.24	0.19	95 ± 9	98 ± 9	0.15	0.34■
Airforce	90 ± 5	91 ± 10	0.29	0.35■	92 ± 4	92 ± 7	0.16	-0.27■	94 ± 10	96 ± 8	0.75	0.06	94 ± 8	93 ± 9	0.29	0.35■
Total Mean	**92 ± 8**	**95 ± 8**	**0.28**	**0.28■**	**93 ± 7**	**96 ± 7**	**0.11**	**0.04**	**96 ± 8**	**96 ± 8**	**0.62**	**0.09**	**95 ± 8**	**96 ± 8**	**0.28**	**0.28■**

* Significant difference between pre and post values ($p<0.05$).

■ Small effect size, ○ Moderate effect size, + Large effect size

The current study demonstrated similar findings as Brock and Legg (1997) and Hofstetter et al. (2012), with the transition from a civilian daily routine to a physically more demanding military routine leads to significant improvements in muscular-endurance and aerobic fitness (Hofstetter et al., 2012). This effect was particularly evident in Airforce recruits who had the lowest fitness level pre JOIC, but made the best overall improvements. Hendrickson et al. (2010) and Hoffman et al. (1999), also found similar outcomes in aerobic fitness and muscular-endurance with college athletes and new recruits joining the Israeli military respectively.

Regardless of service and initial aerobic fitness level, all officer trainees in the current study made notable increases in aerobic fitness over the 6-week duration. The mean improvement observed is comparable with Brock and Legg (1997), who found an increase in aerobic fitness when measuring VO_{2max} and strength in female recruits in the British army over a 6-week period. A statistically significant ($p < 0.05$) increase in aerobic fitness occurred (45.7 $ml.kg.^{-1}min^{-1}$ to 46.7 $ml.kg.^{-1}min^{-1}$) and was reflected in a 6.1% improvement in maximal cycling time in a cycle ergometer test. In a study by Hofstetter et al. (2012), at the fusilier infantry training school in Switzerland, recruits completing 7-weeks of infantry training displayed similar aerobic fitness improvement to the trainees in the current study regardless of starting level of fitness. Hofstetter et al. (2012) outlined that over 7-weeks results showed there was significant improvement in the distance and velocity covered in the Conconi progressive endurance run test (Conconi et al., 1996).

Of the three services in the current study, Army trainees performed better in the 2.4km run at baseline and showed significant improvement pre-post JOIC for both males and females. Regardless of initial aerobic fitness, results show that all trainees improved in the current study. This was supported by Orr et al. (2010), when discussing recruit trainees who possess low levels of fitness will often make considerable physical performance gains due to having more room for improvement.

Findings from the present study show a significant increase in maximal press-ups pre-post for all JOIC officer trainees collectively ($p < 0.01$). This appears to have been achieved through a combination of both daily prescribed PT and daily manual-handling of equipment (field-stores, pack and weapon). Previous research by Williams, Rayson, and Jones (2002) also documented a similar relationship between traditional prescribed PT (6-8 weeks), manual-handling and muscular-endurance improvement. Interestingly however, although Williams et al. (2002) research was focused on lower body, a similar mean improvement of 28% for maximum repetitions during squatting was found.

With core muscular-endurance, although not a specifically targeted training modality, the inclusion of 'functional core training' throughout the course (gym circuits, pack walks, running, swimming, log lifts and tyre flips), likely contributed to an increase in core muscular-endurance. Similar to that observed by Haddock, Poston, Heinrich, Jahnke, and Jitnarin (2016), when prescribed strength training is combined with core strength and functional training within the PT program, it can be very effective in addressing the requirement of improving general strength condition and local muscular-endurance. As there was a requirement to lift, carry and manual-handle equipment on a daily basis further to prescribed PT, a functional training effect may have been gained from such activities (Knapik et al., 2003; Kraemer & Szivak, 2012).

The current study is not without its limitations. These include the lack of control around some of the measures, (e.g., the 2.4km run was outside on the road and weather dependent), and there was no metronome for press-ups and curl-ups or standardisation for the height of the press-ups apart from full extension at the elbows. A further limitation is the difficulty to make comparisons between countries for these tests since most countries and individual militaries use different physical tests for fitness assessments, and the observation that the cohort fell into the 'short sleeping category Future research should use standardised tests to make these comparisons in fitness levels across other militaries around the world. Future research should also consider implementing and comparing specific interventions to further increase physical adaptations during the 6-week JOIC, (e.g. nutrition, training, and recovery).

Conclusion

In conclusion, results from this study have demonstrated that regardless of gender, service and starting fitness level, aerobic capacity and muscular-endurance can be positively enhanced from a combination of both prescribed PT and military manual-handling activities over the 6-week JOIC duration. Army officer trainees possessed greater physical characteristics at baseline and post testing compared to the other two services (Navy and Airforce). Collectively, results showed that 6-weeks of JOIC improved aerobic fitness by ~8%, and muscular-endurance by ~31%. In the future, looking at strategies to improve sleep, recovery and adaptation to gain even greater benefits over the 6-week JOIC and New Zealand Defence Force training courses should be given consideration.

CHAPTER FOUR

Under pressure: The chronic effects of lower-body compression garment use during a 6-week military training course.

Edgar, D., Beaven, C., Gill, N., & Driller, M. (2021). (2022) Under Pressure: The chronic effects of lower-body compression garment use during a 6-week military training course. *International Journal of Environmental Research and Public Health*. 19(7), 3912.

Prelude: In Study One, it was identified that perceived recovery during the 6-week course was poor. In an attempt to help with their day-to-day recovery during a JOIC, Study Two investigated the practical recovery strategy of using compression garments at the end of each day in an attempt to aid their recovery and long-term physical performance.

Abstract

Background: Previous studies have shown that compression garments may aid recovery from exercise in the acute setting. However, less is known about the long-term use of compression garments for recovery. This study aimed to assess the influence of wearing compression garments (CG) on changes in physical performance, subjective soreness and sleep quality over 6-weeks of military training. **Methods:** 55 officer-trainees aged 24 ± 6 y from the New Zealand Defence Force participated in the current study. In a randomised, counterbalanced, parallel-group design, 27 participants wore CG every evening for 4-6 h, and 28 wore standard military issue attire (CON) over a period of 6-weeks. Subjective questionnaires (soreness and sleep quality) were completed weekly, while 2.4 km run time-trial, maximum press-ups, and curl-ups were tested pre and post 6-weeks of military training. **Results:** A repeated-measures ANOVA indicated no significant group x time interactions for any performance measure (p >0.05). However, there were *small* effects in favour of CG over CON for improvements in 2.4km run times (46.8s vs 28.9s; d = -0.24) and press-ups (5.2 vs 1.5 repetitions; d = 0.36), respectively. Subjective soreness also resulted in no significant group x time interactions, but displayed *small* to *moderate* effects for reduced soreness in favour of CG. **Conclusion:** While not statistically significant, compression garments provided *small* to *moderate* benefits to muscle soreness and *small* benefits to aspects of physical performance over an intense 6-week military training regime.

Introduction

Military training involves periods of high-intensity exercise interspersed with long periods of low-intensity on-feet activity with minimal recovery time (Edgar, Gill, & Driller, 2020; Knapik, Redmond, et al., 2018; Orr & Pope, 2015). Down-time and recovery periods may be maximized via the use of recovery interventions, such as compression garments, which may support performance recovery following exercise (Argus et al., 2013; Marqués-Jiménez et al., 2016), and perceptions of recovery (Atkins et al., 2020; Driller & Halson, 2013). However, what is less known, is the effect of chronic CG use in the exercise setting over a number of weeks. More specifically, emerging research has suggested the potential for some recovery interventions (e.g. cold water immersion [CWI], non-steroidal anti-inflammatories [NSAIDs]) to have a blunting effect on the physiological adaptations and subsequent physical performance (Broatch, Petersen, et al., 2018; Lundberg & Howatson, 2018).

Isometric and eccentric muscle contractions, essential in lifting and carrying during military training, frequently result in soreness and loss of function which can take several days to recover from (Harty et al., 2019; Howatson et al., 2007), negatively affecting operational readiness in the military (Orr, Pope, Johnston, & Coyle, 2014). Military members are required to maintain a high level of operational performance throughout multiple daily and weekly training phases and while on deployments (Knapik, Redmond, et al., 2018). Those who recover faster from one day to the next may be able to tolerate higher loads, perform better and be more effective operationally (Vartanian et al., 2018). Similar to sport and athletic settings, this is where recovery interventions and strategies could be implemented in military environments, to assist day-to-day recovery.

Although reviews and meta-analyses on the use and benefit of CG have returned mixed findings (Brown, Gissane, Howatson, Van Someren, et al., 2017; da Silva et al., 2018; Lee, Ali, et al., 2020; MacRae et al., 2011; Marqués-Jiménez et al., 2016), the majority of literature supports the use of CG's following exercise as an acute recovery strategy. A meta-analysis by Brown, Gissane, Howatson, Van Someren, et al. (2017), reported that CG's may aid in recovery following resistance training eccentric load, for following day aerobic activities. However, while the acute use of CG's has been well studied, an area that requires future research is the long-term use of CG's as a recovery strategy.

To our knowledge, only one study has evaluated the chronic use of CG's in a long-term setting. A study by Hu et al. (2020) utilised CG for 4-5 hours daily in ten college-aged male novice runners in a crossover study. After three weeks of monitored free living (without CG), participants were randomized and blinded to an intervention group that donned a lower-body CG during a two week daily running regimen or a control group that donned a visually identical but non-compressive sham garment immediately post-exercise. After a 1-week washout, groups crossed over to complete a second two week intensive running regime. Heart rate variability (HRV) results indicated greater mean 1nRMSSD in both free-living and CG intervention compared to the sham trial (p = 0.01), indicating enhanced recovery in the CG group. These novel findings postulate the use of CG in novice runners may be effective in counteracting deleterious effects of overtraining by supporting recovery and attenuating the effects on vagally-mediated HRV during a 2-week daily running block. However, the study did not investigate any performance-related outcomes or subjective measures of fatigue or soreness.

An emerging theory that warrants consideration when using recovery strategies that aim to mitigate inflammation, such as CG's, is that over the long-term, they may blunt molecular mechanisms that result in physiological adaptation (Earp, Hatfield, Sherman, Lee, & Kraemer, 2019). Indeed, this has been demonstrated with CWI protocols, especially following resistance training (Broatch, Petersen, et al., 2018; Roberts et al., 2015). The early recovery phase has been shown to involve the overlapping process of inflammation and the occurrence of secondary muscle damage (Chazaud, 2020). Processes include; macrophages forming part of the inflammatory response to enhance repair, phagocytosis to remove cellular debris, and secretion of cytokines and growth hormones to facilitate vascular and muscle fibre repair (Chazaud, 2020).

A study by Pavis et al. (2021) investigated the contribution of myofibrillar protein synthesis and associated gene signalling to recovery. Protein synthesis rates were elevated during recovery and observed alongside expression of inflammatory and regenerative signalling pathways. Although a nutritional intervention accelerated recovery, gene signalling remained unchanged compared with placebo. However, It was concluded that associated signalling did not explain accelerated recovery from muscle damage (Pavis et al., 2021). In contrast to CG and CWI literature, this study points toward enhanced recovery via inflammation, and subsequent stimulated signalling pathways. Therefore, it may be premature to assume that CG and CWI will support chronic recovery considering the important role these physiological inflammatory processes play in the recovery and adaptation process (Smith et al., 2008). Hydrostatic pressure from CWI and elastic pressure from CG, may enhance blood flow and fluid movement required for nutrient and metabolite delivery to working muscles while reducing inflammation (Broatch, Petersen, et al., 2018; Lee, Law, et al., 2020). It is therefore possible that this process may blunt signalling pathways following exercise, potentially impacting on adaptive strength and power development (Broatch, Petersen, et al., 2018). Whether similar effects of chronic CWI on performance adaptations could translate to CG recovery is yet to be realised.

Despite the plethora of research on acute recovery strategies in athlete settings, the benefit of longer periods of CG wear to aid recovery and subsequent performance is relatively unknown. As has emerged in CWI research, there is a possibility that if CG's reduce muscle inflammation after exercise, their long-term use could potentially blunt the physiological adaptations to training (Broatch, Petersen, et al., 2018; Earp et al., 2019). Therefore, the aim of the current study was to determine the effect of CG's on physical performance and subjective muscle soreness when worn daily for 4-6 h in the evening, for the duration of a 6-week training course in the military setting.

Methods

Participants

A total of 55 healthy officer trainees (44 male/11 female) aged 24 ± 6 years, from the New Zealand Defence Force (NZDF) Joint Officer Induction Course (JOIC), participated in the current study. Participation in the study was voluntary with inclusion dependent on passing the pre-course medical examination. Trainee's data was to be excluded if they withdrew voluntarily from the course, or were medically removed. Ethical approval for the study was obtained from an institutional Human Research Ethics Committee.

Experimental Design

The experimental design included a randomised, parallel-group intervention study, whereby participants were split into two groups; compression garments (CG, *n* = 27) and control (no compression [CON] *n* = 28). All participants were tested on their physical performance pre and post 6-weeks of officer training. Physical performance data was collected in weeks one and six during two 90-minute sessions, with subjective wellbeing monitoring (muscle soreness and sleep quality) completed weekly at the conclusion of each week's training.

Compression Garments

Sports compression tights-*with stirrups* (2XU, Melbourne, Australia), were used in the current study. The 2XU MCS (Muscle containment stamping) compression tights were made from PWX 105D INVISTA LYCRA ®FIBER fabric, and consisted of 65% Nylon (140 denier) & 35% Elastane (360 denier). The garments were graded with a level II compression rating from the manufacturer, defined by a pressure range of 23-32mmHg (Kennzeichnung, 2000).

All CG were individually sized following the manufactures guidelines, based on stature and body mass and ran from the medial malleolus of the ankle (incorporating the midfoot in a stirrup) to superior to the iliac crest. The CG's were required to be worn for a period of 4-6 h every evening, but not for longer than 6 h and were required to be removed before going to bed. For the full duration of the 6-week course, CG's were worn every night apart from nights spent on field exercise (one night in Week 3, and three nights in Week 5). Therefore, the CG group wore the compression for a total of

32-nights throughout the study. Two sets of CG were issued to each trainee to allow for daily rotation of washing and for hygiene purposes.

Compression Garment Pressure Monitoring

The applied pressure of the compression garments was tested using a Kikuhime pressure monitoring device (MediGroup, Melbourne, Australia) at the medial malleolus of the ankle, and at the mid-point and maximal circumference of the calf and thigh. These landmarks are commonly used when measuring the pressure of full-length compression garments (Atkins et al., 2020; Dascombe, Hoare, Sear, Reaburn, & Scanlan, 2011; Hettchen et al., 2019). Garment pressure measurements were taken in the first week of the course on day three, and in the last week of the course, Week-6 on day five. The Kikuhime pressure monitor has been shown to be a valid (ICC = 0.99, CV = 1.1%) and reliable (CV = 4.9%) tool for compression measurement in athlete settings (Brophy-Williams, Driller, Halson, Fell, & Shing, 2014).

Subjective Monitoring

During the study period, trainees completed a psychological questionnaire at the completion of each week on a Monday morning in a class prior to the next week commencing, as used previously (Edgar, Gill, Beaven, Zaslona, & Driller, 2021). The questionnaire was individually completed via a paper-based form, and assessed each trainee's general muscle soreness and sleep quality on a five-point scale of 1 to 5 with 0.5 point increments (5 = very-good, 4 = good , 3 = normal, 2 = poor, 1 = very-poor). Muscle soreness and sleep quality was included in the current study, as previous research has shown that less soreness (via the use of recovery interventions) may lead to improved sleep (Halson, 2013b).

Physical Training Program

Physical training (PT) comprised a controlled two-week introduction phase of body weight exercises and aerobic conditioning. In weeks three and four, the intensity of PT increased to challenge individuals. Week 5 and Week 6 then focused on functional fitness and conditioning. This progressive training included increased load carriage with a combination of field packs, day packs, webbing, and weapons. A total of 18 x 90-minute periods were allocated to physical training over the 6-week period and included a combination of aerobic interval running, strength training, circuits, swimming, and bike-boxing-rowing intervals as outlined in Table 5.

Table 5. Joint officer induction course physical and military training program outline.

Variation	Activity	Duration	Number of Sessions Per Week						
	Physical Training		Wk1	Wk2	Wk3	Wk4	Wk5	Wk6	**Total**
1	Aerobic Interval Running	90 min	1	1	1	1	1		**5**
2	Circuit Training (Strength Endurance)	90 min	1	1	1	1	1		**5**
3	Swimming / Pool Circuit	90 min	1	1	1	1		1	**5**
4	Stretch, Mobility & Recovery Flush	90 min	1	1		1		1	**4**
	Military Training								
1	Drill (Parade Ground)	30-60 min	3	2	3	2	2	3	**15**
2	Weapons Training	4hr +	1	4	3	2	2	3	**15**
3	Land Navigation	3-6 hr		1	2	1			**4**
4	Sea Survival	24 hr					1		**1**
5	Bush Craft	6hr		1	1	1			**3**
6	Tactical Field Exercise	5 days						1	**1**
		Weekly Total	**8**	**12**	**12**	**10**	**7**	**9**	

Note: A ten minute 6:00 am early morning activity (EMA) was also conducted daily including stretching, mobility and cognitive reaction games.

Fitness Testing

The standard NZDF JOIC fitness evaluation was conducted by NZDF Physical Training Instructors (PTIs) pre and post the course. This evaluation consisted of three key components, 1) 2.4 km time-trial road run, 2) maximum curl-ups (also known as sit-ups), and 3) maximum press-ups conducted on a wooden gym floor. These tests have previously been used in military a population to provide an evaluation of fitness (Edgar et al., 2020). Fitness testing was conducted at 0900 with identical morning routines prior to each testing session. Run times were measured via stopwatch to the nearest second by a designated PTI. Press-ups and curl-ups repetitions were counted by a PTI every time the full range of motion was completed, maintaining a consistent tempo, until failure. For both the press-ups and curl-ups, one warning was given for an incomplete repetition, prior to fatigue or participants being stopped by the PTI (Edgar et al., 2020)

Statistical Analysis

Descriptive statistics are shown as mean ± SD values unless stated otherwise. All statistical analyses were performed using the Statistical Package for Social Science (V. 22.0, SPSS Inc., Chicago, IL), with statistical significance set at $p \leq 0.05$. To examine whether there were any performance differences between groups, a 2x2, Group (GCT and CON) x Time (pre and post) repeated-measures ANOVA was conducted and interactions were assessed. For soreness and sleep, a repeated measures ANOVA 2x6 Group (GCT and CON) x Time (Week 1, Week 2, Week 3, Week 4, Week 5 and Week 6) interaction was performed on weekly scores between groups. A Bonferroni adjustment was applied if significant main effects were detected. Analysis of the distribution of residuals was verified visually with histograms and also using the

Shapiro-Wilk test of normality. Magnitudes of the standardized effects between pre and post scores between groups were calculated using Cohen's *d* and interpreted using thresholds of 0.2, 0.5, and 0.8 for *small, moderate and large,* respectively (Cohen, 1988). Effects were deemed unclear if the 90% confidence intervals overlapped the thresholds for the smallest worthwhile change (*d* ±0.2).

Results

From trainees who began the study (*n* = 56), one did not complete the study due to withdrawing from military training. The applied pressure of the CG at commencement was 25.4 mmHg at the ankle, 21.6 mmHg at the calf and 15.0 mmHg at the thigh, indicating the average CG profile was graduated (Table 6). There was a significant decrease in CG pressure pre to post training course (Table 6).

Table 6. Applied pressure measurements (Mean ± SD [mmHg]) for full length lower limb compression garment at the ankle, calf, and thigh. Pre to post 6-weeks of military training.

	Pre (mmHg)	**Post (mmHg)**	**Change (mmHg)**	**p-value**
Ankle	25.4 ± 2.1	19.7 ± 1.8	-5.7 ± 1.9	< 0.01
Calf	21.6 ± 2.8	18.3 ± 1.9	-3.3 ± 1.9	= 0.01
Thigh	15.0 ± 4.3	11.8 ± 3.1	-3.2 ± 2.0	< 0.01

The ANOVA detected no significant Group x Time interaction for performance measures, however, *small* effects were observed in favour of CG for run and press-up performance (Table 7). Specifically, the CG group improved 18 s more than the CON group (46.8 vs 28.9 s, *d* = -0.24, *small*) in the 2.4 km run, and by 3.7 more repetitions (5.2 vs 1.5 repetitions; *d* = 0.36, *small*) in the press-ups (Figure 6).

When comparing subjective soreness data for the 6-week training period, a significant and *moderate* effect ($p < 0.01$, $d = 0.77$) was observed for CG in Week-2. Non-significant-*moderate* effects were observed for CG for change over time from Week 1 to Week 4 ($p = 0.08$, $d = -0.79$), and Week 1 to Week 6 ($p = 0.18$, $d = -0.67$) however, only *small* effects were observed in Weeks 1, 4 and 6 (Figure 14). Subjective sleep quality displayed no significant Group x Time interaction ($p = 0.59$), with only *trivial* effects between groups ($d = -0.14$, Figure 7).

Table 7. Mean ± SD comparison for pre to post 2.4km run, press-ups and curl-ups, for the compression garment (CG) and control (CON) groups, including group interaction *p*-value, *d*-value and effect size for the duration of a 6-weeks of military training.

					Group x Time Interaction	
		Pre	**Post**	**Change**	**p-value**	**ES (*d*) ±90% CI**
2.4 km Run (sec)						
	CG	650.5 ± 88.7	603.7 ± 79.5	-46.8 ± 66.1	0.284	0.24 ±0.36, *Small*
	CON	620.7 ± 70.1	591.8 ± 55.2	-28.9 ± 53.3		
Press-Ups (repetitions)						
	CG	31 ± 10	36 ± 10	5 ± 8	0.17	0.36 ±0.43, *Small*
	CON	28 ± 7	29 ± 10	1 ± 10		
Curl-Ups (repetitions)						
	CG	37 ± 13	41 ± 18	4 ± 18	0.52	0.19 ±0.50, *Trivial*
	CON	40 ± 20	41 ± 17	1 ± 20		

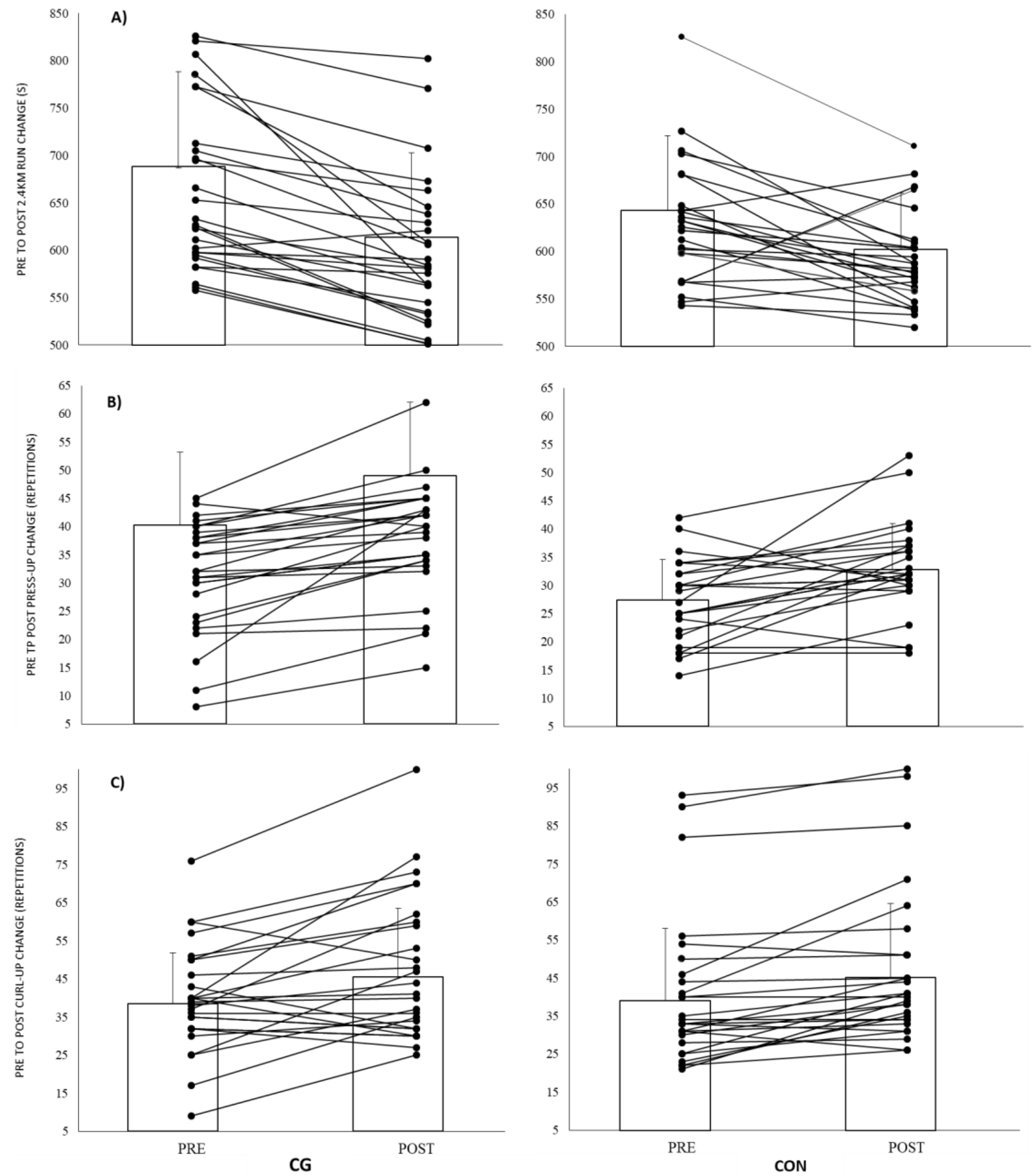

Figure 6. Pre to post performance change for Compression Garments (CG) and Control (CON) groups over the 6-weeks of military training. Boxed columns indicate mean ± SD, while lines indicate individual participant results. A) 2.4km Run (s), B) Press-Ups (Repetitions), C) Curl-Ups (Repetitions).

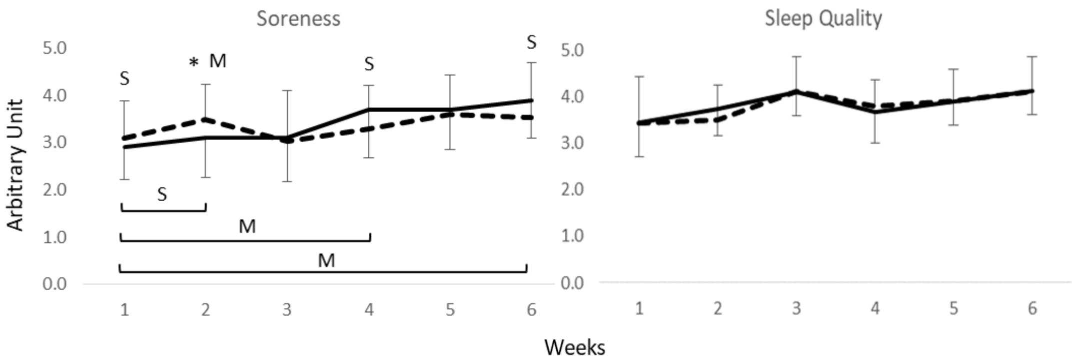

Figure 7. Mean ± SD comparison for weekly subjective muscle soreness and sleep quality for compression garments (GC) (bold line) and CON (dashed line), for the duration of a 6-weeks of military training. *Significant difference between group values (p<0.05), M: *moderate* Cohen's d effect (d > 0.5), S: *small* Cohen's d effect (d > 0.2).

Discussion

The aim of this study was to determine the effect of CG use on physical performance, subjective muscle soreness and sleep quality over 6-weeks of military training. Findings suggest that although not statistically significant, wearing lower body CG for 4-6 hours each evening indicated *small* trends toward improved 2.4km run time and press-up performance. Furthermore, there were significant benefits (p <0.05) associated with a *moderate* effect size for reducing muscle soreness in the CG group at certain time points. We would also suggest that from these results, CG's were not detrimental to physical performance when used in the chronic setting, and therefore, it is unlikely they had a negative impact on the adaptation response to training, as has been seen in previous CWI studies (Broatch, Petersen, et al., 2018; Roberts et al., 2015; Yamane, Ohnishi, & Matsumoto, 2015).

To our knowledge, no research to date has evaluated the daily use of CG over an extended time frame (e.g. more than 2-weeks), with most studies investigating the acute application of CG immediately post exercise. Hu et al. (2020) did find application of

CG over a 2-week period contributed to improved HRV markers of recovery in amateur runners. Their study reported that post training use of CG’s in novice runners over an extended period may play a role in counteracting some of the deleterious effects from overtraining in the absence of adequate rest/recovery. In the current study, limited time was specifically scheduled for recovery and only two full rest days were allocated over the 6-week course. The runners in the Hu et al. (2020) study did not show adaptive changes from rigorous training, but did exhibit better recovery after wearing CG, concluded to have occurred from increased venous return and decreased venous pooling; reducing swelling and muscle soreness. In the current study, although not significant, changes observed provided *small* effects in favour of CG for run and press-up performance. However, significant and *moderate* positive effects were observed for muscle soreness in Week two, Weeks 1 to 4 and Weeks 1 to 6 as the course continued. These findings suggest the CG group recovered better and were able to maintain a better training intensity thereafter.

Although performance results were associated with *small* effect size in favour of CG, these trends towards improvements do not support recent literature that would suggest CWI recovery interventions may in fact provide a blunting effect in the chronic setting, with either negligible or negative effects on performance (Broatch, Petersen, et al., 2018; Earp et al., 2019). However, in a chronic CWI study by Halson et al. (2014) of endurance trained cyclists, similar to the current study, performance improvements were observed in a recovery intervention group when compared to CON. Similarly, Tavares et al. (2019) investigated the effects of daily chronic CWI during a 3-week pre-season period (12-days in total), in elite rugby players, and found that chronic use of CWI supported a *moderate* beneficial effect on muscle soreness when compared to a control group. Both Halson et al. (2014) and Tavares et al. (2019) did not report any detrimental effects to performance, but suggested long term benefits to adaptation and reducing fatigue and soreness from chronic application of CWI.

Brown, Gissane, Howatson, Van Someren, et al. (2017) CG's meta-analysis on acute recovery, discussed how previous research has shown that acutely CG's may help recovery after resistance training. In the long term CG's may potentially assist participants in being able to cope with the load better, as indicated in perceived muscle soreness, and therefore be able to train at a higher quality potentially leading to long term gains, when compared to control group (Brown, Gissane, Howatson, Van, et al., 2017; Duffield et al., 2008). If using recovery strategies such as CGs do allow athletes to undertake greater workloads during subsequent training sessions, then this may lead to better training adaptations (Kyröläinen et al., 2017; Roberts, Nosaka, Coombes, Peake, & Peake, 2014; Trenell, Rooney, Sue, & Thomspon, 2006). A CG review paper by (Marqués-Jiménez et al., 2016), discussed how training studies have previously shown improved physical performance and adaptation (Gill, Beaven, & Cook, 2006; MacRae et al., 2011) and recovery (de Glanville & Hamlin, 2012; Duffield et al., 2008) post CG use. Improvements in performance have also been observed in basket-ball free-throw shooting accuracy and proprioception of movement mechanics (Wong et al., 2020), and trends toward increased hip and knee kinematics in college jump athletes (Zamporri & Aguinaldo, 2018), post CG application.

Research to date shows benefit to the acute application of CG in various performance and sport settings (F. Brown et al., 2020), and evidence suggests that CG are effective for ameliorating the symptoms of exercise induced muscle damage (EIMD), soreness

(Duffield, Cannon, & King, 2010; Upton, Brown, & Hill, 2017) and structural impairment (MacRae et al., 2011; Platts et al., 2009). In the current study the significant and *moderate* effects on muscle soreness and *small* effects on performance in CG, likely indicates that muscular function has been better maintained, possibly due to better recovery, and as a result better physical adaptation has taken place in the CG group. An important observation in the current study is the blunting effect that has been observed in previous studies with the use of CWI and NSAIDs (Broatch, Petersen, et al., 2018; Lundberg & Howatson, 2018) appears to be absent. Therefore, it is unlikely that the aforementioned detrimental effects on muscular adaptation occur with CG use, however, further research is warranted to confirm these findings.

The current study displayed significant *moderate* effects for subjective perceptions of muscle soreness in favour of CG. These findings draw parallels with the Roberts et al. (2014) investigation on CWI, where it was outlined that; central perceptions of better recovery may play a more dominant role than peripheral physiological factors in the capacity for athletes to recover from exercise. Our findings also align closely with the meta-analyses of Born, Sperlich, and Holmberg (2013), which generally showed improved perception of muscle soreness with the use CG's in the acute setting. A potential link associated with reduced muscle soreness is sleep quality, and although it has been hypothesized that sleep may be impaired with high levels of soreness (Leeder, Gissane, van Someren, Gregson, & Howatson, 2012), the current study displayed no difference between CG and CON groups for sleep quality over the 6-week course.

Mechanisms associated with improved recovery from physical exercise when wearing CG are not fully understood and warrant further investigation. Limitations from the current study included only monitoring weekly soreness, and the number of performance measures assessed. Daily soreness measures may have provided a clearer indication of muscle soreness fluctuations around specific training days and activities. If it were also possible to assess lower body strength and power, and mechanistic measures such as muscle biopsies to investigate mitochondrial biogenesis adaptations (e.g., PGC-1α mRNA and p-AMPK) (Broatch, Petersen, et al., 2018), a much clearer picture as to the chronic benefit of CG may have been provided. Consideration should also be given to the finding that CG fabrics can lose integrity/pressure over time with regular wear, which may reduce their efficacy; new garments provided half way through the course may have prevented the observed reduction in pressure profiles. However, we feel the current study is more likely to replicate what happens in the real world environment where participants only own a single pair of CG's, therefore increasing the ecological validity of the study.

Conclusion

Results from the current study indicate that the chronic wearing of CG for 4-6 h in the evening over 6-weeks of military training resulted in *small* improvements in aerobic running and press up performance, and provided *moderate* benefits to perception of muscle soreness. These results suggest that CG's might provide a viable recovery strategy in the military context, where high-volumes of strength and endurance training are performed, and causing high levels of muscle soreness. Given there were no detrimental effects of CG's to physical performance over the 6-week duration, they may allow for military personnel to manage their training loads and muscle soreness more effectively during intense training courses.

CHAPTER FIVE

Sleep duration and physical performance during a 6-week military training course.

Edgar, D., Gill, N., Beaven, C., Zaslona, J., & Driller, M. (2021). Sleep duration and physical performance during a 6-week military training course. *Journal of Sleep Research*. 30(6).

Prelude: Based on the information obtained in Studies One and Two, in Study Three we aimed to further investigate the common theme that had been challenging the recruits, sleep. Therefore, this study aimed to investigate the relationship between sleep and changes in physical performance and subjective wellbeing over 6-weeks of military training.

Abstract

Sleep is vital in influencing effective training adaptations in the military. This study aimed to assess the relationship between sleep and changes in physical performance over 6-weeks of military training. A total of 22 officer-trainees (age: 24 ± 5 y) from the New Zealand Defence Force were used for this prospective cohort study. Participants wore wrist actigraphs to monitor sleep, completed subjective wellbeing questionnaires weekly, and were tested for: 2.4 km run time-trial, maximum press-up and curl-ups before and after 6-weeks of training. Average sleep duration was calculated over 36-nights (6:10 ± 0:28 h:min), and sleep duration at the mid-point (6:15 h:min) was used to stratify the trainees into two quantile groups (UNDERS: 5:51 ± 0:29 h:min, $n = 11$) and (OVERS: 6:27 ± 0:09 h:min, $n = 11$). There were no significant group x time interactions for 2.4 km run, press-ups, or curl-ups ($p > 0.05$); however, *small* effects were observed in favour of OVERS for 2.4 km run (59.8 vs 44.9 s; $d = 0.26$) and press-ups (4.7 vs 3.2 reps; $d = 0.45$). Subjective wellbeing scores resulted in a significant group x time interaction ($p < 0.05$), with *large* effect sizes in favour of the OVERS group for Fatigue in Week 1 ($d = 0.90$) and Week 3 ($d = 0.87$), and Soreness in Week 3 ($d = 1.09$) and Week 4 ($d = 0.95$). Sleeping more than 6:15 h:min per night over 6-weeks was associated with *small* benefits to aspects of physical performance and *moderate* to *large* benefits on subjective wellbeing measures when compared to sleeping less than 6:15 h:min.

Introduction

An estimated 75% of young adults sleep less than eight hours per night (Owens, 2014). Sleep deficiency is of growing concern for the general public (Brown et al., 2013), and for the military with the recruitment of young adults (Good et al., 2020; Miller & Shattuck, 2005). Military personnel can experience even greater challenges with sleep due to the stressful and constantly changing nature of daily training and operation (Good et al., 2020). Sleep management in the military can be complicated due to the need to undertake tasks both day and night at very short notice (Williams et al., 2014). In a consensus paper by Lovalekar et al. (2018), sleep was identified as an emerging research priority area at the International Congress on Soldiers Physical Performance, ranking third out of 43 topics identified by 502 attendees from 32 countries at the congress.

It has been established that sleep can be negatively affected during military training (Williams, Collen, Wickwire, Lettieri, & Mysliwiec, 2014), and further impacts physical performance when deployed (Brown et al., 2013), especially when below the recommendation of 7 to 9 h per night for adults stated in the joint consensus of the American Academy of Sleep Medicine and Sleep Research Society (Watson et al., 2015). A review paper by Miller et al. (2012), discussed the effects of sleep deprivation on human performance and outlined research showing that short sleep duration has a negative effect on operational physical performance tasks in the military such as; carrying and lifting, patrolling over distance, weapons handling, and equipment control. It has also been suggested that a lack of sleep may contribute to reduced gains in physical performance and increased injury occurrence in the military (Lentino et al., 2013; Miller et al., 2012). Consecutive days of reactive operation can also diminish task effectiveness due to an adverse effect on sleep quality (Miller, Shattuck, & Matsangas, 2011; Williams et al., 2014). Chronically sleeping less than the recommended 7-9 h per night has also been reported to negatively impact physical performance and can contribute to fatalities during military operations (Williams et al., 2014).

Therefore, the importance of sleep and its role in recovery and enhancing physical performance in the military is of the utmost importance (Brown et al., 2013). Williams et al. (2014) determined that insufficient sleep occurs during both basic training and during academic phases of study at military academies and identified that United States (U.S) Military Academy cadets had an average weekday sleep duration of less than five hours per night, and average weekend sleep duration of ~6.5 h (Williams et al., 2014). Previous research supports how the recommended duration of sleep generally does not occur in the military environment (Good et al., 2020; Lentino et al., 2013; Moore et al., 2020). The need for further research on the long term effect of lack of sleep on adaptation to training and physical development in military personal has also been highlighted (Miller, Shattuck, & Mateangas, 2010). Lentino et al. (2013) found that short sleepers were less likely to have a healthy body composition, meet physical training recommendations, and pass their Army physical fitness tests.

The current body of literature is limited when assessing the effect of sleep on long term physical performance adaptation in the military. There is also limited information on the use of objective sleep measures (e.g. wrist actigraphy) in military settings. Therefore, the purpose of this study was to investigate the relationship between sleep (via wrist actigraphy), physical performance, and the subjective wellbeing of officer trainees during 6-weeks of initial military training.

Methods

Participants

A total of 22 healthy officer trainees, a representative sample of the New Zealand Defence Force (NZDF) Joint Officer Induction Course (JOIC) participated in the current study (Table 8). Participation in the study was voluntary with inclusion dependent on passing the pre-course medical examination. Trainee's data was to be excluded if they withdrew voluntarily from the course, or were medically removed. Ethical approval for the study was obtained from the University if Waikato Human Research Ethics Committee (HREC) (Health) #2018-01.

Table 8. Participant demographics for the included and excluded sample. Data shown as mean ± SD.

Group	No	Male	Female	Age	Weight (kg)	Height (cm)
Sample	22	19	3	24 ± 5	81 ± 28	180 ± 18
Non-Participants	72	55	17	22 ± 5	78 ± 18	177 ± 8
Full Cohort	94	74	20	23 ± 4	79 ± 12	178 ± 9

Study Design

The study design was a prospective cohort study, whereby sleep was monitored via wrist actigraphy in all trainees over a 6-week JOIC with physical performance assessed pre and post training. Fitness and performance data were collected in Week 1 and 6 of the JOIC across two 90-minute sessions, with subjective wellness questionnaires collected weekly. The sleep of trainees was monitored via wrist actigraphy for the entire duration of the 6-week course in order to assess the relationship between sleep and changes in physical performance.

Wrist-Actigraphy

Wrist-actigraphy has previously been used as a practical sleep assessment method in a military environment (Kushida et al., 2001). A Micro Motionlogger® (Ambulatory Monitoring Inc, Ardsley NY, USA) Sleep Watch was allocated to every trainee, data were collected using the device's zero-crossing mode and recorded in 1-min epochs with individual devices worn continuously for the full duration of the course during both wake and sleep on whichever wrist felt comfortable (Driller, O'Donnell, & Tavares, 2017). The validity and reliability of the Micro Motionlogger has previously been reported and deemed acceptable (Tryon, 2008). Sleep and wakefulness were inferred based on activity count using the Cole-Kripke software algorithm for sleep estimation using the methods described by Quante (2018). This technique using the AMI software analysis has previously been compared to polysomnography and shown to correctly distinguish sleep from wakefulness approximately 88% of the time (Morgenthaler et al., 2007). The device was removed for any water submersion activities and placed back on the wrist immediately post activity. Double scoring by two trained members of the research team was undertaken on 33% of randomly selected sleep files to assess the reliability of manual selection of sleep intervals. Any discrepancies of more than 15 minutes for either 'start time' or 'end time' of the sleep interval were flagged and re-analysed. A good interrater reliability agreement rate of 88% was achieved (McHugh, 2012).

Subjective Wellbeing Monitoring

During the study period, trainees completed a psychological wellbeing questionnaire at the end of each week that was based on the recommendations of Hooper and Mackinnon (1995). The questionnaire assessed each trainee's fatigue, sleep quality, general muscle soreness, stress levels, and mood on a five-point scale of 1 to 5 with 0.5 point increments (5 = very-good, 4 = good , 3 = normal, 2 = poor, 1 = very-poor).

Physical Training Program

Physical training (PT) comprised a controlled two-week introduction phase of body weight exercises and aerobic conditioning. In Weeks 3 and 4, the intensity of PT was increased and Weeks 5 and 6 then focused on functional fitness and conditioning, including increased load carriage with field packs and weapons. A total of 18 90-minute sessions, including warm-up and cool-down, were allocated to physical training over the 6-week period and included a combination of aerobic interval running, strength training, circuits, swimming, and bike-boxing-rowing intervals (Table 9). The full detail of the JOIC training programme has been described previously (Edgar et al., 2020).

Table 9. Joint Officer Induction Course Physical and Military Training Program Outline.

Note: A ten minute 6:00 am early morning activity (EMA) was also conducted daily including stretching, mobility and cognitive reaction games.

Variation	Activity	Duration	Number of Sessions Per Week						
	Physical Training		**Wk 1**	**Wk 2**	**Wk 3**	**Wk 4**	**Wk 5**	**Wk 6**	**Total**
1	Aerobic Interval Running	90 min	1	1	1	1	1		5
2	Circuit Training (Strength Endurance)	90 min	1	1	1	1	1		5
3	Swimming / Pool Circuit	90 min	1	1	1	1		1	5
4	Stretch, Mobility & Recovery Flush	90 min	1	1		1		1	4
	Intensity varied between: High / Medium / Low								
	Military Training								
1	Drill (Parade Ground)	30-60 min	3	2	3	2	2	3	15
2	Weapons Training	4hr +	1	4	3	2	2	3	15
3	Land Navigation	3-6 hr		1	2	1			4
4	Sea survival	24 hr					1		1
5	Bush Craft	6hr		1	1	1			3
6	Tactical Field Exercise	5 days						1	1

Fitness Testing

The JOIC fitness evaluation was conducted by NZDF Physical Training Instructors before and after the course. This evaluation consisted of three key components: i) 2.4 km time-trial run; ii) maximum press-ups; and iii) maximum curl-ups. The 2.4 km road run, which has been shown to provide an effective evaluation of aerobic fitness (Booth et al., 2006; Burger et al., 1990), was completed on a sealed flat road. The run was conducted in a similar fashion to that described by Knapik et al. (2006), where all participants started together, but individual effort was assessed by participants completing the distance in the quickest time possible. Run times were measured via stopwatch to the nearest second (Edgar et al., 2020).

Curl-ups, as used by Vera-Garcia et al. (2000), provided an evaluation of local muscular-endurance of the core where repetitions were completed until failure. The curl-up was performed with participants in a supine position with knees bent flexed at 90° and feet flat on the floor. Hands were held in a fist with arms straight. Hands slid up the thigh until the wrist met the apex of the knee. Hands then slid back down the thigh until the shoulder blades and shoulders touched the ground. A repetition was counted by the instructor every time the wrist reached the apex of the knee until failure. There was no time limit on repetitions, but they were completed in a continuous fashion with a pause of only 1 to 2 seconds between attempts (Edgar et al., 2020).

Press-ups were used to assess upper-body muscular-endurance similar to the protocol outlined by Booth et al. (2006) and Knapik et al. (2006) and were performed on a flat wooden gymnasium surface. Hands were placed on a line in the prone press-up position just slightly wider than shoulder width. A ‘ready’ cue was then given where the body position was adjusted to the start position of arms straight, feet shoulder width apart and the head looking downward. From the start position the body was lowered eccentrically with a straight-line maintained between the shoulders and heels, until the elbows were at 90°. During the concentric phase arms were extended until straight while maintaining the back and head positions. Repetitions were completed to fatigue in a continuous fashion and counted by the instructor every time the full range of motion was completed. For both the press-ups and curl-ups, one warning was given for an incomplete repetition, prior to participants being stopped (Edgar et al., 2020).

Statistical Analysis

Scores are shown as mean ± SD values unless stated otherwise. We calculated the average sleep duration of all 22-participants over the duration of 36-nights and at the mid-point of total sleep, two quantile groups were identified: UNDERS; averaging less than 6:15 h:min of sleep per night, $n = 11$, and OVERS; averaging more than 6:15 h:min sleep per night, $n = 11$. The initial intention was to split the sleep groups by those obtaining >7 hours (the recommended sleep duration per night for adults) compared to those obtaining <7 hours per night. However, given all participants obtained less than 7 hours per night, the decision was made to split the group in half for further analysis from the median of 6:15 h:min. All statistical analyses were performed using the Statistical Package for Social Science (V. 22.0, SPSS Inc., Chicago, IL), with statistical significance set at $p \leq 0.05$. To examine whether there were any differences between groups, Group (UNDERS and OVERS) x Time (pre and post or weekly) two-way multivariate analysis of variance (MANOVA's) were performed on the pre to post performance data and weekly subjective wellness data (mood, stress, soreness and fatigue). A Bonferroni adjustment for multiple pairwise comparisons was applied if significant main effects were detected. Analysis of the distribution of residuals was verified visually with histograms, and also using the Shapiro-Wilk test of normality.

Magnitudes of the standardized effects between groups were calculated using Cohen's *d*, and interpreted using thresholds of 0.2, 0.5, and 0.8 for *small, moderate and large*, respectively (Cohen, 1988). Effects were deemed *unclear* if the 95% confidence intervals overlapped the *small* thresholds for both positive and negative effects (*d* ±0.2). Correlation coefficients (Pearson's *r* - values) were determined for the whole group (*n* = 22) to describe associations between sleep and physical performance, and interpreted using thresholds of 0.00 to 0.19 *very weak*, 0.20 to 0.39 *weak*, 40 to 0.59 *moderate*, 0.60 to 0.79 *strong*, and 0.80 to 1.0 *very strong* (Evans, 1996).

Results

The participants were a randomly selected, representative sample from the overall cohort size of *n* = 94 (Table 8). We were unable to test all 94 participants due to equipment and personnel constraints. From all (*n* = 22) who started the January/February 2019 JOIC, no trainees withdrew from the course or the study. All participant sleep data from every day was included, no data was missed for weekly wellbeing monitoring, and all participants completed both pre and post physical performance testing. The average sleep duration across the entire group (*n* = 22) for the JOIC 6-week training course was 6:10 ± 0:28 h:min. Total weekly sleep reduced by 6 ± 2% ($p = 0.01$) from Week 1 to 6, the equivalent of a 22 ± 10 minute per night reduction in total sleep duration. The OVERS group slept on average 6:27 ± 9.0 h:min, compared to the UNDERS group averaging 5:51 ± 28.5 min, with the OVERS group accumulating 22:20 h:min more sleep than the UNDERS group over the 6-week period ($p < 0.01$).

The MANOVA detected a significant time effect across all trainees pre-post, regardless of group for 2.4 km run time, press-ups, and curl-ups (all $p \leq 0.01$), but no significant group x time interactions were detected (*p* >0.05). However, effect size analysis identified an overall performance improvement favouring OVERS in the 2.4 km run (*d* = 0.29, *small*) and press-ups (*d* = -0.30, *small*), with a *trivial* difference in the curl-ups (*d* = -0.12). The OVERS group improved 14.9 s more than the UNDERS group (59.8 vs 44.9 s) in the 2.4 km run and by 1.5 more repetitions (4.7 vs 3.2 reps) in the press-ups (Table 10, Figure 8).

Table 10. Mean ± SD pre to post performance test values for UNDERS (<6hr 15min sleep per night, *n* = 11) and OVERS (>6hr 15min sleep per night, *n* = 11), and group x time interactions (*p*-value and effect size).

	2.4km Run time (s)				**Press-Ups (Repetitions)**				**Curl-Ups (Repetitions)**			
	Pre	**Post**	***p*-value**	***Effect size (d)***	**Pre**	**Post**	***p*-value**	***Effect size (d)***	**Pre**	**Post**	***p*-value**	***Effect size (d)***
UNDERS	601 ± 75	556 ± 39	<0.01		29 ± 6	32 ± 8	<0.01		40 ± 16	44 ± 17	0.05	
OVERS	629 ± 47	569 ± 42	<0.01		27 ± 8	31 ± 8	<0.01		39 ± 22	43 ± 19	0.09	
Group x Time Interaction			0.37	0.29, *Small*			0.34	-0.30, *Small*			0.79	-0.12, *Trivial*

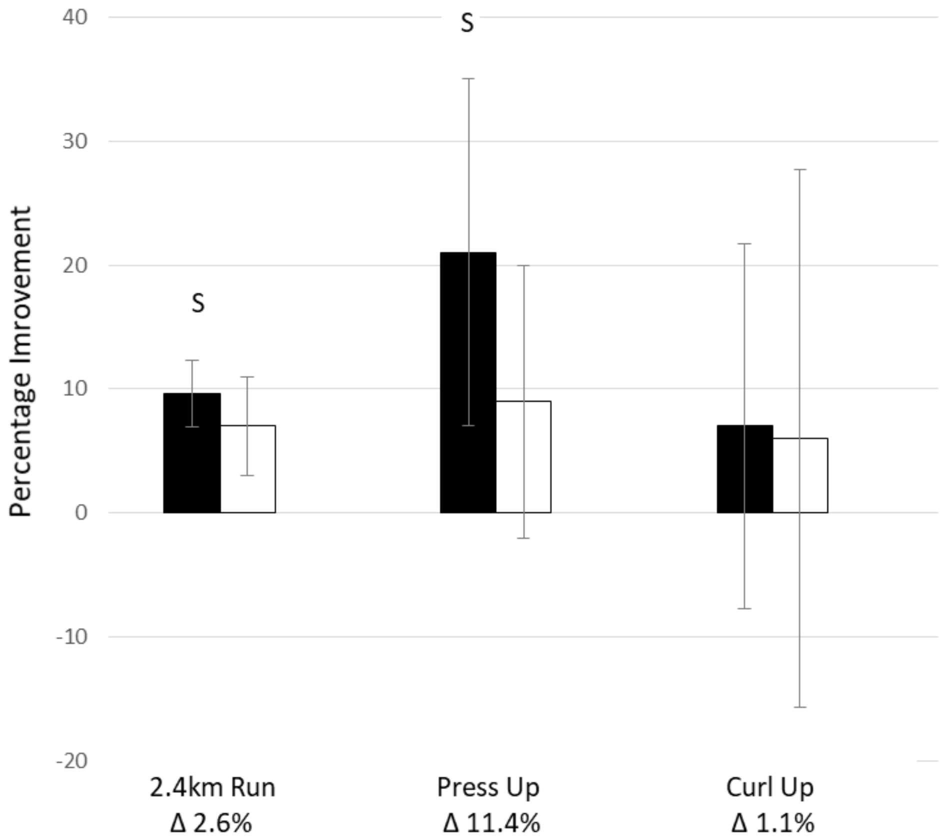

Figure 8. Percentage performance improvement by group over the 6-week Joint Officer Induction Course. Black bars: OVERS (>6:15 min per night) and white bars UNDERS (<6:15 min). S: *small* difference between groups. Error bars are 95% confidence intervals

Subjective wellbeing data for the 6-week training period demonstrated significant and *large* effects in favour of the OVERS group for fatigue and soreness at Weeks 1, 3 and 4. While not statistically significant, there were also *moderate* effects favoring the OVERS compared to UNDERS for stress and mood in Weeks 3 and 4 (Figure 9).

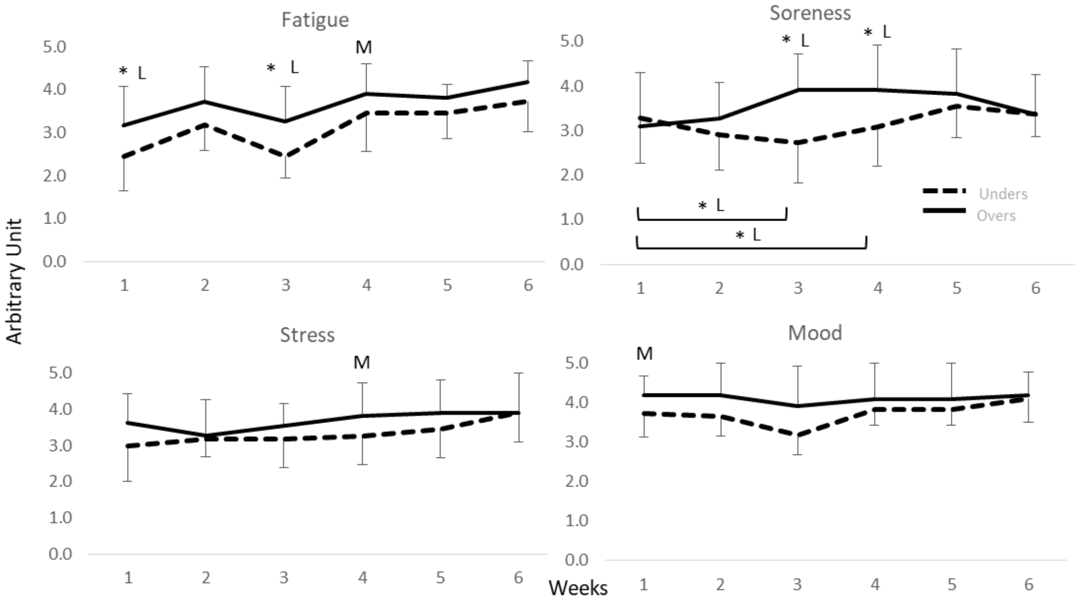

Figure 9. Weekly subjective wellbeing monitoring of Fatigue, Stress, Soreness and Mood by group over the 6-week Joint Officer Induction Course. Solid line; Overs (>6:15 h:min per night) and dashed line; Unders (<6:15 h:min). * Significant difference between groups (p<0.05); L: Large effect; M: Moderate effect. Error bars represent standard deviations.

The correlation between sleep and performance metrics and sleep and wellbeing measures was investigated. Regarding performance variables, *moderate* relationships were observed between time in bed and faster 2.4 km run time (r = -0.47); for sleep onset latency and Press-ups (r = 0.48) and for wake after sleep onset and Press-ups (r = -0.47). Only *weak* or *very weak* relationships were found for all other measures.

Discussion

The main results from this study showed that sleeping on average, more than 6:15 h:min per night lead to *small* gains in physical performance measures and had beneficial effects on aspects of subjective well-being in officer trainees over a 6-week training period when compared to sleeping less than 6:15 h:min per night. The study reinforces previous research and demonstrates that the recommended 7-9 hours of sleep generally does not occur in the international military personnel (Good et al., 2020; Lentino et al., 2013; Moore et al., 2020). Longer sleep duration in the current study correlated to faster 2.4 km run times, improved number of press-ups and a shift toward positive fatigue, mood, soreness, and stress measures. This data indicates that more time in bed will likely support physical performance adaptation and ongoing physical development in individuals with sleep durations below the recommendation of 7 to 9 h (Watson et al., 2015).

Interestingly, the performance improvement observed in the current study was gained in a state similar to that previously described as 'short sleep duration', where military members consistently sleep on or around 6 h per night (Good et al., 2020). While there were no significant differences observed between groups for performance measures, there were *small* effect sizes in favour of the OVERS group for 2.4 km run and press ups.

Previous military research by Ritland (2019) found a positive relationship between sleep extension (1.36 ± 0.7 h) and performance benefits in psychomotor vigilance, executive functioning, standing broad jump distance, and motivation levels in officers under training. In a physically demanding professional rugby environment a ~1 hour sleep extension (from 6:52 to 7:35 h:mm) also showed improved reaction times in a five minute psychomotor vigilance response test (Swinbourne et al., 2018). Although sleep architecture was not measured in the current study, the aerobic improvement seen in the OVERS group in the current study could potentially be related to an increase of growth hormone release and its relationship to physiological recovery (Dattilo et al., 2011). Growth hormone levels have been shown to effect physical performance, aerobic capacity and specifically, VO_2 max; thus it is plausible that these physiological processes have supported muscle recovery and growth and the observed increase in press-ups and run times (O'Donnell, Beaven, & Driller, 2018; Widdowson, Healy, Sonksen, & Gibney, 2009).

Subjective wellbeing in the current study was affected by the quantity of sleep acquired between groups. The reductions in perceived fatigue and soreness in favour of the OVERS group in Weeks 3 and 4 were recorded during stages of high physical and cognitive demand. These observations highlight the important relationship between sleep and enhanced physical and mental wellbeing (Charest & Grandner, 2020; Lentino et al., 2013). Positive outcomes on Stress and Mood scores were also seen in the OVERS group, with reduced stress in Week 4 corresponding with lower soreness, and improved Mood in Week 1. Our data support previous research from Good et al. (2020), that also outlined the strong association between sleep quality and perception of stress and fatigue in military populations, and the association between sleep quantity, cognitive function and reduced physical capacity. In a similar operational environment, McGillis et al. (2017), found that wildland attack firefighters physical performance could be maintained in the initial stages of extended periods of poor sleep and broken shifts (~5 hours a day over 14 to 18 days), but as days progressed, poor judgment, deflated mood, increased fatigue, muscle soreness, and a decrease in reaction time and physical performance did occur.

Similar to the findings of Moore et al. (2020), the current study observed short sleep duration in this initial stage of military training, due to non-standard shift work schedules and routinely participating in demanding and highly variable daily schedules of greater than 12 hours in duration across several days. A study by Miller and Shattuck

(2005), with similar aged officer trainees and sleep to the current study, found that U.S Military Academy Cadets sleep ranged from 5 h and 50 min to 6 h 32 min during initial training and trainees often struggled with intense physical training. It has also been acknowledged that military training, even at academies and officer training schools similar to the JOIC environment, is characterised by highly demanding physical and academic training loads with limited sleep opportunities (Moore et al., 2020). Further to this finding, research conducted by the U.S Naval postgraduate school over the last decade highlights a common trend of soldiers, sailors and Marines world-wide accumulating high levels of sleep debt (Miller et al., 2012), supported by the results of the current study.

Within the constraints of conducting research in the military environment, we acknowledge a limitation in the current study was that the time available to sleep was confined to a specific window from 'lights out' at 2200 hr to 'to wakeup' at 0545 hr. This narrow window of sleep opportunity led to a relatively minor difference in sleep duration between the OVERS and UNDERS groups. It is possible that if the sleep and wake times were not set, self-selected differences in sleep duration might have been more pronounced, and had a greater impact on the differences in the outcome variables. Future research in military settings should consider comparing groups where different sleep opportunities are set (e.g. <6 hours versus the recommended 7 to 9 h) via manipulating sleep and wake times, while measuring physical, cognitive and wellbeing variables.

Conclusion

Results from this study have demonstrated that in two groups of trainees who were grouped by sleep duration derived from wrist-actigraphy, a non-significant but *small* improvement in aerobic fitness and press-up performance were seen in recruits sleeping more than 6:15 h:min compared to those sleeping less than 6:15 h:min per night. The group sleeping approximately 37 min more per night, and thus 22:20 h:min over the duration of the training course, also showed benefits in aspects of perceived well-being (fatigue, soreness, mood and stress). Thus, even a modest increase in sleep duration in a short sleeping cohort may result in enhanced physical performance and perceived wellbeing.

CHAPTER SIX

Automatic-scoring actigraph compares favourably to a manually-scored actigraph for sleep measurement in healthy adults

Edgar, D., Beaven, C., Gill, N., Zaslona, J., & Driller, M. (2022). Automatic-scoring actigraph compares favourably to a manually-scored actigraph for sleep measurement in healthy adults. *Sleep Science*. (Accepted 30th August 2022).

Prelude: As identified in Studies One to Three, sleep was a recurring theme as being a major challenge to military recruits. Before looking to stage a sleep intervention to target this, in Study Four, we set out to validate the tools we had available and also investigate the use of a newly emerging technology in sleep measurement, automatic-scoring actigraphy.

Abstract

Background: Actigraphy has been used widely in sleep research due to its non-invasive, cost-effective ability to monitor sleep. Traditionally, manually-scored actigraphy has been deemed the most appropriate in the research setting; however, technological advances have seen the emergence of automatic-scoring wearable devices and software. **Methods:** A total of 60-nights of sleep data from 20-healthy adult participants (10 male, 10 female, age: 26 ± 10 y) were collected while wearing two devices concomitantly. The objective was to compare an automatic-scoring device (Fatigue Science Readiband™ [AUTO]) and a manually-scored device (Micro Motionlogger® [MAN]) based on the Cole-Kripke method. Manual-scoring involved trained technicians scoring all 60-nights of sleep data. Sleep indices including total sleep time (TST), total time in bed (TIB), sleep onset latency (SOL), sleep efficiency (SE), wake after sleep onset (WASO), wake episodes per night (WE), sleep onset time (SOT) and wake time (WT) were assessed between the two devices using mean differences, 95% levels of agreement, Pearson-correlation coefficients (*r*), and typical error of measurement (TEM) analysis. **Results**: There were no significant differences between devices for any of the measured sleep variables (p = 0.061 to 0.974). All sleep indices resulted in *very-strong* correlations (*all r* ≥0.84) between devices. A mean difference between devices of <1 min for TST was associated with a TEM of 15.5 min (95% CI =12.3 to 17.7 min). **Conclusion:** Given there were no significant differences between devices in the current study, automatic-scoring actigraphy devices may provide a more practical and cost-effective alternative to manually-scored actigraphy in healthy populations.

Introduction

The measurement and quantification of sleep in population research and clinical settings is of increasing importance due to its integral role in physical and mental health (Chinoy et al., 2021). Diverse methods of monitoring and researching sleep have been extensively investigated and validated in the literature (Van de Water et al., 2011). Although polysomnography (PSG) is regarded as the 'gold standard' of sleep measurement, it is a somewhat intrusive and expensive form of assessment (Dunican et al., 2018; O'Donnell et al., 2018). Additionally, PSG typically requires an individual to sleep in an unfamiliar lab-based clinic while sleep is being assessed via the use of multiple electrodes to monitor neurophysiological and cardiorespiratory variables, which may be difficult and invasive for many individuals and may compromise the ecological validity of the data attained outside of a strictly pathological sleep assessment (Driller, McQuillan, & O'Donnel, 2016; Van de Water et al., 2011). Over the last decade, many emerging sleep-monitoring devices, such as commercially-available wearables, have demonstrated promising capability for tracking sleep and wake episodes (Chinoy et al., 2021). A popular method of minimally-invasive sleep monitoring is via wrist actigraphy, where wearable devices allow for continuous monitoring of sleep movement during sleep with either automatic or manual-scoring options available (Dunican et al., 2018).

Although various products are now available on the market, actigraphy generally involves a device being housed in a wristwatch, bracelet, or ring that contains an accelerometer capable of sensing movement along each of three axes (Chinoy et al., 2021; Palotti et al., 2019). The tri-axial accelerometer samples multiple times per second and with each limb movement, the accelerometer estimates metrics of sleep and wake including total sleep time (TST), total time in bed (TIB), sleep efficiency (SE%), wake after sleep onset (WASO), and sleep onset latency (SOL), as well as sleep and wake times. Data is then stored in the device memory to be downloaded and either automatically or manually scored (Chinoy et al., 2021).

The advantage of actigraphy over traditional PSG is that it can record continuously for 24-hours a day for days, weeks, or even longer (Ancoli-Israel et al., 2003), and can easily be utilised to monitor sleep-wake patterns in home-based or ecologically valid settings. As a result, it has also been proposed that actigraphy could be adapted for use in primary care settings to improve sleep health in the community (Noor, Smith, Smith, & Nissen, 2013). To date, actigraphy has been used widely in sleep research to provide continuous monitoring of rest/wake activity rhythms in varying environments; including residential care patients (Wulff et al., 2012), elite athletes (Fullagar et al., 2016), shift workers (Arendt, 2010; Tremaine et al., 2013), and in operational settings such as firefighting (McGillis et al., 2017) and the military (Adler et al., 2017).

Manually scored actigraphy has historically been used in sleep research settings (Chow et al., 2016; Sadeh, 2011). Despite this, it can be difficult to make conclusions on the overall reliability of manually-scored actigraphy data given variations in methods of scoring, different brands of hardware, varying software, and inter/intra-scorer reliability (Sadeh, 2011). Studies have shown that high inter-rater agreement for manually scored data (e.g. α = 0.975 for rest onset, and α = 0.998 for rest offset) can be achieved with clearly defined scoring criteria by trained researchers (Follesø et al., 2021). However, a limitation of manually scored actigraphy is the possibility of human error and the time requirement of analysing large groups of participant data (Ancoli-Israel et al., 2003; Driller et al., 2016). Recent advances in technology have seen the emergence of automatically-scored, commercially-available actigraph devices (Adler et al., 2017;

Driller et al., 2016) and the accuracy and relability of these devices has improved considerably (Chinoy et al., 2021; Dennis et al., 2016). These developments include devices specifically tailored to detect periodic limb movements and the introduction of new algorithms (Athavale et al., 2019). Most sleep-wake scoring algorithms are based on a combination of linear compilations of activity levels (in predefined windows around the scored minute) and smoothing or other logical decisions.

Many of the commercial wearable devices on the market, such as the Readiband™ (RB), contain tri-axial accelerometers that record the frequency and intensity of limb movement that can be converted to sleep-wake periods using a built-in automated scoring algorithm. In a study by Chinoy et al. (2021) evaluating seven consumer sleep-tracking devices, the RB performed comparably to other devices and displayed high intraclass correlations (>0.93) for overall epoch-by-epoch sensitivity (Chinoy et al., 2021). In one previous study of 50 adults who wore an automatically scored RB device and a manually scored device (ActiGraph GT3X+) for 7-nights, sleep onset, sleep duration and wake time were compared (Dunican et al., 2018). The RB performed similarly to the manually scored device when measuring these sleep metrics, during an unfamiliar laboratory night stay and when worn at home in a familiar environment. It was concluded that the RB could be used in the same capacity as the ActiGraph for the collection of sleep metrics (Dunican et al., 2018).

With the emergence of new sleep-monitoring technologies, it is important to understand what differences exist between manually and automatically-scored devices to enable decisions regarding whether the data obtained is comparable. Therefore, the aim of the current study was to investigate the differences between sleep metrics from a device using manual scoring of sleep metrics to a commercially-available actigraphy device that uses automatic scoring, by evaluating 60-nights of sleep data from 20-healthy adult participants wearing the two devices concurrently.

Methods

Participants

A total of 20 healthy adults (10 male, 10 female, age: 26 ± 10 y [mean ±SD]), participated in the current study. Participation in the study was voluntary and all participants provided written consent before taking part, with inclusion dependent on being free from any diagnosed sleep disorders. Ethical approval for the study was obtained from the University's Human Research Ethics Committee (HREC) (Health) #2018-0. Sample size was calculated for the current study using an a priori analysis based on an expected *r*-value of 0.8, a precision value of ±0.2 and 95% confidence levels using a web-based calculator (Arifin, 2018). This calculation resulted in an estimated n=18 participants.

Experimental Design

Participants were required to wear two different wrist actigraphs, the automatically scored Readiband™ (AUTO) and the manually scored Micro MotionLogger® (MAN), and have sleep recorded for a 3-day/night period concurrently, similar to the procedures of Dennis et al. (Dennis et al.). In the current study, both the MAN and AUTO devices were tightly secured together with the MAN on top of the AUTO, using electrical tape so that the devices could not move independently of each other. Devices were initialised before being worn on whichever wrist felt comfortable (Driller et al., 2017), and data commenced recording in 1-minute epochs (Dennis et al., 2016). Total sleep time (TST), sleep efficiency (SE), time in bed (TIB), sleep onset latency (SOL), wake after sleep onset (WASO), wake episodes (WE), sleep onset time (SOT), and wake time (WT) were all assessed (Table 12). The devices were removed for any water submersion activities and placed back on the wrist immediately post activity. Participants were instructed to maintain their usual sleep habits and general daily activity patterns during the 3-day monitoring period, before actigraphs were removed and data downloaded.

Table 11. Definitions of each sleep variable measures to be compared and validated between the Fatigue Science Readiband™ (AUTO) and Micro Motionlogger® (MAN) actigraphy devices.

Sleep indices	Units	Description
Total Sleep Time (TST)	Minutes	Total time spent asleep
Total Time in Bed (TIB)	Minutes	Total time spent in bed
Sleep Efficiency (SE)	%	Total sleep time divided by total time in bed
Sleep Onset Latency (SOL)	Minutes	Time taken for sleep onset
Wake Episodes per Night (WE)	Number count	Total number of awakenings per night
Wake After Sleep Onset (WASO)	Minutes	Time spent awake after sleep onset per night
Sleep Onset Time (SOT)	Time of day (p.m.)	Time fell asleep at night
Wake Time (WT)	Time of day (a.m.)	Time woken in morning

Automatic Scoring Actigraphy

The AUTO actigraph (Readiband™ version-5, Fatigue Science, Honolulu, USA), has been previously used in sleep research (Fowler et al., 2015; Fullagar et al., 2016; Noor et al., 2013), and records data at a sample rate of 16 Hz. The AUTO uses a patented algorithm to automatically score sleep data derived from raw acceleration signals via specialized Readiband Sync™ software (Adler et al., 2017; Lee et al., 2021). The AUTO device has shown accuracy in distinguishing sleep from wakefulness approximately 82% of the time when epoch scoring against PSG (Russell et al., 2000). The RB has also been approved by the US Federal Drug Administration for measurement of sleep (Lee et al., 2021).

Manually Scored Actigraphy

The MAN actigraphy (Micro MotionLogger®, Ardsley, New York, USA) uses a tri-axial accelerometer which has also been compared to PSG, and distinguished sleep from wakefulness accuracy approximately 80% of the time (Russell et al., 2000). Data were collected using the device's zero-crossing mode ad recorded in 1-min epochs (Meltzer, Walsh, Traylor, & Westin, 2012). Using the manufacturer's software (Action-W version 2.7.3045, Ambulatory Monitoring Inc., Ardsley, New York, USA), sleep and wakefulness were estimated based on activity count using the Cole-Kripke algorithm (Cole, Kripke, Gruen, Mullaney, & Gillin, 1992). Manual scoring of the sleep data involved one technician scoring all 60 night's sleep files individually for 'start time' and 'end time' of the rest interval, and for any wake periods throughout the rest interval for each participant (Ancoli-Israel et al., 2003). Points were placed on the computer file to mark the intervals the participants were in bed and the times the device was removed. To then assess the reliability of manual selection of rest intervals, a randomly selected 33% (20 sleep files) were double scored by a second independent trained researcher. Any discrepancies of more than 15 minutes for either 'start time' or 'end time' of the rest interval were flagged and re-analysed by both technicians. If agreement could not be reached on any files, a third independent researcher would have been used for scoring; however, this did not occur. A total of four files were re-analysed by both researchers with a final accuracy rate of 87.9% achieved between the two researchers, this threshold has previously been described as acceptable (McHugh, 2012).

Statistical Analysis

Simple group descriptive statistics are shown as means ± standard deviations unless stated otherwise. A paired t-test was used to compare AUTO and MAN metrics using a Statistical Package for Social Science (V. 22.0, SPSS Inc., Chicago, IL), with statistical significance set at $p<0.05$. Inter-device agreements for AUTO and MAN were examined using Pearson correlation coefficients (*r*) with 95% confidence intervals (95% CI) and interpreted using thresholds of <0.30: *poor*, >0.30: *fair*, >0.50: *moderately strong*, >0.80: *very strong* (Chan, 2003). The mean differences/bias and upper and lower limits of agreement (1.96 standard deviations or 95% of a normally distributed population) between devices were determined in absolute values for TST, SE, TIB, SOL, WE, and WASO. Between-device typical error of measurement (TEM) was determined using a customized excel spreadsheet (Hopkins, 2017). Consistent with previous research, we defined an *a priori* difference between the two devices of <30 min for TST, and <5% for SE as satisfactory (Werner, Molinari, Guyer, & Jenni, 2008).

Results

There were no significant differences between devices (AUTO and MAN) for any of the measured sleep variables ($p > 0.05$, Table 12). There was a mean difference between devices of less than 1-min over the 60 nights of data for TST and 1.1% for SE (Table 12), with *very strong* correlations between devices for both these measures (Table 13).

Table 12. Mean ± SD values for both the automatically scored Readiband™ (AUTO) and the manually scored Micro Motionlogger® (MAN) actigraphy devices, for all measured sleep variables and p-values for each comparison.

Sleep Indices	AUTO	MAN	P-Value
Total Sleep Time (min)	438.6 ± 87.5	439.1 ± 90.6	0.974
Sleep Efficiency (%)	91.1 ± 5.1	92.2 ± 5.2	0.240
Total Time in Bed (min)	459.1 ± 96	465.3 ± 92.6	0.717
Sleep Onset Latency (min)	19.4 ± 14.5	16.7 ± 11.9	0.145
Wake Episodes per Night (Number)	8.0 ± 4.9	9.7 ± 5.0	0.061
Wake After Sleep Onset (min)	30.0 ± 23.3	32.6 ± 20.7	0.528
Sleep Onset Time (Time of day)	21:49 ± 0:48	21:59 ± 0:42	0.231
Wake Time (Time of day)	5:49 ± 1:01	5:55 ± 1.02	0.634

Table 13. Typical error of measurement (TEM), mean difference, range of difference and Pearson correlations for each sleep metric between automatically scored Readiband™ (AUTO) and manually scored Micro Motionlogger® (MAN) actigraphy devices.

	TEM (95% CI)	Mean difference (± SD)	Range of mean difference (1.96xSD)	Pearson correlation coefficient (95% CI)
Total Sleep Time (min)	15.5 (12.3 to 17.7)	0.53 ± 20.6	-39.7 to 40.8	0.97 (0.96 to 0.98)
Sleep Efficiency (%)	2.7 (2.3 to 3.4)	1.1 ± 2.9	-4.6 to 6.8	0.84 (0.74 to 0.90)
Total Time in Bed (min)	29.6 (25.0 to 36.2)	6.2 ± 29.4	-51.4 to 63.9	0.95 (0.92 to 0.97)
Sleep Onset Latency (min)	6.4 (5.4 to 7.8)	-2.6 ± 6.5	-15.4 to 10.1	0.90 (0.83 to 0.94)
Wake Episodes per Night (No)	1.4 (1.2 to 1.7)	1.6 ± 1.4	-1.2 to 4.5	0.96 (0.93 to 0.97)
Wake After Sleep Onset (min)	12.6 (10.7 to 15.4)	2.5 ± 12.6	-22.2 to 27.2	0.84 (0.75 to 0.90)

The variables of SOL, TIB, and WE resulted in *very strong* correlations between devices and a mean difference of <6.2 min (Table 13). Comparison between devices for these variables also resulted in TEM's of <29.6 min (Table 13). The remaining variables: SE and WASO, also resulted in *very strong* correlations between devices, with TEM values of 2.7%and 12.6 min, respectively (Table 13). Level of agreement (Bland-Altman) plots showing ± 95% limits of agreement between AUTO and MAN for key sleep variables of TST, SOL, and SE are displayed in Figure 10.

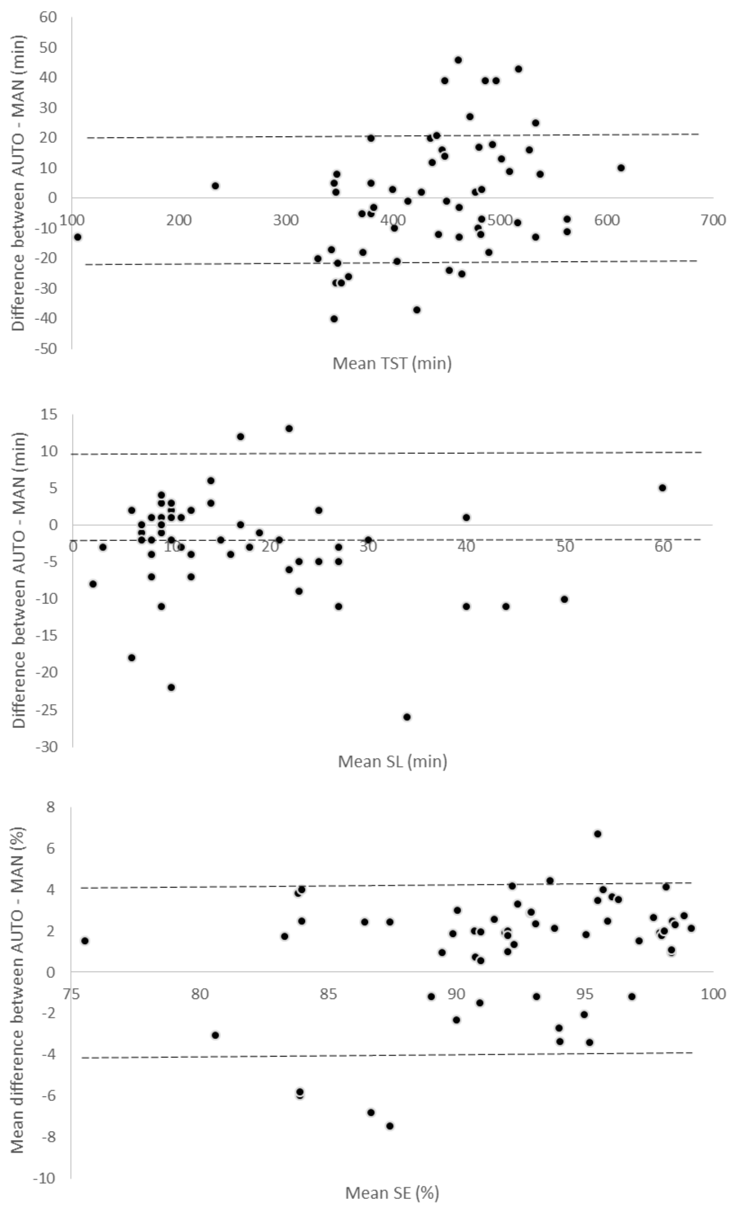

Figure 10. Level of agreement (Bland-Altman) plots showing ± 95% limits of agreement between automatically-scored Readiband™ (AUTO) and manually-scored Micro Motionlogger® (MAN) for a) total sleep time (TST); b) sleep latency (SL); c) sleep efficiency (SE).

Discussion

This study examined the differences between a commercially available, automatic-scoring actigraph when compared to a manually scored actigraph in healthy adult participants while wearing both devices concurrently. The aim of the study was to simply compare the metrics coming from the two devices and not to evaluate the overall validity or accuracy of actigraphy as a method of monitoring sleep. The correlation between these manually and automatically scored devices was *very strong* for all sleep variables with no significant differences in any of the measured sleep variables between devices. The automatically scored device performed comparably to the manually scored device in the current study, suggesting a practical alternative to achieve similar levels of accuracy without the time demand or expertise of a trained technician required to score the actigraphy trace.

Werner et al. (29) stated that a difference between two devices of < 30 min for TST and a difference < 5% for SE can be considered satisfactory. Indeed, results from the current study were under < 30 min for TST and < 5% for SE, with mean differences between devices of less than 1-min over the 60 nights for TST and 1.1% for SE. Accordingly, based on the suggestions of Werner et al. (2008), the differences between devices for these identified key sleep metrics in the current study can be deemed acceptable, and the AUTO can be considered an appropriate alternative for use in both practical and research settings.

In the current study, TST, TIB, SOL, WASO, WE and SE for AUTO and MAN indicated no significant difference and all Pearson correlation coefficients were *very-strong*. Dunican et al. (2018) compared the automatically-scored RB to a different manually-scored actigraph (ActiGraph GT3X+) during a laboratory observation night, and when worn at home for 7-nights in a healthy adult population. Dunican et al. (2018) reported that TST showed no difference between the devices in the laboratory condition ($p = 0.58$), but a longer sleep duration (38 ± 61 min, $p < 0.001$) and differences for time at lights-out for RB in the at-home condition. For SE, the RB estimated 5-12% less (p

<0.001), with longer SOL (22-36 min, $p < 0.05$) than the ActiGraph GT3X+ device in both conditions (Dunican et al., 2018). It was concluded that the differences between the at-home and laboratory condition between devices were due to inaccuracies of the RB reporting time at lights out compared to ActiGraph's requirement to self-report (e.g. using a marker button on the watch), and highlighted the challenge of accurately defining these metrics due to different assessment methods (Dunican et al., 2018). When compared to the current study, our results indicated no significant difference between devices, suggesting that there were similarities between the proprietary AUTO algorithms and MAN scoring. Thus, the results align with the conclusion of Dunican et al. (2018), who stated that the RB automated algorithm may be used in the same capacity as a manually scored actigraph for the collection of key sleep measures.

Previous research has identified the inter-device reliability of the AUTO device used in the current study (Driller et al., 2016). In this study by Driller et al. (2016), participants wore two RB-SBV2 devices concomitantly for 77 nights of sleep where sleep data was assessed. The Driller et al. (2016) study, found no significant differences between devices for any of the measured sleep variables ($p < 0.05$). Mean differences of 2.1 and 0.2 min for TST and SL were associated with a low TEM between devices (9.5 and 3.8 min, respectively). Interestingly, the non-significant differences between devices observed in the Driller et al. (2016) study for all sleep metrics, are remarkably similar to those observed in the current study. Driller et al. (2016) also reported *very-high* intraclass correlations between devices indicating the RB to have acceptable inter-device reliability. In comparison, while the current study had slightly higher TEMs for some of the measures, this is somewhat expected, as the current study included two different brands of device, with different algorithms and methods of scoring (manual vs. automatic). It is therefore promising that the differences were similar when comparing the inter-device reliability (RB vs. RB) and the comparison of two different devices (MAN vs. AUTO). RB has been shown to be reliable (inter-device), and RB compares favourably to MAN, indicating RB can be considered a valuable tool for monitoring sleep metrics.

The current study is not without limitations, these include comparing AUTO vs MAN devices and associated algorithms in only an at-home environment and not in a laboratory condition, where differing results may have occurred between devices (Dunican et al., 2018). We also acknowledge that not comparing to PSG was a limitation, however, this comparison has already been made for both devices (Dunican et al., 2018; Meltzer et al., 2012; Russell et al., 2000) and the main aim of the current study was to compare AUTO and MAN devices.

Conclusion

In conclusion, AUTO may provide an accurate and practical solution for use in healthy populations to give an indication of sleep/wake patterns. An automatically scored device such as the RB does not require any expertise, and when compared to the time required for manual scoring of actigraphy traces, the RB may provide a more time-efficient alternative, therefore allowing large groups of individuals to be monitored effectively with comparable accuracy.

CHAPTER SEVEN

Operation early-bird: Investigating altered light exposure in military barracks on sleep and performance - a placebo-controlled study

Edgar, D., Beaven, C., Gill, N., Zaslona, J., & Driller, M. Operation early-bird: Investigating altered light exposure in military barracks on subsequent sleep, wellbeing, and performance - a placebo-controlled study. *Journal of Sleep Research.* (Accepted 5th October 2022).

Prelude: Based on Studies One to Three, where we identified that sleep was a major challenge for new recruits, we decided to implement an intervention to improve sleep in the military context. Study Five investigated the efficacy of reduced-temperature lighting on sleep, physical performance, and objective wellness measures, while also investigating the efficacy of a placebo sleep device.

Abstract

Background: The manipulation of light exposure in the evening has been shown to modulate sleep, and may be beneficial in a military setting where sleep is reported to be problematic. This study investigated the efficacy of low-temperature lighting on objective sleep measures and physical performance in military trainees. **Methods:** 64 officer-trainees (52 male/12 female, mean ± SD age: 25 ± 5y), wore wrist-actigraphs for 6-weeks during military training to quantify sleep metrics. Trainee 2.4km run time and upper-body muscular-endurance were assessed before and after the training course. Participants were randomly assigned to either: low-temperature lighting (LOW, n=19), standard-temperature lighting with a placebo 'sleep-enhancing' device (PLA, n=17), or standard-temperature lighting (CON, n=28) groups in their military barracks for the duration of the course. Repeated-measures ANOVAs were run to identify significant differences with post-hoc analyses and effect size calculations performed where indicated. **Results:** No significant interaction effect was observed for the sleep metrics; however, there was a significant effect of time for average sleep duration, and *small* benefits of low temperature lighting when compared to CON (d=0.41 to 0.44). A significant interaction was observed for the 2.4km run, with the improvement in LOW (Δ92.3s) associated with a *large* improvement when compared to CON (Δ35.9s; p=0.003; d=0.95 ±0.60), but not PLA (Δ68.6s). Similarly, curl-up improvement resulted in a *moderate* effect in favour of LOW (Δ14 repetitions) compared to CON (Δ6; p=0.063; d=0.68 ±0.72). **Conclusion:** Chronic exposure to low-temperature lighting was associated with benefits to aerobic fitness across a 6-week training period, with minimal effects on sleep measures.

Introduction

Sleep is requisite for human health and well-being, and is crucial to physiological and cognitive functioning (O'Donnell et al., 2018). It is known that the human circadian timing system is particularly sensitive to ocular short-wave light exposure (Cajochen et al., 2005) and that phototransduction of specific light wavelengths can be manipulated to impact sleep (Figueiro et al., 2014). Chronic exposure to bright lighting environments before bedtime has been shown to have a profound suppressive effect on melatonin levels, shortening the body's internal representation of night duration (Boyce, 2010; Chellappa, 2020; Gooley et al., 2011; Munch et al., 2006). Wavelength-specific impacts of light extend to eliciting changes in sleep architecture and decreases in slow-wave sleep (Chellappa, et al., 2013). In contrast, chronic reductions in bright light and short-wavelength blue-light exposure in the hours before bed have been shown to promote sleep and support the normal circadian biorhythm of melatonin (Kozaki et al., 2008; Rahman et al., 2017; Vethe et al., 2021). Amber-lens glasses that specifically block short-wavelength light also improve sleep quality and can decrease sleep onset latency in recreational athletes when worn in the evening prior to bed; however, the implications for recovery and performance were identified as key areas to be addressed (Knufinke et al., 2019; Shechter et al., 2018; Van der Lely et al., 2015).

Obtaining sufficient sleep can play an important role in physical recovery (Halson, 2008) as well as in the consolidation of learning (Stickgold, 2005), emotional processing (Simon et al., 2020) and skill acquisition (Kuriyama et al., 2004). Short sleep duration and decreased sleep efficiency as a result of variability in sleep–wake time, can also have negative ramifications for mood and mental wellbeing (Chellappa, Morris, & Scheer, 2020). With respect to physical performance, longer sleep durations have demonstrated improved training capacity (Cook et al., 2012), and improved aerobic adaptations in athletes (Teece et al., 2021). Similarly, when stratifying military trainees into two quantile groups based on sleep duration, small benefits in aerobic fitness were observed in those who averaged only a modest 36 minutes longer sleep duration than a short sleeping cohort (Edgar et al., 2021).

Military personnel can experience even greater challenges than the general population with sleep, due to the stressful and constantly changing nature of daily training and operational roles (Good, Brager, Capaldi, & Mysliwiec, 2020). Following sleep disruption, there is potential for neurocognitive and physiological processes to be compromised (Banks & Dinges, 2007; Durmer & Dinges, 2005; Halson, 2008). A lack of sleep in the military context has been shown to have an impact on combat effectiveness by reducing vigilance, alertness, motivation and inability to physically perform (Charest & Grandner, 2020; Good et al., 2020). Poor sleep quality in a military context has also been associated with poorer occupational well-being (Mantua, Pirner, et al., 2021), increases in high risk behaviours (Mantua, Bessey, et al., 2021), and greater injury risk (Ritland et al., 2021). Sleep was identified as a third highest priority area out of 43 topics for military personnel's health and physical performance in a consensus paper by Lovalekar et al. (2018). Additionally, sleep was ranked as the highest priority area by 99 of the 502 (~20%) of the attendees from 32 countries at the International Congress on Soldiers' Physical Performance. In the military occupational context, five specific sleep modulators (surface, light, air quality, noise, and temperature) have been identified with the potential to improve health, wellness, and operational performance (Ritland, 2019).

The manipulation of environmental light exposure to improve sleep outcomes has been shown to have a range of benefits to performance, wellbeing, and recovery in the general population. However, to our knowledge, no previous research has evaluated the effects of altering night-time light exposure over a six-week period in the living quarters of soldiers during an intense period of training. Therefore, the current study aimed to investigate the effect of reduced temperature lighting on objective sleep measures and physical performance in military recruits over a six-week training course. Specifically, based on the work of Knufinke et al. (2019), we hypothesized that lighting with a lower circadian sensitivity would improve objective sleep quality and decrease sleep latency, and that these improvements would translate into measures and enhanced physical performance assessed via a fitness evaluation that consisted of a 2.4 km time-trial road run, curl-ups, and press-ups.

Methods

Participants

A representative total sample of 64 healthy officer trainees (50 male/14 female, age: 25 ± 5 y [mean ± SD]) from a total of 116 officer trainees (91 male/25 female, age 24 ± 6 y) on the Joint Officer Induction course from Army, Navy, and Air Force from the New Zealand Defence Force participated in the current study. An a priori power calculation was informed by minimal detectable change and variability from a closely matched cohort Edgar et al., (2021) With inputs of a 2-sided alpha of 0.05, 0.8 power, calculations indicated a minimum sample size requirement of 24 (press-ups), 52 (sit-ups), and 54 (2.4 km run), to detect meaningful differences using the website (http://hedwig.mgh.harvard.edu/sample_size/js/js_parallel_quant.html). Participation in the study was voluntary and ethical approval for the study was obtained from an institutional Human Research Ethics Committee (HREC) (Health) #2018-01.

Experimental Design

The current study implemented a pre-post parallel-group study over six weeks, with an intervention group, a placebo group, and a control group. Trainees were assigned to either; LOW; low temperature lighting in living quarters (n =19, 7 female/12 male), PLA; standard temperature lighting and a placebo sleep enhancing device (n =17, male), or CON; a standard temperature lighting control group (n =28, 7 female/21 male) (Table 1). Group assignment was random and dependent on barrack allocation (outside of our control). There was no specific assignment due to occupation specialty, unit, or capability. The only specific split was male / female, where each sex resided in their own gender-pure barrack rooms. All barrack rooms were identical in size with open plan cubical spaces defined by dresser, wardrobe and bed. All participants were tested for physical performance pre and post 6-weeks of officer training and sleep was monitored for the entire 6-weeks using wrist actigraphy. Trainees only had access to electronic devices (e.g. mobile phones) for 30 minutes on one day per week in the morning (Sunday), this protocol was specific to the training course. Trainees were only in their barracks after 6pm and for quick uniform changes during the day. Sleep was confined to a specific window of ‘lights out’ between 2200-2230 h and ‘wakeup’ between 0530-0545 h.

Experimental Groups

Control group (CON)

The CON group was exposed to standard barrack ceiling lighting (7000 K, 58 W / 391 ± 58 lx / ~386 nm) and warm-white LED bedside bulbs (7000 K, 8 W / 958 ± 128 lx / ~412 nm, Table 18) for the 6-week duration. Each room contained four ceiling lights (two florescent tubes in each, eight-tubes in total), and eighteen LED individual bedside lamps sitting approximately 1-m from the head of the bed.

Low-circadian light group (LOW)

For the 6-week duration, florescent ceiling tubes and were replaced in the living quarters with warm low temperature lighting tubes (3000 K, 58 W / 316 ± 25 lx / ~698 nm, Table 18). The warm-white LED bulbs in the bedside lamps were also replaced with warm-white incandescent bulbs (60 Watt / 300 ± 31 lx / ~704 nm, Table 1) for the 6-week duration.

Placebo group (PLA)

The PLA group was exposed to standard barrack ceiling lighting for the 6-week duration identical to the CON group (Table 18). A placebo sleep device was also placed in the centre of one barrack room in clear view of all trainees (Figure 11). The device was introduced to trainees in the PLA group through a 15-minute presentation, as a 'novel sleep-promoting device' that is emitting a frequency through antennas within a 20 m radius that will be detected by the brain and enhance sleep. The presentation cited previous research investigating other novel sleep devices, including devices that emit white noise (Forquer, Johnson, & Hypnosis, 2007), low energy emissions (Reite et al., 1994), and mixed-frequency white noise (Stanchina, Abu-Hijleh, Chaudhry, Carlisle, & Millman, 2005). The device was also introduced as being a beta-product testing device that had not yet been studied, and given the nature of the invention, it was highly classified. All beds spaces were within 15 m of the device in the centre of the barrack room. The lid of the device was removed for demonstration to show trainees the internal system, battery packs, 'on-off' and 'frequency level' switches (set to high), and various coloured flashing LED lights to give the impression it was a functioning device. The lid was then replaced and locked (with padlocks) with no flashing lights visible, and no access for trainees.

Figure 11. Placebo 'novel sleep-promoting device' with 'frequency emitting' antennas that was placed in the centre of the room reaching a 20 m radius.

Light Measurement

The lux of each barrack was measured using a calibrated Cabac professional digital light multimeter (T8268, Ecco Pacific Ltd, Cabac NZ). Kelvin and wattage are reported as manufacture ratings, and nm and circadian stimulation were determined from the Mount Sinai Light and Health Research Centre conversion calculator (Figueiro, Gonzales, & PeDLer, 2016). Lux was measured on the second day, in the first week of the course at 9:00 pm at night when standing in the middle of the room approximately 200 cm away from the ceiling light, and sitting on the bed approximately 100 cm from the bed side lamp in similar fashion to Rahman et al. (2017).

Table 14. Lighting descriptors for the three light interventions: LOW (low-temperature light), PLA (standard-temperature light combined with a placebo 'sleep-enhancing' device), and CON (standard lighting). W: Watt, K: Kelvin temperature rating, Lux: Luminous flux, nm: wavelength in nanometre, and CS: circadian stimulation rating derived from Mount Sinai Light and Health Research Centre conversion calculator. LOW (low-temperature light), PLA (standard-temperature light + placebo 'sleep-enhancing device') and CON (standard-temperature lighting).

GROUP	Fluorescent Ceiling Tube (58 W)				Bedside Incandescent Bulb (60 W)				Bedside LED Bulb (8 W)			
	K	lx	nm	CS	K	lx	nm	CS	K	lx	nm	CS
LOW (n=19)	3000	316 ± 25	~698	~0.298	2700	300 ± 31	~704	~0.267	-	-	-	-
PLA (n=17)	7000	433 ± 57	~387	~0.614	-	-	-	-	7000	916 ± 76	~427	~0.646
CON (n=28)	7000	391 ± 58	~386	~0.605	-	-	-	-	7000	958 ± 128	~412	~0.649

Wrist-Actigraphy

An actigraphy device was worn on the wrist continuously for the full duration of the course during both wake and sleep on whichever wrist the individual felt comfortable with (Driller et al., 2017), to assess four objective sleep metrics we recorded daily and then summed to provide weekly change scores: average night-time total sleep time (TST), sleep efficiency (SE), sleep onset latency (SOL), and wake after sleep onset duration (WASO). A combination of both Readiband™ (Fatigue Science, Vancouver, BC, Canada, n = 20) and Micro Motionlogger® (Ambulatory Monitoring Inc, Ardsley NY, USA, n = 44) actigraphy devices were used. Pilot work from our laboratory showed that when these two devices were compared for inter-device reliability, there were no significant differences for TST, SE, SOL, and WASO (all (p >0.05); and *high* to *very high* intraclass correlation coefficients were observed for all variables (0.81-0.97). The Readiband actigraph is automatically scored and records data at a sample rate of 16 Hz (Dennis et al., 2016). When validated against lab-based polysomnography (PSG), accuracies of ~90% have been determined for TST (Dunican et al., 2018). The Micro Motionlogger actigraph uses a tri-axial accelerometer which has also been validated against PSG, and distinguishes sleep from wakefulness 88-90% of the time (Gotoh, 2006). As the Micro Motionlogger was manually scored, double scoring by two trained members of the research team was undertaken on 33% of randomly selected sleep files to assess the reliability of manually selected sleep intervals as performed previously (Edgar et al., 2021). Any discrepancies of more than 15 minutes for either 'start time' or 'end time' of the sleep interval were flagged and re-analysed. An accuracy rate of 87.9% was achieved between the two researchers, which is deemed acceptable (McHugh, 2012).

Physical Training Program

Physical training (PT) comprised a controlled two-week introduction phase of body weight exercises and aerobic conditioning. In weeks three and four, the intensity of PT increased to challenge individuals. Weeks five and six then focused on functional fitness and conditioning. A total of 18, 90-minute exercise sessions were allocated to physical training over the 6-week period and included a combination of aerobic interval running, strength training, circuits, swimming, and bike-boxing-rowing intervals. The recruit training course has been detailed previously in Edgar et al. (2020).

Fitness Testing

The standard NZDF JOIC fitness evaluation was conducted by Physical Training Instructors (PTIs) pre and post the course. This evaluation consisted of three key components that were collected as measures of physical performance: 1) 2.4 km time-trial road run, 2) maximum curl-ups (also known as sit-ups), and 3) maximum press-ups conducted on a wooden gym floor. Fitness testing was conducted at 9:00 am with identical morning routines prior to each testing session. Run times were measured via stopwatch to the nearest second by a designated PTI. Press-ups and curl-ups repetitions were counted by a PTI every time the full range of motion was completed, maintaining a consistent tempo, until failure. For both the press-ups and curl-ups, one warning was given for an incomplete repetition, prior to fatigue or participants being stopped by the PTI (Edgar et al., 2020).

Statistical Analysis

Descriptive statistics are shown as mean ± SD values, while Cohen's *d* effect sizes are represented as mean ±95% confidence intervals. All statistical analyses were performed using the Statistical Package for Social Science (V. 27.0, SPSS Inc., Chicago, IL), with statistical significance set at $p \leq 0.05$. To examine whether there were any sleep and performance differences between groups, two-way repeated-measures analysis of variance (ANOVA) were performed for Group (LOW, PLA & CON) and Time (pre and post) on the performance data, and weekly sleep data: (TST, SE, SOL, and WASO). A Bonferroni adjustment was applied if significant main effects were detected. Analysis of the distribution of residuals was verified visually with histograms and also using the Shapiro-Wilk test of normality. Magnitudes of the standardized effects between pre and post physical tests were calculated using Cohen's *d* and interpreted using thresholds of <0.2, 0.2, 0.5, and 0.8 for *trivial*, *small, moderate and large*, respectively (Cohen, 1988). Effects were deemed unclear if the 95% confidence intervals overlapped the thresholds for both *small* positive and negative effects ($d \pm 0.2$).

Results

All participants (n =64) completed the entire training program. All participant sleep data from each night was included (n =2,304 nights), and all participants completed the pre and post physical performance testing. There was no significant difference between groups for physical performance at baseline (all $p > 0.05$).

Sleep Measures

The repeated-measures ANOVA revealed no significant Group x Time interaction for TST (p =0.186); although there was a significant effect of time ($p < 0.001$) and the main effect of group was $p = 0.090$ (Figure 12). Specifically, TST in Week 5 was significantly lower than all other weeks except Week 6 ($p < 0.001$), and TST in Week 6 was significantly lower than all other weeks except Weeks 4 and 5 ($p < 0.05$). Effect size analysis revealed *small* differences in sleep duration between the LOW and CON groups at Week 3 (15.4 min; $d = 0.44 \pm 0.58$) and Week 6 (21.2 min; $d = 0.41 \pm 0.57$), and *moderate* differences between PLA and CON in Week 3 (18.9 min; $d = 0.58 \pm 0.58$; Figure 12). The rebound (increase in sleep duration) from Week 5 to Week 6 was also greater in the LOW compared to the CON group (20.6 min; $d = 0.42 \pm 0.59$; Figure 12). There were no significant differences between LOW and PLA for TST at any time point; however, the significant decrease in TST seen in the PLA (-28.4 min; $p = 0.026$) and CON groups (-26.5 min; $p = 0.028$) over the six weeks training was not observed in the LOW group (-3.3 min; $p = 0.693$; Figure 12).

Regarding the remaining sleep metrics, no significant interaction or main effects, nor any substantial differences were observed for sleep efficiency, SOL, or WASO; there was a moderate group difference for WASO ($p = 0.039$) and the main effect of time was p =0.092. The WASO was consistently lower in the LOW compared to the CON and PLA groups, and was substantially lower than CON in Week 2 (8.7 min; $d = 0.44 \pm 0.59$) and Week 3 (8.7 min; $d = 0.48 \pm 0.58$; Figure 13). Data for all sleep metrics are presented in Table 15.

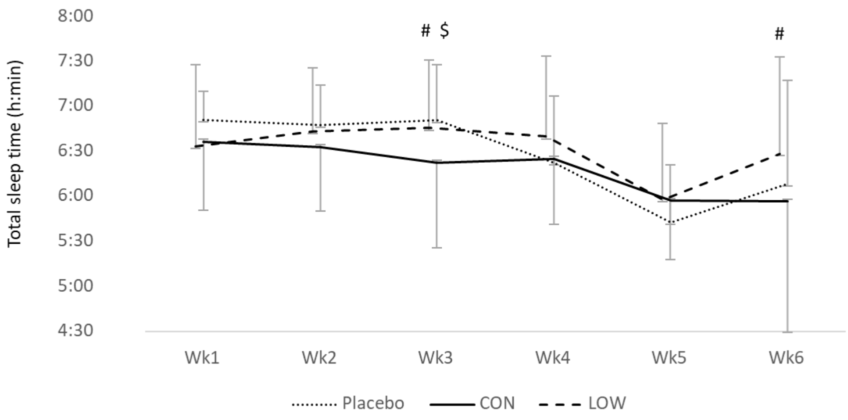

Figure 12. Average total sleep time data across the 6-week training course. Dashed line: LOW (low-temperature light), dotted line; PLA (standard-temperature light + placebo 'sleep-enhancing device') and solid line; CON (standard-temperature lighting) over 6-weeks of military training. [#]significant difference between LOW and CON, [$]*moderate* difference between PLA and CON.

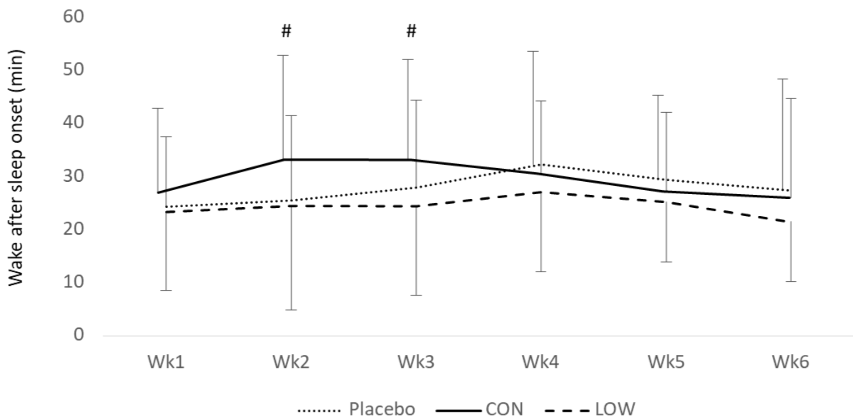

Figure 13. Wake after sleep onset data across the 6-week training course. Dashed line: LOW (low-temperature light); dotted line: PLA (standard-temperature light + placebo 'sleep-enhancing device'); and solid line: CON (standard-temperature lighting) over 6-weeks of military training. [#]Moderate difference between LOW and CON.

Table 15. Average sleep metrics (mean ± SD) over the 6-week training course. LOW: low-temperature light, PLA: standard-temperature light + placebo 'sleep-enhancing' device, CON: standard-temperature lighting, TST: Total sleep time, SE: Sleep efficiency, SOL: Sleep onset latency, WASO: Wake after sleep onset.

Group	Time in Bed (h:m)	TST (h:m)	SE (%)	SOL (min)	WASO (min)
LOW					
Week 1	7:18 ± 0:08	6:22 ± 0:36	91 ± 6	16 ± 7	23 ± 15
Week 2	7:22 ± 0:10	6:28 ± 0:28	91 ± 6	14 ± 4	25 ± 20
Week 3	7:26 ± 0:13	6:30 ± 0:30	91 ± 6	14 ± 5	24 ± 17
Week 4	7:22 ± 0:31	6:26 ± 0:36	91 ± 5	15 ± 6	27 ± 15
Week 5	6:51 ± 0:26	5:58 ± 0:34	91 ± 5	16 ± 4	25 ± 11
Week 6	7:17 ± 0:29	6:18 ± 0:43	91 ± 6	17 ± 9	22 ± 11
Overall Mean	**7:16 ± 0:16**	**6:20 ± 0:34**	**91 ± 6**	**15 ± 6**	**24 ± 15**
PLA					
Week 1	7:22 ± 0:09	6:34 ± 0:13	92 ± 4	15 ± 4	24 ± 13
Week 2	7:19 ± 0:16	6:31 ± 0:18	92 ± 4	14 ± 4	25 ± 16
Week 3	7:21 ± 0:20	6:33 ± 0:25	92 ± 4	14 ± 4	28 ± 17
Week 4	7:20 ± 0:10	6:14 ± 0:30	90 ± 4	16 ± 6	32 ± 21
Week 5	6:46 ± 0:34	5:48 ± 0:26	92 ± 4	14 ± 4	29 ± 16
Week 6	7:01 ± 0:54	6:05 ± 0:46	90 ± 8	17 ± 10	27 ± 21
Overall Mean	**7:24 ± 0:26**	**6:18 ± 0:26**	**90 ± 5**	**15 ± 5**	**28 ± 17**
CON					
Week 1	7:18 ± 0:18	6:24 ± 0:31	92 ± 5	15 ± 7	27 ± 16
Week 2	7:19 ± 0:19	6:21 ± 0:29	91 ± 5	15 ± 4	33 ± 20
Week 3	7:16 ± 0:34	6:14 ± 0:38	91 ± 4	17 ± 10	33 ± 19
Week 4	7:12 ± 0:27	6:16 ± 0:29	91 ± 4	16 ± 5	31 ± 14
Week 5	6:50 ± 0:29	5:58 ± 0:26	92 ± 4	16 ± 6	27 ± 15
Week 6	6:58 ± 0:52	5:57 ± 0:58	91 ± 6	18 ± 9	26 ± 19
Overall Mean	**7:09 ± 0:30**	**6:12 ± 0:35**	**91 ± 5**	**16 ± 7**	**30 ± 17**

Performance Measures

The repeated-measures ANOVA detected a significant Group x Time interaction effect for 2.4 km run (p = 0.009), but not for press-ups (p = 0.808) or curl-ups (p = 0.067). Post-hoc analyses revealed that the *large* improvement in 2.4 km run time in the LOW group was significantly greater than the CON (Δ56.0 s; p = 0.003; d=0.95 ±0.60), but not the PLA group (Δ23.7 s; p = 0.239; d = 0.40 ±0.68; Figure 14A). No significant group differences were seen in press-up performance (Figure 14B). Although not significant, LOW resulted in *moderate* improvements in curl-up performance compared to CON (Δ7.8 repetitions; p = 0.063; d = 0.68 ±0.72), but not the PLA group (Δ6.1

repetitions; *p* = 0.173; *d* = 0.50 ±0.73; Figure 14C). All performance data is presented in Table 16.

Table 16. Physical performance changes across a 6-week training program. * Significantly greater than pre-training value (p<0.01). **Significantly greater than CON, p<0.01. LOW (low-temperature light), PLA (standard-temperature light + placebo 'sleep-enhancing device') and CON (standard-temperature lighting).

		Pre-training	Post-training	%Δ Pre-Post	Effect size vs LOW (*d*)	Effect size vs CON (*d*)
2.4 km Run (s)	**LOW**	711 ± 111	619 ± 66*	13 ± 8 **	-	0.95±0.60** ***Large***
	PLA	624 ± 64	556 ± 31*	11 ± 10	0.40 ±0.68 *Unclear*	0.55±0.63 ***Moderate***
	CON	623 ± 69	587 ± 52*	6 ± 10	-	-
Press-Ups (Reps)	**LOW**	28 ± 9	34 ± 11*	21 ± 18	-	-0.07 ±0.60 *Unclear*
	PLA	32 ± 10	38 ± 10*	21 ± 21	0.20 ±0.72 *Unclear*	-0.19 ±0.67 *Unclear*
	CON	28 ± 9	33 ± 9*	19 ± 30	-	-
Curl-Ups (Reps)	**LOW**	38 ± 15	52 ± 26*	37 ± 39	-	-0.68 ±0.72 ***Moderate***
	PLA	39 ± 19	47 ± 15*	21 ± 23	-0.50 ±0.73 *Unclear*	-0.19 ±0.67 *Unclear*
	CON	40 ± 20	47 ± 20*	15 ± 20	-	-

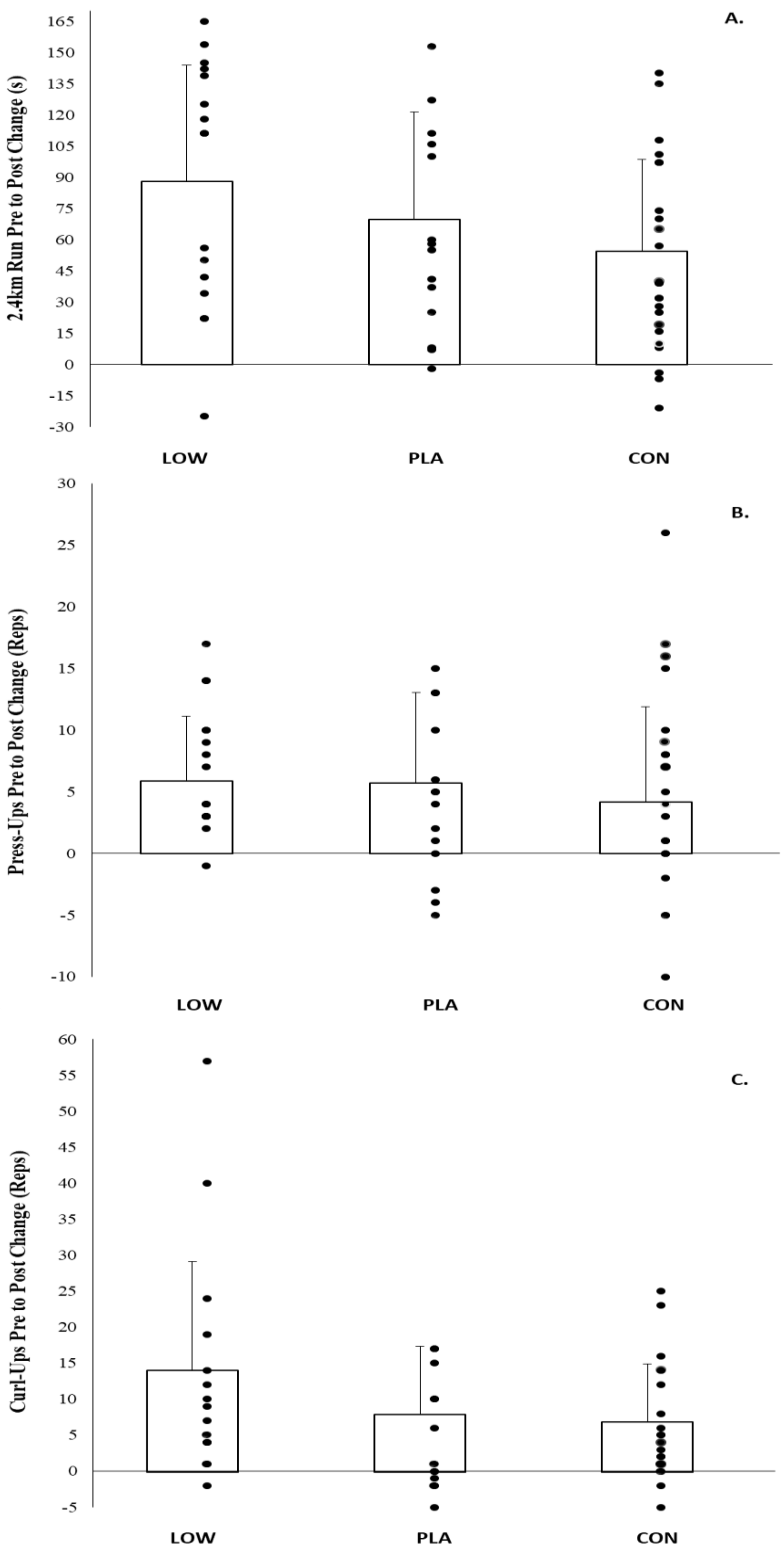

Figure 14. Performance improvement over the 6-week training course. A: 2.4 km time-trial run, B: curl-up and C: press-up performance. Bars (Mean + SD), scatter dots (individual participants). LOW: low-temperature light, PLA: standard-temperature light + placebo 'sleep-enhancing' device, CON: standard-temperature lighting, Reps: repetitions.

Discussion

The main results from this study demonstrate the effectiveness of a chronic modification of the lighting environment on sleep, with *small* improvements in sleep duration relative to a control group over a 6-week intervention. These improvements were also reflected in less time awake after sleep onset and importantly, in 2.4 km run performance. Other objective sleep metrics measured by actigraphy (sleep efficiency and sleep onset latency) showed no significant differences between the groups, which did not support our original hypotheses. Of note, a placebo sleep device did show a benefit to sleep duration when compared to the control group. Thus, the current study adds novel insight into the impact of low temperature night-time lighting on objective sleep metrics and physical performance over a 6-week intense training program.

The low temperature lighting in the current study led to improvements in aerobic capacity across six weeks of training relative to the standard lighting provided. Earlier research has demonstrated that, when cohorts are dichotomised into high and low durations of sleep, longer sleep durations are associated with improved aerobic performance in both sporting (Teece et al., 2021) and military cohorts (Edgar et al., 2020). The improvements in aerobic fitness relative to the control group are of particular note given the specific negative effects of sleep loss on aerobic capacity reported in military personnel (Grandou et al., 2019). In a 2017 review, the lack of sleep intervention studies that address real-world issues was cited as an important limitation of the existing sleep literature (Grandner, 2017). Here we present data that takes an important step beyond simply making recommendations, by demonstrating a potentially valuable passive intervention to address the health implications of poor sleep by manipulating the lighting environment.

It is well established that light detected at the retina provides the stimulus for circadian and biological regulation, as well as the release of melatonin (Cajochen et al., 2005; Figueiro et al., 2006b; Rahman et al., 2017). It is also clear that these physiological outcomes have important implications for sleep (Chellappa, Gordijn, & Cajochen, 2011; Kozaki et al., 2008; Munch et al., 2006; Vethe et al., 2021). As a result, interventions to minimise circadian misalignment including the use of blue light-blocking glasses (Knufinke et al., 2019; Van der Lely et al., 2015) and blue-depleted environmental lighting (Vethe et al., 2021) have been assessed and shown to improve objective and subjective sleep metrics. Here we show that manipulating evening lighting with a lesser circadian stimulation rating of 3000 K led to meaningful improvements in sleep when compared to 7000 K light. Specifically, the LOW group tended to display longer sleep durations across the 6 weeks and less reduction in TST per night from the first to the last week of the training period (difference of ~ 3 min) when compared to the PLA and CON groups where TST was reduced by ~ 29 and ~ 27 min, respectively over the 6-week period. Of note, previous research has shown acute decreases in slow wave sleep, as a proxy for sleep quality, under similar lighting conditions (Chellappa et al., 2011; Kozaki et al., 2008). The significantly shorter WASO durations observed in the early part of the 6-week training period, can also be interpreted as enhanced sleep quality in the LOW group relative to the CON group (Appleman et al., 2016). Appleman et al. (2016) and colleagues also demonstrated an association between shorter WASO and skill acquisition, and these findings could have far-reaching ramifications across a range of work personnel (e.g. military, aviation, medical).

In a military context, sleep deprivation is common, with less than a third of US service members attaining 7-8 h of sleep (Luxton et al., 2011; Mysliwiec et al., 2013). Of note, short-term sleep extension in military cadets has been shown to improve motivation and performance in cognitive and physical tasks (Ritland, 2019). In addition, the Millennium Cohort Study identified that short sleep duration was associated with greater odds of developing post-traumatic stress disorder and anxiety (Gehrman et al., 2013). Neurological research has determined the potential links between sleep debt and emotional instability via an enhanced response of the amygdala to negative emotional stimuli (Motomura et al., 2013). It is worth noting that actigraphy has been reported to underestimate WASO, and overestimate sleep duration (Dunican et al., 2018) thus, the data presented here likely represent a 'best-case scenario' for sleep duration and fragmentation.

An interesting finding in the current study is the PLA group responding more positively in TST and 2.4 km run than the CON group. In the current study, the PLA group received specific education around potential positive effects of the electromagnetic device placed in their sleeping quarters and, although the device was a sham, this would have created positive expectations regarding efficacy. Therefore, our data support the concept that beliefs and expectations can affect neurophysiological and neurochemical activity (Beauregard, 2007). In a sleep context, placebo pills have previously been shown to improve perceived sleep quality (Yeung, Sharpe, Geers, & Colagiuri, 2020) and decreased wakefulness after sleep onset as assessed by polysomnography (Um et al., 2018). Of note, the LOW group were entirely unaware of the change in the lighting environment; thus, the positive effects observed in this group occurred in the absence of expectation.

As highlighted by Grandner (2017), insufficient sleep is highly prevalent globally and has been associated with "significant morbidity and mortality". Studies of sleep restriction suggest that cognitive deficits accumulate when adults attain less than 7 hours per night (Goel, Rao, Durmer, & Dinges, 2009). Chronic sleep restriction, which is not uncommon in a military environment, can result in cognitive deficits equivalent to those observed after 24-h of wakefulness (Van Dongen, Maislin, Mullington, & Dinges, 2003), and this level of sleep deprivation results in deleterious effects similar to drink-drive limits (Fairclough & Graham, 1999; Lowrie & Brownlow, 2020). Further, emotional, behavioural, and functional dysfunction have all been identified in a military context following poor sleep quality (Mantua, Bessey, & Sowden, 2020b; Mantua et al., 2021a). It is worth noting that chronotype and genetic susceptibility to sleep loss were not assessed in the current study.

Conclusion

While we also acknowledge the constrained sleep opportunity window, uneven group size, relatively small sample, lack of control over light exposure outside the barracks, and use of actigraphy as limitations in the current study, we did observe improvements in total sleep time and aerobic fitness from chronic exposure to lower-temperature lighting over 6-weeks when compared to a control group. Within the constraints of conducting research in the military environment, this passive and readily implementable lighting intervention has the potential to offset some of the negative sequelae of cumulative sleep deficit. Future work may consider incorporating wearable polysomnography, individualised light and melatonin monitoring to establish dim light melatonin onset and the physiological basis of the lighting effects, and incorporating the Walter Reed Army Institute of Research Kit-Actigraphy (WORK-A) (Devine et al., 2020) that more accurately characterise soldier sleep. While we acknowledge the constrained sleep opportunity window and use of actigraphy as limitations in the current study, we did observe improvements in total sleep time and aerobic fitness from chronic exposure to lower-temperature lighting over 6-weeks when compared to a control group. This passive and readily implementable lighting intervention has the potential to offset some of the negative sequelae of cumulative sleep deficit.

CHAPTER EIGHT

Summary, Practical Applications, Limitations and Future Research

Thesis Summary

Five experimental studies designed to address the main aims of the this thesis were completed; firstly, changes in the physical characteristics of New Zealand Army, Navy and Airforce officer trainees' over a 6-week Joint Officer training were assessed (Study One, Chapter Three). Then, the chronic effects of lower-body CG wear (over 6-weeks) on performance adaptations and subjective wellbeing was investigated (Study Two, Chapter Four), and then the relationship between sleep duration and changes in physical performance in recruits during 6-weeks of military training (Study Three, Chapter Five). This was followed this by comparing automatic-scoring and manual-scoring actigraphy for sleep measurement in healthy adults (Study Four, Chapter Six), and finally, investigating the longitudinal effect of altered light exposure in military barracks on subsequent sleep, well-being, and physical performance (Study Five, Chapter Seven).

The series of studies in this thesis provides a direction and foundation for better understanding the physical fitness characteristics of military trainees, as well as sleep and recovery considerations in the general military setting. Although trainees presented to initial military training with low levels of fitness, significant improvements were observed over the 6-week training period. It was also evident that recovery and sleep are generally poor during these initial military training courses and given little focus. However, positive recovery observations were evident with the use of CG which provided some benefits to perceived muscle soreness, physical performance, and small improvements in sleep were also observed with the implementation of a lighting intervention over the duration of a training course. Results from this thesis augment our understanding of sleep and recovery in military trainees and the general military environment. This body of work may help to inform decision-making in the design and implementation of intensive recruit military courses and the tactical training environment. This work highlights the need for a greater emphasis on sleep and recovery practices in both the initial training space and the operational tactical space to enhance both the physical adaptation to training and the overall well-being.

The results from Study One demonstrated that regardless of sex, service and starting fitness level, aerobic capacity and muscular-endurance can be positively enhanced from a combination of both prescribed PT and military manual handling activities. Army officer trainees possessed greater physical characteristics at baseline and post testing compared to those in the Navy and Airforce. Collectively, results showed that 6 weeks of a JOIC improved aerobic fitness by ~8%, and muscular-endurance by ~31%.

Results from Study Two indicate that the chronic wearing of CG for 4–6 h in the evening over 6 weeks of military training resulted in *small* improvements in aerobic running and press up performance, and provided *moderate* benefits to perception of muscle soreness. These results suggest that CG can provide a viable recovery strategy in the military context to mitigate the associated muscle soreness, where high-volumes of strength and endurance training are performed. Given there were no detrimental effects of CGs to physical performance over the 6-week duration, this passive and practical intervention may allow for military personnel to manage their training loads and muscle soreness more effectively during intense training courses.

Study Three demonstrated that in two groups of trainees who were stratified into two groups based on by sleep duration, non-significant but *small* improvement in aerobic fitness and press-up performance were seen in recruits sleeping more than 6:15 h:min compared to those sleeping less than 6:15 h:min per night. The group sleeping approximately 37 min more per night, and thus a total of 22:20 h:min over the duration of the training course, also showed benefits in aspects of perceived wellbeing (fatigue, soreness, mood, and stress). These data indicated that even a relatively modest daily increase in sleep duration in a short-sleeping cohort of military recruits, can result in enhanced physical performance and perceived well-being.

Study Four concluded that automatic scoring actigraphy may be used in the place of more traditional manually-scored actigraphy, which provides a practical alternative when monitoring large groups of military personnel in the field training and tactical operational environment. No significant differences were observed between devices for any of the measured sleep variables (p = 0.061 to 0.974) and sleep indices resulted in *very-strong* correlations (*all r* ≥0.84) between devices. An automatically scored device such as the Readiband™ does not require any expertise, and when compared to the time required for manual scoring of actigraphy traces, the RB provides a more time-efficient alternative, allowing large groups of individuals to be monitored effectively.

Study Five observed how improvements in total sleep time and aerobic fitness can be attained as a possible effect from chronic exposure to lower-temperature lighting (3000K) over 6-weeks when compared to a control group (7000K). A *large* improvement was observed for the 2.4 km run (Δ92.3s), and a *moderate* improvement for curl-ups compared to a control group. This passive and readily implementable lighting intervention designed to limit circadian disruptions was effective to offset some of the negative sequelae of cumulative sleep deficit, through *small* benefits to TST (*d* = 0.41 to 0.44) and manifested in enhanced physical performance.

The studies included within this thesis aimed to provide novel data and further the knowledge of sleep indices and recovery in the military training environment. The need for high levels of fitness is still essential for daily task completion and for safe operation during military deployment (Kyröläinen et al., 2017), and given the underpinning factor that the need for physically capable men and women to deploy and fight in ground, sea, and air spaces is still essential in the modern military world (Friedl et al., 2015), it is important for military personnel individually, as well as their commanders, to understand sleep and the consequences poor sleep can have on physical performance and recovery. This thesis demonstrates easily implementable interventions to combat the war on sleep.

Practical Applications

The following practical applications are based on the outcomes of the five studies within this thesis.

- Regardless of sex, service and starting fitness level, aerobic capacity and muscular-endurance can be positively enhanced from a combination of both prescribed PT and military manual handling activates during military training.
- The chronic wearing of CG for 4–6 h every evening for 6 weeks in a high-load, high-intensity training environment can provide benefits to aerobic training, muscular endurance, and perception of muscle soreness.
- More sleep is better; sleeping more than 6:15 h:min per night in the military training environment supported physical performance and aspects of perceived wellbeing (fatigue, soreness, mood and stress).
- There was little difference between automated and manually scored actigraphy devices. Thus, indicating that the accuracy of more traditionally-used actigraphy devices are now being matched with commercially-available and more practical alternatives. This may allow for the monitoring of sleep/wake patterns in functional and operational environments such as elite sport, emergency services, and the military, where large numbers of participants may be monitored at the same time, with limited skills and expertise required to analyse actigraphy data.
- Chronic exposure to lower-temperature lighting may provide a passive and readily implementable lighting intervention which has the potential to offset some of the negative sleep deficit
- A placebo sleep device placed in the vicinity of the sleeping space may provide positive benefits to sleep duration. Indicating the importance of psychology in improving sleep.

Limitations

The findings and outcomes presented in the thesis have direct and practical outcomes for understanding performance, sleep, and recovery in the military environment. Whilst each experimental study acknowledged its own specific limitations, the ecological validity of the research is high. The overall limitations for the research and thesis are outlined below.

- Physical performance tests provided some constraints as they are standard in the military, and could not be adapted to better suit our research purposes. In some cases, the test-retest reliability of these tests might not have been as tight as we would have liked. An example of this was the 2.4 km run being performed outside with no control over environmental conditions. Ideally, we would have had more control over the physical testing environment, however, this was not possible.
- The inability to control or monitor all training loads and intensities in some studies, and the difficulty to make comparisons between countries and individual services for fitness testing, as countries and individual militaries around the world use different physical tests for fitness assessments, in different environmental settings. There are contrasting differences in operational requirements that will also influence outcome and results due to fitness and conditioning levels.
- Although CGs are used extensively in the performance arena, consideration should be given to the finding that fabrics can lose integrity/pressure over time with chronic wear, which may reduce their efficacy.
- Within the constraints of conducting research in the military environment, we acknowledge a limitation in the current series of studies that the time available to sleep was constrained. Being confined to a specific window from 'lights out' at 2200 h to 'wakeup' at 0545 h, meant that this narrow window of sleep opportunity, in some cases, led to only minor or no statistical differences between groups. If sleep and wake times were not set, self-selected differences in sleep duration may have been more pronounced, and had a greater impact on

the differences in the outcome variables. However, the military training environment in which the research was conducted reflected the true nature of the operational daily training setting in which training is conducted.

- Actigraphy can potentially inaccurately indicate time at lights out and underestimate WASO. However, both automated and manually scored actigraphy devices have been extensively used and reported in the literature as being effective for accurate collection of selected sleep-wake metrics. We acknowledge the limitation of using two types of actigraph in Study Five, however, as determined in Study Four, these devices were very comparable. The ability to utilise portable EEG or PSG would have enabled a more accurate ability to monitor and track sleep-wake metrics, including sleep-staging information which may have been useful for the interpretation of the lighting-related data (Study 5). However, this was not practical or feasible due to the large number of participants in the studies and the practical constraints of the testing environment.

Future Research

Based on the outcomes, findings and results presented within this thesis, a range of future research is warranted. In the future, looking at strategies to enhance sleep and recovery in the highly intensive military training environment may improve and enhance overall training and subsequent physical adaptations and performance.

- Further alterations to lighting and lighting-temperature may help to better support sleep over a longitudinal period, and improve subsequent recovery and physical performance. While Study 5 in this thesis focussed on the evening light-exposure, future research could also consider the 24/7 light exposure, including the optimisation of morning light to overall circadian rhythms and sleep. The measurement and monitoring of 24/7 light exposure using wearable light sensors may also be important to establish areas where improvements could be made.
- Future sleep investigations specific to the military should assess sleep hygiene strategies in relation sleep and physical performance of Army soldiers during extended (7-12 day) tactical field exercises, assess the relationship between sleep and night-lighting on Navy ships in sailors, and investigate the relationship between long distance air travel between differing time zones in operational airmen and pilots. Research should be directed toward improving sustainable long-term sleep behaviours in operational settings
- Mechanisms of chronic CG wear needs further attention; e.g. via muscle biopsies and blood flow measurement to determine if there are any negative effects on physiological adaptation with the long-term use of CG's.
- A further area of investigation in the military setting should be the comparison of groups who are allocated different sleep opportunities (e.g. <6 h versus the recommended 7–9 h) via manipulating sleep and wake times, while measuring physical/injury, cognitive, and wellbeing variables. Although training environments in the military tend to adhere to well-established and 'traditionally ingrained' sleep protocols/windows, militaries worldwide are starting to shift toward evidence-based scheduling due to high injury and attrition rates.

- Further investigation into the ideal living environments to aid sleep behaviours in military barracks is warranted. This may include a combination of lighting manipulation, temperature optimisation, noise reduction and even matching personnel for their chronotypes.
- With rapidly developing technology and availability of modern devices, investigation into the benefit and validity of wearable technology should take priority. Activity and performance trackers that measure GPS metrics, HR, HRV and sleep could provide long range monitoring in an operationally tactical environment with minimal or no impact on individual performance and operational outcomes. Enabling this to occur and acting on real-time information could enhance a service person's physical performance, health, cognitive status, recovery, injury risk, and ultimately, reduce attrition rates.
- Finally, a paucity of literature in the area of applied recovery strategies in military training environments is evident, and a targeted research approach in this area may help to further improve training outcomes and operational sustainability. This approach may involve a deployable tactical recovery centre to enhance war fighter readiness and wellbeing; whereby, the use of various recovery tools commonly used in the sporting environment are investigated.

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APPENDICES

Appendix A: Human Ethics Approval

The University of Waikato
Private Bag 3105
Gate 1, Knighton Road Hamilton, New Zealand

Human Research Ethics Committee
Julie Barbour
Telephone: +64 7 837 9336
Email:humanethics@waikato.ac.nz

THE UNIVERSITY OF WAIKATO
Te Whare Wānanga o Waikato

13th January, 2018

Dear Matt,
UoW HREC(Health)#2018-01:

Thank you for submitting your application HREC(Health)#2018-01 for ethical approval. Your application was approved out of committee.

We are now pleased to provide formal approval for your project including:

- Use of data collected during NZDF officer training courses for research and publication purposes.

Please contact the committee by email (humanethics@waikato.ac.nz) if you wish to make changes to your project as it unfolds, quoting your application number with your future correspondence. Any minor changes or additions to the approved research activities can be handled outside the monthly application cycle.

We wish you all the best with your research.

Regards,

____

Julie Barbour PhD
Chairperson
University of Waikato Human Research Ethics Committee

Appendix B: Co-Authorship Forms from Chapters Three to Seven

THE UNIVERSITY OF WAIKATO
Te Whare Wānanga o Waikato

Co-Authorship Form

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Please indicate the chapter/section/pages of this thesis that are extracted from a co-authored work and give the title and publication details or details of submission of the co-authored work.

Chapter 3 - Edgar, D., Gill, N., & Driller, M. (2020). Physical characteristics of New Zealand Army, Navy and Airforce officer trainees' over a 6-week joint officer induction course. *The Journal of Sport and Exercise Science*, 4, (2), 63-71. doi: 10.36905/jses.2020.02.01

Nature of contribution by PhD candidate	Research conceptualization, development of study design, data collection and analysis, manuscript preparation and journal submission.
Extent of contribution by PhD candidate (%)	75

CO-AUTHORS

Name	Nature of Contribution
Matthew Driller	Supervised the research process, suproted data collection and feedback on the drafting on the paper and reviewed it prior to publishing.
Nicholas Gill	Contributed to research conceptualization and study design, supervised the research process, feedback on the drafting on the paper and reviewed it prior to publishing.

Certification by Co-Authors

The undersigned hereby certify that:

- the above statement correctly reflects the nature and extent of the PhD candidate's contribution to this work, and the nature of the contribution of each of the co-authors; and

Name	Signature	Date
Matthew Driller	[signature]	**20/10/2022**
Nicholas Gill	[signature]	**20/10/2022**

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Chapter 4 - Edgar, D., Gill, N., Beaven, C., & Driller, M. (2022). Under pressure: The chronic effects of lower-body compression garment use during a 6-week military training course. International Journal of Environmental Research and Public Health, 19 (7), 3912. doi: 10.3390/ijerph19073912

Nature of contribution by PhD candidate	Research conceptualization, development of study design, data collection and analysis, manuscript preparation and journal submission.
Extent of contribution by PhD candidate (%)	80

CO-AUTHORS

Name	Nature of Contribution
Matthew Driller	Supervised the research process, supported data collection and feedback on the drafting on the paper and reviewed it prior to publishing.
Martyn Beaven	Supervised the research process, feedback on the drafting on the paper and reviewed it prior to publishing.
Nicholas Gill	Contributed to research conceptualization and study design, feedback on the drafting on the paper and reviewed it prior to publishing.

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Martyn Beaven		20/10/2022
Nicholas Gill		20/10/2022

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Chapter 5 - Edgar, D., Gill, N., Beaven, C., Zaslona, J., & Driller, M. (2021). Sleep duration and physical performance during a 6-week military training course. Journal of Sleep Research, Dec; 30 (6), e13393. doi: 10.1111/jsr.13393

Nature of contribution by PhD candidate	Research conceptualization, development of study design, data collection and analysis, manuscript preparation and journal submission.
Extent of contribution by PhD candidate (%)	75

CO-AUTHORS

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Nicholas Gill	Provided feedback on the drafting of the paper and reviewed it prior to publishing.
Jennifer Zaslona	Provided feedback on the drafting of the paper and reviewed it prior to publishing.

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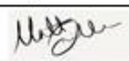
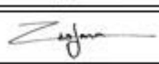
Name	Signature	Date
Matthew Driller		20/10/2022
Martyn Beaven		20/10/2022
Nicholas Gill		20/10/2022
Jennifer Zaslona		20/10/2022

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Chapter 6 - Edgar, D., Gill, N., Beaven, C., Zaslona, J., & Driller, M. (2022). Automatic-scoring actigraph compares favourably to a manually-scored actigraph for sleep measurement in healthy adults. Sleep Science. (Accepted 30th August 2022).

Nature of contribution by PhD candidate	Research conceptualization, development of study design, data collection and analysis, manuscript preparation and journal submission.
Extent of contribution by PhD candidate (%)	75

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Chapter 7 - Edgar, D., Beaven, C., Gill, N., Zaslona, J., & Driller, M (2022). Operation early-bird: Investigating altered light exposure in military barracks on subsequent sleep, wellbeing, and performance - a placebo-controlled study. Journal of Sleep Research. (Accepted 5th October 2022).

Nature of contribution by PhD candidate	Research conceptualization, development of study design, data collection and analysis, manuscript preparation and journal submission.
Extent of contribution by PhD candidate (%)	75

CO-AUTHORS

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