UNIVERSITY OF SOUTHAMPTON

FACULTY OF ENVIRONMENTAL AND LIFE SCIENCE

Hip and Lower-limb Movement Quality of Phase-1 and 2 Military Personnel.

by

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ABSTRACT

Musculoskeletal injury (MSKI) contributes significantly to recruit attrition during military training, where females are 1.7-times more likely to sustain a MSKI than males. The current research programme assessed movement control in military recruit cohorts to better understand the interactions between movement quality, sex and injury risk.

Study-1 undertook secondary data analysis of pre-training health, fitness and movement quality of Royal Navy Phase-1 recruits (n=956), relative to prospective MSKI data i.e. injury site (location), onset (acute vs. over-use), severity and when in training (time), to generate an injury prediction model (Chapter 4). Functional Movement Screen (FMS) total score significantly contributed to the model but only accounted for 8.5% of the variation in the data. Moreover, there was no difference between the pre-training FMS scores for males (14.6±2.3) and females (14.4±2.4), despite females sustaining 1.7-times more MSKI. All further investigations adopted the Hip &Lower Limb Movement Screen (H&LLMS), as FMS lacked focus on the hip.

Study-2 conducted a 3D motion capture investigation of movement quality of Army Phase-2 recruits (15 male, 15 female). Differences in H&LLMS score and kinematics were assessed under three load conditions: unloaded; loaded to 30% bodyweight; and standardised load (16 kg) (Chapter 6). Load interacted with H&LLMS scores for the “knee over toe” fault, and ankle dorsiflexion and pelvic tilt kinematics, but not with sex.

Study-3 investigated the feasibility of delivering a 12-week neuromuscular control exercise intervention and its effect on movement control of a mixed-sex cohort of Phase-1 military recruits (n=127) (Chapter 7). Troops were randomly block-assigned to the intervention (INT; n=97) or control (CON; n=32) group. The INT group completed 35% of the planned weekly sessions and their movement quality improved by 7%; whilst the CON group worsened by 14% (ΔH&LLMS: CON +3.8±6; INT -2.2±7; P≤0.001). Thus, movement quality can be influenced through physical activity interventions.

An interaction exists between body weight, load carriage and movement quality. Additionally, movement quality is both positively and negatively modifiable, which may influence injury risk. The present findings indicate a randomised controlled trial is warranted to determine whether neuromuscular training to improve movement quality will reduce injury risk.

FACULTY OF ENVIRONMENTAL AND LIFE SCIENCE

<u>Health Science</u>

Thesis for the degree of Doctor of Philosophy

IMPROVING MOVEMENT QUALITY OF MILITARY PERSONNEL TO PROTECT HIPS AND LOWER LIMBS FROM INJURY

Conor Niland Trent Power

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DECLARATION OF AUTHORSHIP

I, Conor Power, declare that this thesis and the work presented in it are my own and has been generated by me as the result of my own original research.

Hip and Lower-limb Movement Quality of Phase-1 and 2 Military Personnel.

I confirm that:

1. This work was done wholly or mainly while in candidature for a research degree at this University;
2. Where any part of this thesis has previously been submitted for a degree or any other qualification at this University or any other institution, this has been clearly stated;
3. Where I have consulted the published work of others, this is always clearly attributed;
4. Where I have quoted from the work of others, the source is always given. With the exception of such quotations, this thesis is entirely my own work;
5. I have acknowledged all main sources of help;
6. Where the thesis is based on work done by myself jointly with others, I have made clear exactly what was done by others and what I have contributed myself;
7. [Delete as appropriate] None of this work has been published before submission [or] Parts of this work have been published as: [please list references below]:

Signed: 

Date: 25 March 2020..

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Definitions and Abbreviations

Movement quality:

The use of motor control to maintain optimum joint dynamic alignment (Sahrmann, 2001).

Chapter 1: Introduction

Musculoskeletal injuries (MSK) are a significant cause of medical attrition in male and female military service personnel (Ministry of Defence, 2014). Heagerty *et al.* (2018) states that the military has a "strong professional and moral responsibility to understand and address the causation of potentially reducible training injuries". However, the military is diverse and includes roles such as engineer, human resource, finance and support, intelligence, communication and information technology, medical, logistics and support, and music as well as combat. Each role requires specific physical standards, where recruits undertake repetitive work over an extended period of time to prepare for their career roles. This variety of military roles leads to variety in trade training and role requirements. Therefore, there is a disparity between the physical requirements of these roles. However, all who enter the military commit to attaining a physical standard at the end of Phase-1 training. Consequently, MSK injuries have been suggested as a recognised by-product of Phase-1 military training (Heagerty *et al.*, 2017).

In the most physically demanding roles, load carriage, manual handling and marching over rough terrain are all examples of training activities. These activities have been shown to increase the risk of injury in military populations (Heagerty *et al.*, 2017). However, similar risk levels have also been shown in other physically active populations that require physical standards testing, such as police (McGill *et al.*, 2015) and firefighters (Frost *et al.*, 2012). Each of these populations has a period of training and an entry-level of fitness required before one can join the respective cohort. In military populations, this period of initial military training involves 18-24 year olds from the general population being exposed to military physical training in two phases. Phase-1, which lasts between 10-14 weeks, emphasises physical training. Whereas, Phase-2, which lasts between 10 weeks and 3 years, emphasises trade training depending on their career pathway. The military understands that the emphasis on physical training during Phase-1 increases the risk of injury (Heagerty *et al.*, 2017) and takes precautions to mitigate it (Lisman *et al.*, 2013; Gibbs *et al.*, 2014). However, military recruits are still at a high risk of injury. Research has highlighted that upper-body injuries were sustained at similar rates between men and women, while lower-limb musculoskeletal injuries were 1.5 times greater in women than men, and lower-limb stress fractures are three times more prevalent in women than men (Ministry of Defence, 2016). Movement patterns have been suggested as a potential reason for the injury discrepancy between male and female football players (Soligard *et al.*, 2008). However, while movement quality has been shown to interact with injury likelihood in military cohorts, there is less evidence that this is the principle variable in the injury rate discrepancy.

All studies within this research programme are linked by a singular epistemological view, which represents a singular research theme and have informed the subsequent studies. The singular epistemological view is that movement dysfunction can and will lead to injury, with the aims of the research to understand how best to identify movement dysfunction, to better understand what is meant by movement dysfunction, and to identify if movement dysfunction is modifiable. The current research programme will analyse the appropriateness of movement screens for use within military cohorts.

1.1 Thesis diagram:

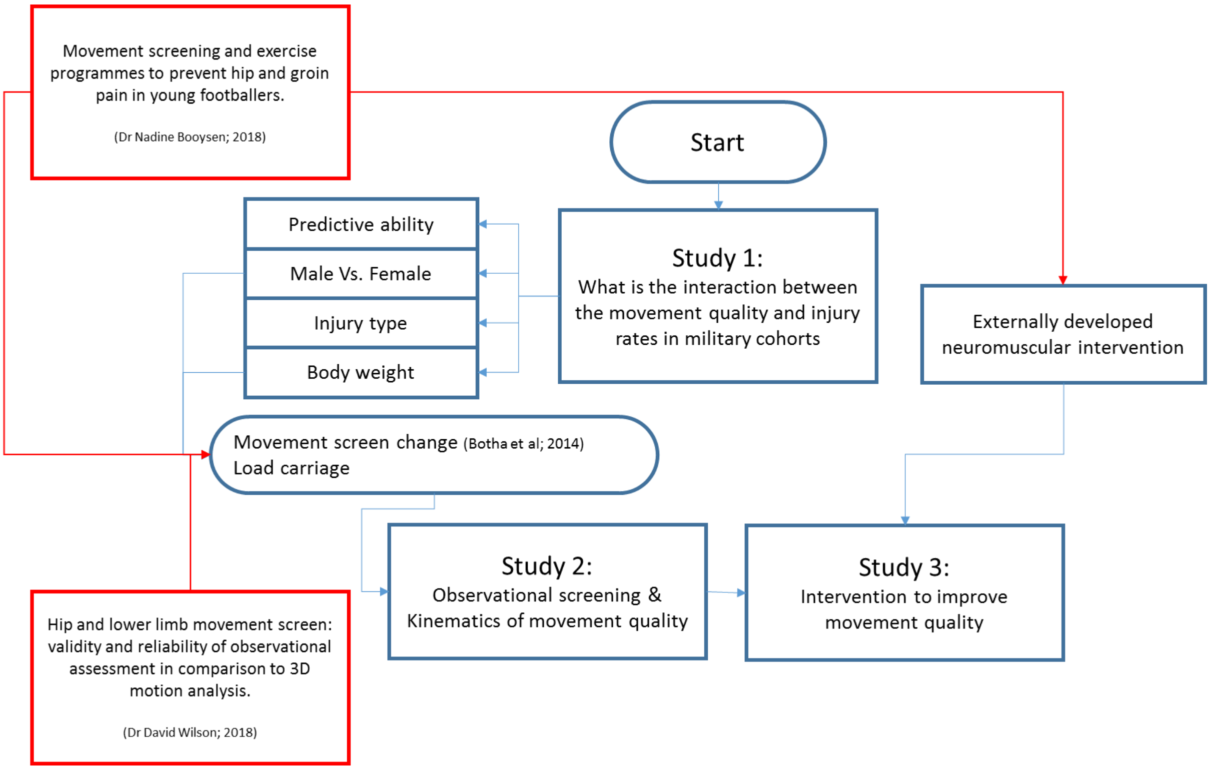


Figure 1-1: Diagram of the thesis progression and overview of the larger research programme that included two other PhD studies.

The number of injuries sustained by recruits represents a great financial responsibility and burden for the military. Injuries sustained during military service and training will cost a reported £1.2bn over the next 15 years excluding the costs of rehabilitation and return to training (Heagerty *et al.*, 2018). Additionally, an increase in the number of recruits sustaining injuries will result in fewer recruits successfully passing fitness standards and therefore passing on to further military training or full service at first attempt. Moreover, the most prominent variable in predicting future injury is past injury (Brockett *et al.*, 2004). Therefore, those who sustain injuries during training are more likely to sustain an injury later in their service career. Thus exposing the military to greater potential for future personnel injuries and rehabilitation which would ultimately lead to a greater financial burden.

Therefore, injuries sustained during Phase-1 training are likely to impact the recruit and military service throughout the service career of the individual.

Military training aims to prepare recruits for the physical demands of military service. As previously stated, military service is varied, with training tailored to the specific requirements of each role. However, through Phase-1 training, all recruits must pass standardised physical tests. Regardless of one's intended career in the military, all those who enlist in Phase-1 military training must attain a set, and blanket standard of fitness. Phase-1 training is considered the entry-level, from which Phase-2 and further military careers can require greater physical fitness. Despite this being the entry-level required, for some less fit individuals, attaining this standard may be challenging. Heagerty *et al.* (2017) states that the transition from civilian to soldier may represent an abrupt increase in physical activity, which may contribute to the increased risk of MSK injury. It is important to recognise that those referred to in this thesis as recruits were civilians in the general population before starting their Phase-1 training (participants in study 3, Chapter 4 & 7), and perhaps only 14-weeks before Phase-2 training (participants in study 2, Chapter 6). This cohort could more accurately be described as a sub-set of the general population when they are initially recruited. Therefore, the findings of the current research programme will be specifically addressing the high levels of injuries within a single population, while also maintaining relevance to other physically active populations that recruit from the general population.

Phase-1 training aims to improve the physical fitness of recruits. During such time, the recruits are trained in initial military education that includes, but is not limited to, manual handling and lifting, physical fitness training, firearms and hand to hand combat training. These training phases are progressive and preparatory but are also physically and mentally demanding. Therefore, although a great deal of attention has focused on reducing the number of injuries during training, recruits are still considered likely to sustain an injury during training (Lisman et al., 2013). This again highlights that the physical demands of the various military roles are sufficiently arduous as to significantly increase injury risk. Although many variables that increase one's chances of injury have been identified, such as previous injury, 2.4-km run time, ethnicity, Army training type, and body mass index (Blacker *et al.*, 2008), identifying the principal reason for injury remains difficult. Moreover, even with all of the identified variables, predictive models are still not able to predict injury likelihood accurately. Due to the high numbers of injuries during Phase-1 training, it is likely to be a result of something present in or occurring during military training. As previously stated, Phase-1 training involves a variety of physical training methods, at higher exposure levels than in the general population. This alone has been shown to increase injury (Heagerty *et al.*, 2017). However, Hislop *et al.* (2017) have also indicated that a person's movement during such physical exercise can also effect injury likelihood. This research programme postulates that movement quality is a factor in tissue modification and therefore will explore the interaction between movement quality and injury. If this is the case, this may increase the likelihood of the cause being modifiable or preventable.

As of the 5th June 2018 (Table 1-1), females represent around 10 percent of the military population, although this is subject to small variations based on the specific military service. Consequently, there are fewer instances of females injured, however, female recruits sustained a greater percentage of injury compared with male recruits (38 % vs. 27 %, respectively) (Gibbs *et al.*, 2014) regardless of service. Between 16-24% of all recruits sustain an injury during military training but further examination shows that females are 10 times more likely to sustain hip and pelvic stress fractures than males (Gibbs et al., 2014). Since 2018, the restriction on females enlisting in, and serving in ground close combat roles, was lifted, giving females the same opportunities as their male counterparts. The military has a duty of care to better understand the mechanism of injury and to propose mitigating strategies. This thesis will, therefore, examine the differences between males and females in Phase-1 and 2 training to better understand the role that a person's sex has on their injury risk.

Table 1-1: Employment statistics from (Clark., (2018).

Service	Total	Female	Percentage
Army	81120	7560	9.32
Navy	25480	2930	11.50
RAF	32960	4660	14.14
Marines	7010	10	0.14
Total	146570	15160	10.34

Reducing population-specific injury risk effectively and appropriately requires a specific and progressive programme. While the recurring theme is that all decisions must be evidence based, there are a number of steps that must be completed. This thesis included three investigative studies linked to these three different stages. Each study explored the phenomenon of the differing injury rates between male and female military recruits using movement quality:

1) Firstly, there must be a tool or system in place, based on a mechanism that has shown to contribute to the phenomenon, which can detect a person's likelihood of sustaining an injury.
    - Movement quality has been assessed in US military cohorts, with the use of the Functional Movement Screen (FMS) (Kiesel *et al.* (2007), however, few papers have examined this relationship in the United Kingdom (UK). As such, a secondary analysis of retrospective Navy Phase-1 recruit data was used to better understand the variables that contribute to injury during initial (Phase-1) training. (Chapter 4)

2) Secondly, mechanisms associated with movement quality must be examined.
    - Although movement screens have shown some ability to predict injury (Kiesel et al. (2007), this has yet to yield a movement quality mechanism of injury. Therefore, the present research programme conducted a laboratory study to better understand the kinematics of movement

while under loaded conditions between bodyweight and loads typical of initial training (Chapter 6)

3) Thirdly, there must be evidence that demonstrates that these identified mechanisms can be modifiable through specific intervention.

- Previous papers have demonstrated that a person can improve their movement quality when assessed with the FMS. If it is accepted that FMS score is indicative of movement quality, then these papers also showed a change in movement quality. However, the studies that assessed intervention induced modification in FMS score, did not assess injury, and those who used movement quality interventions to reduce injury, did not asses post-intervention movement quality. Moreover, many of these studies did not assess the longevity of the movement quality / injury reduction adaptation or the return to previous or risk following a period of no intervention. This study aims to understand if these movement quality interventions can be developed and deployed with a regimented structure, such as that of Phase-1 military training, as this has yet to be established. Therefore the present research programme examined the effect on movement quality in Phase-1 recruits, of an innovative pre-exercise neuromuscular exercise intervention developed at the University of Southampton (Booysen, 2013; Botha *et al.*, 2014) (Chapter 7).

Throughout the present research project it was important that movement quality be observable and gradable. This was achieved by employing movement quality observation tools. Initially, the FMS was used, however, as Chapter 4 will show, this was not deemed appropriate for further use in this project and another tool was required. Research and development from the Active Living and Rehabilitation Research Group School at The University of Southampton has centred on the development of a lower limb screening tool with a focus on the hip. The development of the tool began with Dr Nadine Booysen's MSc dissertation which progressed to two PhD programmes (Dr Nadine Booysen and Dr David Wilson) that further developed the screen and investigated the reliability, validity and applied the screen to investigate potential changes in movement quality following a neuromuscular focused exercise programme. Initial assessment of the screen showed internal consistency within groups that were similar to military recruits. As such, the developing screen, referred to as the Hip and lower-limb movement screen, was introduced into a third PhD study to further assess the utility within a novel population. Chapter 5 explains in greater detail how the methods were developed and will provide data on the reliability and validity of the screen. Figure 1-1 demonstrates how this project fits within the larger scale research into movement quality. This topic area involved two other PhD studies that were near completion when the H&LLMS was adopted by the present research programme.

Chapter 2: The interaction between movement and skeletal structure

There is a relationship between mechanical factors and tissue behaviour (Radin *et al.*, 1991). More specifically, the way a person moves interacts with their hard and soft tissue structure (Katsuragawa *et al.*, 1999). Tissue structure can limit the movement available at specific joints (Lamontagne., 2009). For example, the bony aspect of the hip joint capsule may be deeper than typical and reduce the amount of movement, while the musculature around the shoulder may restrict rear arm movement due to tight frontal muscles or large rear muscles. However, repeated movements can also generate changes to tissue structure over time (Yamamoto *et al.*, 2006). For example, high numbers of high velocity knee extensions that result in the foot impacting an object can lead to Osgood-Schlatter disease which presents with additional bone growth on the frontal aspect of the tibia (Kabiri *et al.*, 2014), while baseball pitching at a young age has been linked to humeral retroversion (Reagan *et al.*, 2002). In humeral retroversion, over an extended period of time of exposure to high rotational loads, the humerus rotates around its axis so that the ends are now misaligned.

This changes the observed external rotation of the arm and hand at any given shoulder position (Yamamoto *et al.*, 2006). This is most easily observed while comparing those presenting with and without such anatomic abnormalities during external shoulder rotation while the upper arm is abducted. If you were to ask these participants to externally and internally rotate as far as they could, there would likely be a similar range of motion expressed. However, the person with humeral retroversion would be capable of achieving a greater external rotation, and would be limited in their internal rotation. This may seem as though the athlete is generating a greater amount of external rotation, but the shoulder is not externally rotating any further. The difference in position achieved is produced by the modification and rotation to the humerus long bone. This modification in tissue structure allows the participant to throw faster, and therefore may be advantageous for some sports. This example demonstrates that structural changes that influence movement can be advantageous, and facilitate a learning of a new skill. However, this is not necessarily always the case. Joints have structures that allow and limit movement. There are times where what is required for the joint to maintain health, and what is required for the performance of the movement are not aligned.

During any single action, it is likely that there exists an optimal movement of the joint or joints that allows the most efficient transfer of forces through the joint, both in terms of muscle torques (line of action), joint contact forces and movement outcome (Sahrmann, 2002). However, this requires the movement to meet a greater number of criteria that may not synchronise or overlap. The further a movement deviates from this potential optimal, the greater the likelihood of observing compensatory movements. From these adaptations, it is hypothesised that injury likelihood increases as the movement deviates from what is most appropriate for the joint. Moreover, if this movement is repeated, it may result in the joint structure adapting from its original structure. Previously mentioned, humeral retroversion may be a positive performance adaptation. However, this may deviate from that which is most appropriate for the health of the joint. Although no definition of good and poor movement has yet to be established in the literature, some acknowledgment of the potential difference between total movement and joint movement requirements and abilities must be made. Being able to identify when these good and poor movements occur is also vital if we are to understand the role of movement in tissue health and performance. Kinematics and observational tools are available and have been used to examine the relationship between specific movements and injuries in certain cohorts such as the FMS with military recruits (Lisman et al., 2013). The interaction between movement and skeletal structure exists in as much as the structure limits movement. However, more evidence is required to assert that movement can adapt skeletal structures.

This research programme evaluated if specific movements are associated with greater or lower risk of injury, so that these injuries can be mitigated. In order to most appropriately mitigate injury occurrence, one must initially understand the cause and ramifications of the injury. This section will explain how movement can modify hard and soft tissue structure, how these changes can be observed and recorded and how these movements can be reduced during specific training.

2.1 Pathokinesiology

Understanding the mechanism of injury will help inform injury prevention strategies. Moreover, considering the pathokinesiology and kinesiopathology approaches may also help. However, these terms are often used interchangeably, without an apparent appreciation of the contradictory differences between the two. Therefore, the following text will clarify the two epistemological viewpoints separately.

Pathokinesiology considers how tissue dysfunction can lead to movement impairment (Alrwaily et al., 2017) and refers to the study of abnormal movement that results from pathology, injury or pain (Dingenen et al., 2018). There are clear cases to demonstrate where hard tissue (bones) and soft tissue (muscle, ligaments and tendons) structure dysfunction will impact on a person's movement. Pathokinesiological principle dictates that if a person's hard and soft tissue structures vary from the normal range displayed in the general population, this will impact on their movement capabilities and limitations. These can be classified into three major groups: 1) those born with an immediately present abnormality; 2) those born with an abnormality or condition that is progressive through life, and 3) those who have had their hard and soft tissue changed due to an incident after birth. In all cases, the hard and soft tissue abnormalities will change aspects of movement possibilities such as, but not limited to, range of motion, path of action and motor performance. Consequently, the useable pathways of motion will also adapt in order to perform movements that can easily fit within the limitations of these abnormal hard and soft tissue structures (Gordon and Ferris, 2007).

The pathokinesiological approach is prevalent in rehabilitation, although limitations with this approach have been raised (Dingenen et al., 2018). Often the terms used to describe the injury or patho-anatomic diagnosis are vague, which can lead to those under the same heading exhibiting clinical presentations that vary and/or are not comparable. One example of this is rotator cuff disease, which can result from minor strains, partial tears or total rupture of the tendons (Cofield, 1985). Although these all present at the same location, the presentation of the disease can be vastly different. Some individuals experience great pain during abduction or a lack of range of motion at the glenohumeral joint, while others may have the disease but be asymptomatic (Yamaguchi et al., 2006). This disease gives such a vague description that it has led some to question if this disease is even a single pathology at all (Symonds, 2009). Whereas, similar clinical presentations can be caused by separate underlying mechanisms or patho-anatomic structures. For example, tendinopathy and bursitis inflammation will, due to proximity, present with the same pain, movement restrictions in the same location. However, tendinopathy is a degenerative disease while bursitis is an inflammatory response. The resultant treatment will differ greatly between the two conditions. The pathokinesiological approach does not identify or address the underlying mechanism of injury and therefore falls short of the ideal clinical diagnosis tool. Consequently, this approach may not be entirely appropriate for informing and influencing rehabilitation practice. Moreover, decisions based on such an approach could render the recommendations of health care professionals ineffective or counterproductive.

In response to these flaws in the pathokinesiological approach, the kinesiopathological approach has gained popularity. Alrwaily et al. (2017) claimed that this approach considers how movement impairment can lead to tissue dysfunction and indicates that the manner in which a person executes a movement is subject to gradation. Dingenen et al. (2018) suggested that the characteristics of a person's movements have direct consequences on neuromusculoskeletal injury likelihood, athletic performance and quality of life. The kinesiopathological approach was originally described by Sahrmann (2002) and focuses on the underlying mechanisms that contribute to musculoskeletal injury rather than focusing on the patho-anatomic diagnosis, with the aim of more accurately directing physical therapy rehabilitation and intervention.

To better understand the kinesiopathological approach, a single joint movement can be used as an example. The primary movement of the knee joint is flexion / extension, but even if it is assumed that all supporting structures within the knee are intact and working effectivity, there is some laxity and capacity for torsion, anterior / posterior gliding and displacement. Therefore, the knee can perform movement for which it is not best suited or designed (Shultz *et al.*, 2007). This may introduce elements of force and velocity transfer inefficiency and movement accuracy error into this single action movement. If a person were to perform a movement that caused the knee to move in a way that increased rotational torsion or disproportionately allocated load to a single side of the joint, this would create a loading condition within the joint that would deviate from that which the joint is best suited (Shultz *et al.*, 2007). Moreover, the movement itself would be performed inefficiently; as any movement performed at a joint that does not fit the primary motion of that joint would result in a less efficient movement occurring. If a movement that created such an abnormal loading condition were to be repeated regularly, the joint would be exposed to abnormal forces and inefficient movement pattern more often. This has been suggested as a contributing factor in joint structural changes and development of injury, such as osteoarthritis (Radin *et al.*, 1991). Moreover, these forces may also contribute to hard and soft tissue adaptations to better cope with such loads, that may lead to pathological difference, increased injury risk and pain (Dye and Vaupel, 1994).

Sahrmann (2002) explained that the human movement system is capable of rapid adaptation to external stimulus, such as load and repetition. However, as this occurs without conscious thought, this adaptation is dependent on the movement input rather than the intended output. Therefore, all movements, regardless of how well they are completed, will have the same magnitude of load from external forces on the hard and soft tissue structures responsible for the action through the stresses and load that the movement creates. However, the management of this load dictates the actual internal forces exerted on the hard and soft tissue.

To explain this further the analogy of a small knee bend or single leg squat will be used. The same participant performs a small knee bend with their dominant leg as the load bearing leg. During the movement, the knee of the standing leg moves forwards and over the toes during the downward motion. The main role of the knee is to flex and extend, and therefore this action is within the movement capabilities of the knee. Additionally, the knee also moves medially and towards the non-load bearing leg. This action is referred to as valgus knee movement. This movement is within the movement capabilities of the knee, in so much as the joint will be subject to some level of laxity and will allow the lateral movement. However, the internal forces of the knee are abnormal, as a greater percentage of force is now being applied to the participant's lateral knee cartilage and medial ligaments. In a single instance of movement, such an action would rarely cause an acute injury due to the velocity and forces typical of a step down task. We know this because every day countless people use stairs with no acute detriment to their musculoskeletal system health. However, there is evidence to suggest that if an action is performed repeatedly over a longer period of time that this may lead to hard and soft tissue structural modification (Bennell et al., 2011). It has been suggested that a contributing mechanism for this modification may be the way in which the movement occurs and the influence this has on the forces within the joint. More specifically, if the movement stresses these joint structures, then adaptations to better accommodate these stresses are made (Bennell et al., 2011). This may lead to adaptations that are abnormal in the population and in some cases may increase the risk of injury at the modified joint. If the same person were to perform the same action, but this time with no medial knee movement and presenting with no valgus knee movement, the magnitude and distribution of the external load would be unaltered as the participant's weight has not changed. However, this action will produce internal forces that are within the movement capabilities of the joint and therefore would not stress the structures in abnormal ways (Draper., 2000).

The previous paragraph illustrated that the distribution and magnitude of load will remain similar, but the management of this load will dictate the translation of external forces to internal forces within the joint. Consequently, movements that stress the limits of the joint structures may generate changes to the structures of those tissues involved in the movement. For example, good quality movement, with good alignment of joints, will reinforce tissue structures that allow easier repetitions of good movement. However, the opposite must also be considered. Repeatedly completing a running movement that was inefficient and incorrect could lead to abnormal forces and movement pathways that would trigger adaptations that result in this poorer movement being easier to complete. Adaptations to a previously conducted poor movement would reinforce this poor running movement and increase the likelihood of dysfunction and poorer performance in future repetitions of the same movement.

If hard and soft tissues are influenced by the internal and external forces exerted during movement, and the structures of hard and soft tissue influence the movements and force capabilities of the limb and/or person, then it would stand to reason that this mutually influential relationship is cyclic. This does not indicate which input initiated the pain, pathology or movement abnormality, nor does it give a direction from which to assess the pain, pathology or movement abnormality. However, following a kinesiopathological approach for assessment and intervention may be more conservative and therefore, more appropriate in most cases.

The pathokinesiological approach dictates that the most efficient way to change a person's pathology often requires surgical procedures to modify; whereas, a kinesiopathological approach suggests that movement interventions can modify a person's pathology. This is less invasive than surgical manipulation of hard or soft tissue, while maintaining that efficiency of treatment. Additionally, interventions to modify movement quality have resulted in improvements to movement (Voskanian, 2013), reductions in injuries (Soligard et al., 2008) as well as reducing symptoms for those suffering with osteoarthritis (Bennell and Hinman, 2011), Moreover, such interventions would require less funding and fewer resources, making it more appealing from a cost-benefit perspective. Although previous research cannot establish causation between movement and the initial injury or pathology, the ease of intervention method, lack of invasive surgery, potential changes to structure and symptoms and lack of upfront cost, would seem to suggest that it may benefit all affected parties to initially intervene from a kinesiopathological approach.

2.2 Good and poor movement

The term "good" is intentionally vague at this point due to the nature of the topic. Poor movement is typically simple to demonstrate, observe and identify, but optimal movement is not as clearly defined. However, those who attempt to define this have previously done so by identifying the presence or lack thereof, of poor movements or faults (Botha *et al.*, 2014). In order to identify a movement as "good" one must consider the physical structures in use, and their limitations, the movement of choice and the intended outcome. Moreover, one can also look at the impact of long-term exposure to such a movement if it is a repetitive motion, such as running. Therefore, at this point, it may be beneficial to start with the identification and classifications of poor movement or movement dysfunctions and the epistemological approaches used to interpret them.

Sahrmann (2002) states the pathokinesiological approach explains a person's abnormal movement by diagnosing the patho-anatomical abnormality, which can be classified by a grade that would inform subsequent treatment. However, the abnormal movement itself needs no gradation. Conversely, the kinesiopathological approach bases its analysis on the movement of the person. Therefore, in order for the kinesiopathological approach to be beneficial in injury risk identification, one must first show that movement can be classified as good or poor and that these classifications can be clearly and separately identified. Aspects of movement can be measured such as kinematic factors including speed and distance, to kinetic variables such as force, torque and power, or movement outcomes such as displacement vectors of a projectile or velocity of a movement. All of the aforementioned variables can be given a universal value and used to define what action has taken place. Thus, movement can be measured. Grading movement on a good to poor scale involves exploring linked, but not interlocking categories. The next section will outline the factors effecting the classification of a movement, and explore the varieties of movement classification that have good and poor gradations.

To be considered for gradation, a movement must initially be conducted. For example, a vertical jump can be said to have occurred if the person has left the floor for a period of time greater than zero. However, this dichotomous identification of a jump gives no indication of anything other than the completion of a jump. Therefore, to grade the jump, other defining measures must be identified and recorded. Assessing the outcome performance allows for a gradation of the jump movement. For example, a person can be said to have jumped higher if they achieved a greater height. This scoring system allows for gradation on a continuous scale, which can demonstrate the differences between multiple jumps in vertical distance, and can therefore be classified as an outcome measurement. An outcome measure can give details on the performance of a person such as their speed over a given distance. However, outcome measures give no indication of how the movement was completed. In order to understand how the movement was completed, movement kinematics must be recorded.

Hard and soft tissue structures, such as bone, joints, ligaments and muscle all allow and limit movement. The joints and muscle allow motion and articulation; muscle origins and insertions work in conjunction with joint socket structure to allow and restrict movement (Bartlett, 2007). The knee joint and the surrounding muscles and soft tissue allow flexion and extension to occur at the joint, but the knee restricts more movement than it allows. Consequently, the hard structures of the knee joint are best suited for the movement allowed at the knee while being in contrast to the movements restricted by the joint. Therefore, knowing the structural limitations of any joint used to complete a movement will allow the observer to establish if the movement was performed within these limitations. If a movement were to occur outside of the structural limitations of a joint, immediate damage would be sustained. However, movements that push the structure closer to, or against the limits of movement are also observable. Consequently, movement can be graded based on the quality of the movement. However, identifying the exact location of bone, joint and joint centre of axis or rotation requires very invasive exploration. Therefore, benchmarks and normative data are typically used for ease (Botha *et al.*, 2014). Nevertheless, interpersonal skeletal and muscular differences dictate that these benchmarks and normative values are purely based on mean data. Therefore, a person exhibiting movement indistinguishable from benchmark movement may be moving very differently from that which would be deemed most efficient for that individual.

To grade the quality of a given movement, we must first establish normative values for hard and soft tissue structures and therefore, normative movements at each joint. For example, one could establish the typical RoM and movement through the normative RoM of the knee. Although all joints are susceptible to laxity and small amounts of movement in multiple directions, the principle movements articulated by the knee are flexion and extension. Once normative values are established, a person's ability to achieve such movement ranges could be tested. First, movements that will most accurately and reliably test these specific movement ranges should be identified and grouped together. Once a set or catalogue of movements are collated, a scoring system can then be established. This process will ultimately create a movement screen for a given population, injury type or movement dysfunction. Movement quality screens are typically scored based on a person's ability to successfully mimic a movement without pain. The movement is then graded on a small, 2 or 3-point scale, such as used in the Functional Movement Screen (FMS) (Cook, 2010). Although movement screens are scored in terms of ordinal or dichotomous criteria, this does not mean that movement quality is most appropriately assessed in this manner in all occasions. As movement can be graded with continuous measurement scales (e.g. distance, force, speed), movement quality may also be subject to similar gradation. However, the ability of a practitioner to observe such changes in movement in a single limb movement, let alone total body movement is unlikely.

Optimal, and therefore deviations from optimal are relative terms based on desired outcome. For example, a football player may trip while attempting a shot on goal but still connect with the ball in a way which results in a successful shot and goal. Therefore this can be said to have achieved the intended outcome but has clearly not done so in a way in which the player would like to recreate in future similar situations. Furthermore, the opposite could also be true, in that a perfectly struck ball could have been on target but was saved by the goal keeper, such that the outcome was unsuccessful. However, in the second scenario, there is a greater chance of success in similar situations in the future.

The aim of the current research project is to use the kinesiopathological framework to understand the interaction between movement quality and injury. This states that the level of movement quality is linked to injury risk, and hence ultimately observed injury rates. Consequently, the overarching theme is to determine how injuries might be reduced by modifying movement quality. The current study will not directly interact with or record the performance outcome of movements, but rather the quality of the movement used to perform the action. Therefore, this thesis will state that in all occasions in the experimental studies, the intention of the observed and intervention movements are intrinsic to the movements themselves and not liable to external performance influence. This therefore reduces the separation between intention and good movement, as the intention will be to perform a good movement. There are many ways of achieving a given task or performance, but there are fewer ways in which our skeletal structures can move to achieve these tasks. The consequences of moving in a way that stresses the body structures to, or past their limits may include injury, which will result in an inability to undertake the task in which the person was initially engaged. A movement's performance outputs are directly related to the movement input, and can be seen as secondary or resultant. In order to better understand the underlying cause of any phenomenon, it would be most appropriate to observe and record the base influencer. In the current research programme, this is considered to be movement quality. Therefore, the current study considers movement quality to be of greater importance, and any further mention of movement quality or gradation of movement quality will be in reference to that which will affect the body structures rather than performance outcomes. However, the thesis recognises that the principle aim and potential impact of this research programme is to understand the outcome of movement quality. Specifically, lower-limb injury in military recruit cohorts. Therefore, the thesis will observe and record information on the mechanisms that interact with the outcome, in order to understand and modify this interaction.

Variables created by movement can be measured and graded. This demonstrates that movement as a whole can be measured and graded, and consequently good and poor movement can be distinguished. Being subject to gradation also allows normative data and movement data that is more or less commonly – and subsequently likely or unlikely – to be observed. Therefore, central tendencies and dispersion data are also available to record. This provides the possibility of identifying cohorts and individuals with good and poor movements and to examine and further understand the mechanisms of such cohort differences to aid in movement identification and intervention design.

2.3 Observational movement quality screening tools

If movement quality is to be observed and identified reliably, and with little or no bias from the observer, a singular tool and method must first be created, tested and validated. A number of tools have been developed for this specific task with varying degrees of success. Greater detail of these tools can be found in Chapter 5. However, the process used in the development of many of the tools will be presented here. Initially, a set of movements are selected due to the apparent appropriateness and links with either the cohort's activities or commonly observed injuries. Then, optimal movement is clarified, with deviations from this classified as different from optimal. This thesis suggests that movement quality is subject to gradation and is directly linked to injury risk. Therefore anything that is not recorded as optimal movement can be seen as non-optimal. Thus, based on a graded scale, the further from optimal the movement is, the poorer this movement. Poorer, in this case, refers to the likelihood that the movement would result in injury.

One such tool used within the present study is the Hip and Lower-Limb Movement Screen (H&LLMS), which was developed for use within male football populations (Botha *et al.*, 2014). This observation tool focuses on the lower-limb only rather than also examining upper-limb movements. As the present study is observing movement quality in military trainees, it is vital to use a tool that mirrors common movements and injury types. According to the Ministry of Defence (2016), the majority of medical discharges from Army Phase-1 training were due to lower-limb musculoskeletal injury. The report states that distance running is a typical training activity to improve cardiovascular fitness in military recruits. However, running distance has been stated as a significant risk factor for overuse lower limb injuries during initial military training (Bullock *et al.*, 2010). As lower-limb locomotion represents a high amount of time and mileage during training, and this type and degree of training has been shown to contribute to lower-limb injury, the injury reduction method employed should take both factors into consideration when employing observations and recordings. Therefore, the lower-limb focus of the H&LLMS, may prove to be relevant to a wider population than that which it was originally intended for.

2.4 Motor control

Confirming that movement quality and injury likelihood correlate would only be valuable if movement quality were modifiable. One way to assess this would be to develop an intervention specifically to change movement quality. Thus, exploring the mechanisms that potentially generate change in motor control is vital.

Learned movement can be undertaken with little effort or input from the environment due to neurological pathways being made available through repeated practice (Keele, 1968). In order to acquire a new skill, there are two mechanisms that are employed. Motor sequence learning measures the progress at which a person learns a movement; and motor adaptation tests for the ability to compensate for the environment or external factors (Winstein et al., 2014). Progressing from learning to acquiring a motor skill requires progressive challenges, intensity, problem solving, sufficient motivation, and focused attention (Winstein et al., 2014).

The acquisition and/or adaptation of motor skills is dependent upon many factors. However, in the initial four to six weeks of any training intervention, observed adaptations would most likely be the result of neuroplasticity adaptations rather than alteration to the soft or hard tissue structure (Beck et al., 2007). Neuroplasticity allows for new learning, adaptations and compensation at numerous feedback levels within the body (Winstein et al., 2014). Nevertheless, comparatively little is known about the underlying mechanisms of motor control change after such a period (Taube et al., 2007). Doyon and Benali (2005) identified that during longer interventions, the area of the brain that controls the movement changes and relocates; there is yet to be a consensus on the exact location of control, or the reason for the migration of control (Beck et al., 2007). What is clear is that neuroplasticity is vital for the preventative and rehabilitation adaptations, and that interventions that seek to include activities that utilise this would achieve greater modification in motor control (Taube et al., 2007). Verhagen et al. (2004) have shown that one such movement activity is balance training, as it has been shown to positively effect and restore neuromuscular function after injury and improve this as a preventative measure.

To complete an action, one must first attempt and practice such a motion. However, one cannot simply complete a movement repeatedly and expect to become proficient; attaining a skill requires repetition with purpose (Winstein et al., 2014). Training to perform an action or sets of actions will result in changes to bodily structures, such as muscle density (Yue and Cole, 1992) and bone mineral density (Nichols *et al.*, 2003) changes. In a similar way in which hard and soft tissue structures adapt to movement input, repeating a movement will result in changes in synaptic efficiency and increased activation in supraspinal motor centres (Carroll *et al.*, 2001). Moreover, the manner in which a movement is conducted will affect the neurological pathway creation (Aagaard, 2003). As previously stated, the current study is observing movement quality as applied to bodily structures. As such, if a motor skill is learned and maintained with poor movement quality, it will result in deploying that movement with poor movement quality in the future. This would increase the likelihood of injury, or structural mal-adaptations to bodily structures. However, if learning occurred using good movement quality, the pathways for good movement are reinforced, and the likelihood of movement quality related injuries could be reduced by reducing the stress on bodily structures during movements.

When learning a new skill, Miller (1956) suggest that one must learn each aspect of the movement as individual sections. Compound movements, such as running, are produced by connecting a sequence of more simple, individual movements. These simpler movements are referred to by Miller (1956) as chunks. These are then reconnected during the mastery process of movement learning. Over time with focused practice, complex movements are learned and stored as chunks (Song and Cohen, 2014). An example of this would be an over-arm throw. van den Tillaar and Ettema (2009) concluded that the ability to throw faster, further and more accurately with the dominant arm is likely due to the ability to attain greater velocity of proximal and distal limb segments, while maintaining a consistent total movement. However, poorer throwing with the non-dominant arm may be due to an inability to coordinate the same individual movements that make up the whole throwing movement. An individual may demonstrate similar strength across both limbs, but the ability to coordinate the learned movement chunks differs, such that the performance output would likely differ to a greater percentage than that represented by the strength difference. Movements are stored as chunks to make it easier for movement recall and deployment with little conscious input. Thus, the way in which a movement is learned will impact upon the way in which it is deployed. Although these are set motor pathways, these chunks are subject to modification through training (Ramkumar et al., 2016). Consequently, a person's movement quality may be modifiable through mechanisms that modify motor pathways. Thus, those classified with poor movement quality may benefit from interventions that specifically target movement quality.

2.5 Movement quality neuromuscular exercise interventions

Movement and movement patterns are learned, and can be modified (Song and Cohen, 2014). Although this will be expanded upon in chapter 3, neuromuscular training interventions have been shown to modify movement quality (Soligard *et al.*, 2008) and reduce injuries in several populations (Emery *et al.*, 2015; Thorborg *et al.*, 2017). Interventions to reduce injuries are commonplace in cohorts at high risk of injury, such as sporting populations and individuals engaged in physically active occupational roles (O'Connor *et al.*, 2011; Frost *et al.*, 2012; Kiesel *et al.*, 2014). However, the aim of this thesis is to understand if interventions that prioritise movement quality could be more appropriate than those which prioritise muscular strength and/ or performance outcomes. Moreover, similarly to movement quality observation tools, the intervention should also take into consideration commonly used movements and commonly sustained injuries (Rusling et al. (2015). Therefore, if a cohort were to spend a large proportion of training time in bipedal locomotion and sustain high percentages of hip and lower-limb injuries, the most appropriate intervention would specifically target the hip and lower-limb.

2.6 Summary

Both pathokinesiology and kinesiopathology are likely to be appropriate in observations, identification and attributing potential cause of movement quality abnormalities. However, the pathokinesiological approach is limited to explaining movement quality after structural changes. Although this is clearly evident in many cases of movement quality abnormalities, it is not appropriate in all cases. The kinesiopathological approach provides another avenue of insight into structural changes occurring after movement quality abnormalities. Therefore, the current research programme will employ the use of kinesiopathology to assess movement quality in military cohorts.

Chapter 3: Literature review

The following chapter examines previous literature that has evaluated movement quality, the use of observation movement screening tools, neuromuscular interventions and injuries within physically active populations as well as the more specific population of military personnel. Research of the specific aspects of military service and training, such as load carriage and specific movements have also been included as a result of information gained during study-1 (Chapter 4).

3.1 **Search strategy**

The literature search was designed to collate papers that examined a potential link between movement quality and injury likelihood in military cohorts. Searches were undertaken of the following databases: Delphis, Medline and CINAHL. The search employed a strategy using Boolean operators of 'and' and 'or' with search terms. Keywords used are presented below, and the process is expressed in Figure 3-1. Paper screening followed the PRISMA guidelines and involved multiple stages that would highlight the most relevant papers and exclude irrelevant papers. Initially, the total number of papers collected were subjected to a duplication assessment. A title examination was conducted, where the paper would be sorted into one of three groups (relevant, irrelevant, unsure) based on the relevance of the title.

The next stage would subject the remaining papers to an abstract review. At which point, more detail would be gleaned about the methodology. Exclusion criteria, at this point, consisted of, non-English publication, no access to full-text, irrelevant methods, and if the papers were systematic reviews or meta-analyses. The final stage was to establish the eligibility of the papers, and therefore employed a full text review. At which point, the standard of the paper and relevance was fully assessed. Those papers that remained after these stages were again subject to a further critical review process.

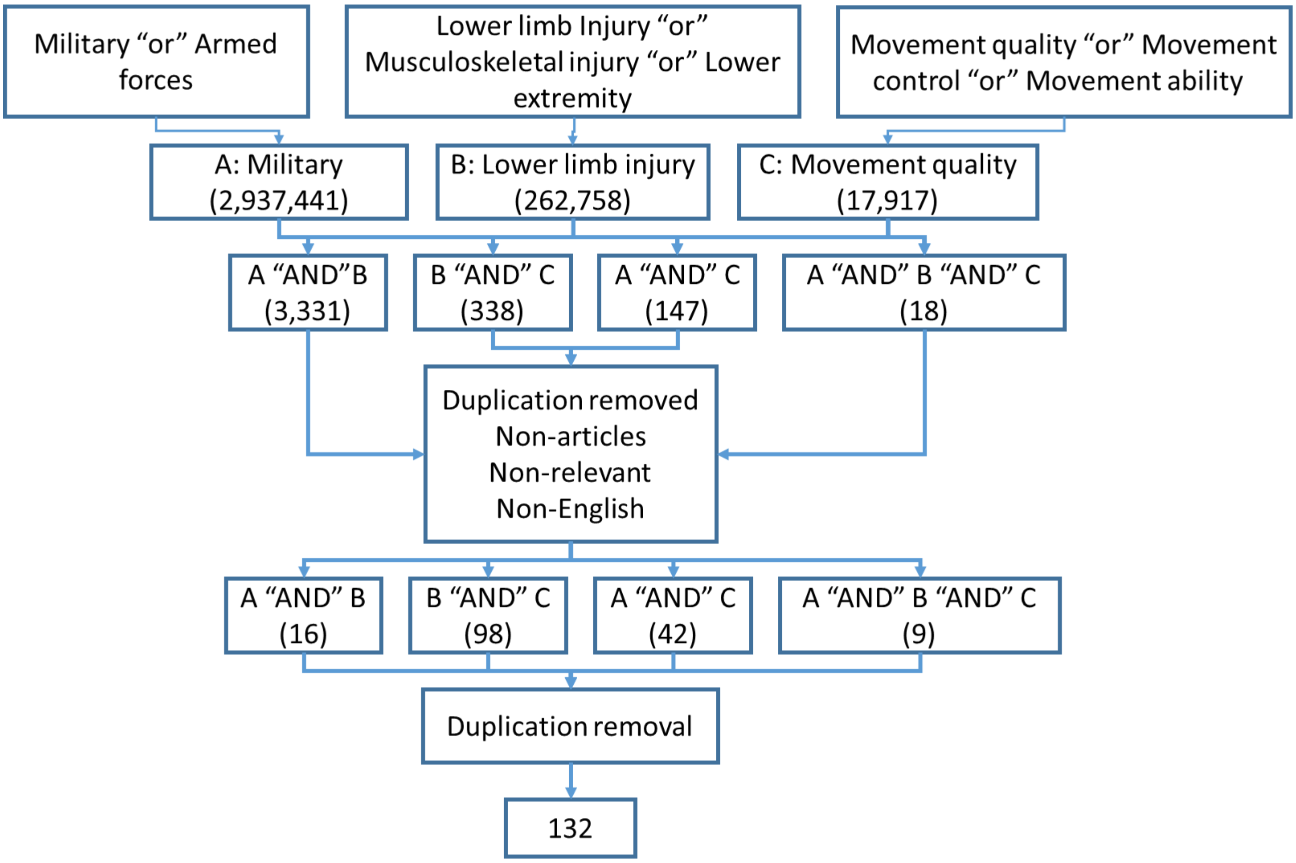


Figure 3-1: Search strategy flow-chart. The term “AND” refers to Boolean search operator used between the search terms expressed by A, B and C. Bracketed numbers represent the amount of research articles remaining after exclusions specific to each level.

3.2 **Movement observations**

The current research programme did not employ a systematic review to collate relevant research articles. However, the search was completed in a systematic manner. Once the 132 articles were collated, they were screened for their relevance to specific topics within the thesis and the quality of research critiqued. Among the 132 papers collated, there were: seven reliability and validity studies that all covered the Functional Movement Screen, nine systematic reviews that cover the Functional Movement Screen (FMS), injury prediction and the 11+ intervention, and one Randomised Control Trial (RCT) (Soligard et al., 2008) that examined the injury prevention properties of a pre-exercise warm-up intervention.

3.2.1 Types of screens and measurement tools

This thesis has previously shown (in chapter 2), that movement can be categorised based on performance or quality. The present research programme considered movement outcome and hard and soft tissue structures movement quality to be the most pertinent to the following research and review. Consequently, there are varieties of ways in which to measure movement. Accurate movement assessment such as: two dimensional (2D) and three dimensional (3D) video analysis (Dingenen et al., 2014), core stability (Okada et al., 2011), musculoskeletal movement analysis (Petersen and Smith, 2007), anthropomorphic analysis (Scarpello et al., 2002), dynamic balance test (Butler et al., 2012) Y-balance test (Chimera et al., 2015), star excursion balance test (Plisky et al., 2006; Gribble et al., 2012), the Landing Error Score System (LESS) (Padua *et al.*, 2015), Functional Movement Screen (FMS) (Cook *et al.,* 2006) and running or walking gait (Trank et al., 2001) have all been used to assess the differences in movement between groups. However, some methods employ performance outcomes, such as distance moved from the standing position in a given direction, such as the Y-balance test (Chimera et al., 2015). While others observe and assess the limb action quality during such movements, such as the observation of the amount of medial knee movement present during the Landing Error Score System (LESS) (Padua *et al.*, 2015). Regardless of category to movement test, each movement test or battery of tests observes various aspects of movement to predict either injury likelihood or performance. The use of performance and quality measures in movement screens dictates the interpretation one can make after scoring.

3.2.2 Movement assessment

The FMS was initially used as a tool to distinguish track athletes from one another, and assess changes over the season (Cook, 2010). The screen uses seven whole body movements scored between ‘0’, which denotes pain during the movement, and ‘3’, which demonstrates perfect movement (Figure 3-2). These scores are combined to provide a singular post assessment score between 0 and 21.

Figure 3-2: The full list of movements, as shown on the Functional Movement Screen website (https://www.functionalmovement.com/files/Articles/572a_FMS_Article_NoBleed_Digital.pdf) .

3.2.2.1 Injury prediction

Although created with no intention of predicting injury or sporting performance, the FMS has been used to do just that. Coaches, sports teams and researchers have all employed the FMS in order to gain information about the potential injury risk and performance of their respective cohorts. The prominence of the FMS's use led to a great number of research articles on the screen, which allowed for a number of systematic reviews to be conducted. Dorrel et al. (2015); Bonazza et al. (2017); and Moran et al. (2017) assessed the apparent ability of the FMS to predict injury and performance. Although these papers were all conducted in the past three years and reviewed papers on the same topic, they do not give a singular conclusion. Dorrel *et al.* (2015) and Moran *et al.* (2017) both conclude that the FMS is not an appropriate tool for injury identification, whereas Bonazza *et al.* (2017) concludes that interrater and intrarater reliability is excellent, and that the FMS demonstrates value in predicting injury. It is not immediately apparent why these papers would give contrasting conclusions, but one potential reason is the observed difference in their search strategy and in the way in which they analysed the individual research data.

All three reviews used similar databases, search terms, and exclusion/inclusion criteria. However, there is a discrepancy in the research papers reviewed in each systematic review. All three review papers assess the ability of the FMS to predict injury, and therefore, there should be an overlap in reviewed articles. However, of the 44 papers reviewed in total, across all three systematic reviews, only five papers appear in all three (Table 3-1). The three systematic reviews were published in sequential years from 2015 to 2017, which resulted in the review published most recently, Moran *et al.* (2017), having more recent papers included, such as papers from 2016 (n=5). This may have resulted in the more recent paper having a maximum of five more modern and potentially more detailed research articles included in its review.

More recently, a meta-analysis by Moore *et al.* (2019) aimed to better understand what has contributed to the variable findings of papers assessing the link between the FMS total score and sporting injury risk. Not specifically between the systematic reviews previously mentioned, but in individual papers. However, understanding this may help to further understand this disagreement between three reviews based on the same objective. Moore *et al.* (2019) include, both Dorrel et al. (2015) and Moran *et al.* (2017) within the analysis, but does not examine Bonazza et al. (2017). Additionally, Moore *et al.* (2019) includes 12 articles that are referenced by the three previous reviews, with Chorba et al. (2010), Kiesel et al. (2007) and Kiesel et al. (2014) representing the only three references now in all four review articles (Table 3-1). Moore (2019) conclude that the effect sizes shown, were typically small in magnitude and that it was unlikely that such results were clinically meaningful. Moreover, they state that the usefulness of the FMS may depend on the population. For example, the FMS total score was more effective for senior participants than juniors. Whereas, null findings were more prevalent in Australian football, basketball and soccer when compared to rugby. Finally, the study concluded that injury definition and injury mechanism, which was defined as non-contact or all-injuries, did not impact the relationship between FMS total score and/or the ≤14 cut-off. If injury definition does not significantly impact the ability of the FMS to predict injury, it would suggest that the FMS is not sensitive to the mechanisms behind injury. Therefore, it may well prove to be that the FMS in unable to give greater insight into the mechanisms of injury and fall short of the basic principles of a movement screen.

Table 3-1: Summary of research papers that appeared in all or two of the systematic reviews stated. ‘*’ indicates that all three papers reviewed the article.

Reference	**Dorrel *et al.* (2015)**	**Bonazza *et al.* (2017)**	**Moran *et al.* (2017)**
Azzam *et al.* (2015)			✓
Bardenett *et al.* (2015a)			✓
Beach *et al.* (2014)		✓	
Bushman *et al.* (2016)			✓
Butler *et al.* (2013)*	✓	✓	✓
Chorba *et al.* (2010)*	✓	✓	✓
Clifton *et al.* (2013)		✓	
Dossa *et al.* (2014)		✓	✓
Frost *et al.* (2015)		✓	
Garrison *et al.* (2015)		✓	✓
Gribble *et al.* (2013)		✓	
Gulgin and Hoogenboom (2014)		✓	
Hammes *et al.* (2016)			✓
Hotta *et al.* (2015)			✓
Kazman *et al.* (2014)		✓	
Kiesel *et al.* (2007)*	✓	✓	✓
Kiesel *et al.* (2014)*	✓	✓	✓
Knapik *et al.* (2015)		✓	✓
Kodesh *et al.* (2015)			✓
Leeder *et al.* (2016)		✓	
Letafatkar *et al.* (2014)			✓
Liberati *et al.* (2009)			
McGill *et al.* (2012)			✓
McGill *et al.* (2015)			✓
Minick *et al.* (2010)		✓	
Moher *et al.* (2009)			
Mokha *et al.* (2016)			✓
O'Connor *et al.* (2011) *	✓	✓	✓
Onate *et al.* (2012)		✓	
Parenteau-G *et al.* (2014)		✓	
Peate *et al.* (2007)	✓		
Rusling *et al.* (2015)			✓
Schneiders *et al.* (2011)		✓	
Schroeder *et al.* (2016)			✓
Shojaedin *et al.* (2014)	✓		✓
Shultz *et al.* (2013)		✓	
Smith *et al.* (2013)		✓	
Teyhen *et al.* (2012)		✓	
Warren *et al.* (2015)		✓	✓
Whiteside *et al.* (2016)		✓	
Whiting *et al.* (2011)			
Wiese *et al.* (2014)			✓
Wright *et al.* (2015)		✓	
Zalai *et al.* (2014)			✓
Shared references	**6**	**9**	**9**
Total references reviewed	**7**	**25**	**24**

Bonazza *et al.* (2017) states that an FMS total score of ≤14 predictably identifies those at a greater risk of injury. However, Dorrel *et al.* (2015) explain that of the studies that show that a total FMS score of ≤14 best predicts injury likelihood, only 1 study (Kiesel *et al.*, 2007) prospectively identified this as the cut-off appropriate for their group. Three other studies used the cut-off point because it had been shown to predict injury, and of those, only one conducted a post-hoc analysis to review the accuracy of the cut-off using area under the curve (AUC) analysis. Therefore, although ≤14 was recognised as the cut-off that predicted a greater rate of injuries, it is not clear if this was the most accurate cut-off point in all cases. Moreover, Both Dorrel *et al.* (2015) and Bonazza *et al.* (2017) state that O'Connor et al. (2011), who conducted the area under the curve (AUC) analysis, was unable to identify a cut-off that both maximised sensitivity and specificity for either overuse or serious injury in military cohorts. Moreover, Moran *et al.* (2017) gave a comprehensive depiction of all reviewed articles, data analysis type and results. Of these results, only two articles used AUC to analyse the cut-off point of total FMS score and both gave results close to 0.5 (0.55±0.09; 0.5±0.11). Thus suggesting that the FMS is capable of predicting injury to a similar extent as random chance.

3.2.2.2 Performance prediction

The FMS screen rates movements based on outcome variables, such as distance and depth of the movement. Therefore, the FMS could be categorised primarily as a performance-based movement assessment tool. Shoulder range of motion measures, and bases the score on, the distance between the participant's hands. The deep squat test is measured and scored based on the depth of the movement as well as the forward movement of the overhead held hands. In contradiction to this performance-based assessment, each movement in the screen is subject to gradation, such as squat depth. However, as a fail and a perfect movement are both strictly defined, scoring a two in each movement seems to be the gap between these definitions. Thus, suggesting that the FMS scoring scale does not allow for gradation. Although this is difficult to justify, the work of Dorrel *et al.* (2015) may aid in the assertion. The middle score that can be achieved in the FMS is 14, with 21 and 7 as the dichotomous extremes without exhibiting pain during the screen. Dorrel *et al.* (2015) state that 14 was the most commonly observed score within their cohort. This does not necessarily mean that those who do not clearly show a one or a three are pooled as a two. Nevertheless, it does show that this is the most commonly given score. Additionally, the FMS employs a scoring system firmly based on the end position of the movement. For example, in Figure 3-2, the deep squat movement is shown as scoring the full 3 points for perfect movement. However, the end range is the only point in the movement given to indicate a perfect score and no points are given for the path a person would use to achieve this movement. Therefore, the functional movement screen may not be observing movement, but rather the limits of movement or end range of motion. This suggest that the FMS may be better presented as an end range of motion observation tool. Consequently, this suggests that the FMS is more aligned to observing and recording performance, and could be classified as a performance-based observation tool.

Although the review articles disagreed on the level to which the FMS should be used across all cohorts, they concur that clinical application of the FMS should be exercised with caution due to the lack of confirmed validity in injury prediction. However, Moran *et al.* (2017) suggest that the FMS may have applications relevant to specific cohorts and that any judgement on the appropriateness of the FMS should be based on research that most closely mirrors the proposed population. Therefore, in order to assess if the FMS should be used within military recruit populations, the current thesis must focus on such a population.

3.2.3 Use of the FMS in Military cohorts

Although the FMS was not created to better understand injury, the FMS has been correlated to injury likelihood in military cohorts (Kiesel *et al.*, 2007; Kiesel *et al.*, 2011; O'Connor *et al.*, 2011). Consequently, the FMS has gained popularity and has become the most prominent movement screen within the U.S military. Preliminary assessment identified a cut-off point at which injury likelihood was significantly increased. Kiesel et al. (2011) suggested that a score of 14 was the most appropriate cut-off for movement classification and injury prediction as Receiver Operating Characteristics (ROC) curve maximised specificity and sensitivity at scores between 13.5 and 14.5. This finding was reinforced by O'Connor et al. (2011) using a different but similar military cohort, and similar assessment methods. However, the study continued to state that three distinct groups appeared during analysis to show that <14, 15-17 and >18 all showed significantly different injury likelihood. The data indicated that a score of >18 increased the likelihood of injury as shown in Table 3-2. However, this relationship was non-significant and produced risk ratios of between 1.32 – 1.61 that were lower than those with a score lower than 14 compared to over 14. Therefore, the study suggested that a threshold of 14 was the only practically usable score when distinguishing injury likelihood with the FMS. As similar cut-off points were found in two separate studies within military cohorts, it might suggest that the FMS cut-off score of 14 could be generalisable to all military cohorts.

Table 3-2: Risk ratio results from O'Connor et al. (2011).

FMS total score	*n*	Risk ratio	Percentage injured	Total injured
≤14	47	1.82	46.6	22
15 - 17	253	1	25.75	65
>18	137	1.47	36.65	50

When the cut-off point was applied to study data and injury likelihood, both Kiesel et al. (2007) and O'Connor et al. (2011) demonstrated significant differences in injury likelihood for the new FMS score groups. Kiesel et al. (2007) demonstrated that injury likelihood was greater for those scoring 14 or less when compared to those who scored more than 14, with 53% and 10% becoming injured respectively. Moreover, O'Connor et al. (2011) showed that those who scored 14 or less were 1.5 times more likely to sustain an injury during military training. This resulted in 46% (n=53) of those scoring a total FMS score of 14 or less being injured while 32% (n=22) of those who scored a total FMS score more than 14 were injured (Table 3-2). These results show that both studies demonstrate similar injury likelihood for those scoring below 14 but that O'Connor et al. (2011) showed double the likelihood of those who scored above 14. This may have been due to a difference in the cohort, training or the definition of injury used in the study. During the study by O'Connor et al. (2011), 874 military personnel were tested before and after officer training where FMS scores and injury ratios per 1000 days were collected. The study defined injury as any cause that resulted in a person seeking medical care for musculoskeletal discomfort. Whereas, Kiesel et al. (2007) stated that a person was considered injured if they were a member of injury reserve troop for three or more weeks. These two classification differences likely resulted in the stricter classification recording a lower number of total injuries than the other given the same cohort. As they both used a similar military cohort, it would be unlikely that one would have observed a significant difference in the total number of injuries. Consequently, the stricter classification of injury used in Kiesel et al. (2007) may have excluded recruits that would have otherwise have been classified as injured in the O'Connor et al. (2011) study. Thus, reducing the number of recruits classified as injuries in the >14 group.

Although the studies disagreed on the likelihood of those who demonstrate good movement, they suggest that movement quality, recorded by FMS total score, is linked to injury likelihood. Moreover, they agree that a score of 14 can be used as a cut-off in military cohorts. Although the relationship between FMS scores and injury have been seen in the US Army, Gibbs et al. (2014) suggest that there may be differences between these US cohorts and the Royal Navy. Results from Gibbs et al. (2014) suggested that those who scored ≤14 in the FMS were 2.6 times more likely to be injured than >14 and that FMS score, along with sex, body mass, smoking and aerobic fitness, gave significant contributions to the prediction model. This suggested that although UK military and US military cohorts were different and undertook different forms of training, the FMS was still able to distinguish between high and low injury risk. However, Gibbs et al. (2014) highlighted a potential limitation of the FMS within certain military cohorts. The study assessed males (*n*=862) and females (*n*=95) within the same population and found that females were 1.7 times more likely to sustain an injury than males despite there being no significant difference between their respective FMS scores (M+SD: Males 14.6±2.3, Females 14.4±2.4). This suggests two potential options: first, that something other than movement quality is responsible for the difference in injury risk; or, secondly, that movement quality differences exists between the sexes that the FMS is not able to identify. In either option, this shows that the FMS is insensitive to the interaction between movement quality and injury in mixed sex cohorts. Better understanding the relationship between sex and movement quality would allow for more accurate injury prediction and mitigation within cohorts of mixed sex, such as the military.

Although not specifically restricted to military populations, as it reviewed papers on physically active adults, further analysis of the application of ≤14 vs 14> as separate injury likelihood groups have been conducted by other research groups. Mentioned earlier (Table 3-1), Dorrel et al. (2015) includes and reviews the most relevant systematics reviews (*n*=7 papers) available on the FMS. The review assessed the ability of the FMS to predict injury as well as type of injury. The study conducted ROC curves of the compiled studies, which yielded areas under the curve of 0.58, 0.52 and 0.53 for: any injury, overuse injury and serious injuries respectively. Additionally, no ROC curve gave a point of maximised specificity and sensitivity. This conclusion suggests that the FMS provides a level of discriminatory accuracy only slightly better than chance. Moreover, Frost *et al.* (2012) examined the effect of an intervention on FMS score and concluded that the within-subject FMS score variation was too high to use the FMS as an appropriate movement quality change tool. Moreover, if the FMS were an invalid tool for identifying movement quality differences, it would be likely to be invalid for predictions of injury likelihood (Minick *et al.*, 2010; Bardenett *et al.*, 2015b; Ho-Suk and Won-Seob, 2015).

3.2.4 Individual FMS movements injury prediction validity

The lack of ability of the FMS to predict injury has resulted in some papers stating that the FMS should not be used as an injury predictive tool (Schroeder *et al.*, 2016; Moran *et al.*, 2017). As the FMS was never created with the intention of predicting injuries, such suggestions may be warranted. However, the FMS can show distinctions between movement quality (Bodden *et al.*, 2015), and therefore may still be relevant for informing injury prevention intervention strategies. However, before this can be implemented effectively, the FMS should be subjected to greater scrutiny. Rusling et al. (2015) suggested that the way in which the FMS score is calculated may be the principal issue, rather than the screen itself, and that the FMS could be adapted for more accurate prediction, and therefore intervention generation. At present, the FMS is a single composite score of all seven movements. This simplistic scoring system generates a single number, from which, very specific predictions are made. Therefore, one proposed adaptation is to remove certain movements that may dilute the FMS total score potency for accurate predictions. Removing less relevant movements from certain cohort assessment, may give a more specific screen from which to make more accurate predictions and intervention generation.

After assessing which movements gave the greatest contributions to a prediction model, Rusling et al. (2015) showed that the only movements that significantly contributed to the injury prediction model were the deep squat and trunk stability push up. Therefore, five of the movements used, showed no significant contribution towards the prediction model. This confirms that the composite score is too simple a tool for precise predictive purposes. This new reduced screen score may provide greater insight into the mechanisms of injury within a given cohort based on the specific links between the predictive movements and the most common injuries. Rusling et al. (2015) do not state which specific type of injuries were most prevalent within their specific cohort, but they confirmed that the cohort subject to analysis was male football players. There is no reason to believe that other such cohorts would differ greatly in their injury likelihood data. Therefore, other similar cohorts may be able to give evidence to suggest the most commonly sustained injuries in such a cohort. . Ekstrand *et al.* (2011) studied all English Premier League football clubs over a 7-year period, and concluded that hamstring strain was the most prevalent non-contact injury (12%). Less prevalent, but still serious injuries, included abductor strain (9%) and medial collateral injuries (5%). This then identifies that the most prevalent injuries are all sustained to the lower-limb. This, therefore, has links to the deep-squat movement, but less obvious links to the press-up. Rusling et al. (2015) suggested that the reason the deep squat and core press-up were the only significant predictors of injury from the FMS could be due to associations with the kinetic chain, rather than the individual movements themselves. They state that muscles do not work independently, and that groups of muscles are responsible for all human movement. Both, the Deep-squat and core press-up involve the entire body, and therefore may represent the body's ability more globally. This would have an impact on the body's ability to effectively transfer movements from one body segment to another. If so, this might indicate that some movements within the FMS are statistically redundant and might, in fact, dilute the total score for certain populations. It is therefore important to examine and identify, to what extent each individual movement with the FMS contributes to the prediction models.

The FMS uses a composite score from seven individual movements within the FMS that have been shown to differ in their contribution to predictive models of injury. Rusling et al. (2015) suggest that the combined score may result in diluting the effectiveness of the FMS as a prediction tool and the study claims that specific cohorts may require a specific set of movements, fewer than the full seven FMS movements typically administered. To understand if this is the case, one must assess the major injuries within a given cohort and identify individual movements that replicate the conditions in which such an injury is more likely to occur. Initially, as the FMS is already in place in several previous research articles and within sporting clubs, it may make sense to start with the seven movements within the FMS. However, it would be naive to assume that the set of seven movements would represent an exhaustive movement set, from which one may not deviate. Conversely, it is likely that there are cohorts, or injuries that are best predicted by movements not represented within the FMS. One such way in which to identify those movements likely to significantly contribute to predictive models is to highlight major or repetitive movements undertaken by the specific cohort. Although it may be inappropriate to conduct as predictive movements, such as a rugby tackle or high impact landing, this may allow for similar movements to be identified, thus leading to subsequent statistical analysis to understand predictive contribution.

Double support movements, such as the deep squat give an indication of the participant's ability to maintain an upright body position during gluteal heavy lower limb movement, and have been shown to significantly contribute to injury prediction models. However, this does not necessarily mean that the deep squat is the most efficient movement in which to predict injury or detect movement dysfunction. Rusling et al. (2015) demonstrated that the deep squat predicted 24% of injuries (M±SD=0.24±0.4 OR). Therefore, within the specific military cohort assessed within the current research programme, there may be other or additional movements that would give a contribution to the prediction model than the deep squat. For example, in football, there are only a few occasions where a deep squat would be replicated in game situation. A more common movement in football is bipedal locomotion in the form of walking, running and sprinting, which typically allows the athletes to cover 10,335m (±1,608m) (Helgerud *et al.*, 2001). The principle difference in a deep squat and bipedal locomotion is that a large proportion of time in locomotion is completed in single leg support rather than double support. Moreover, during bipedal locomotion, one is generating linear movement and transferring momentum from one limb to the other. Doing so, is complex and requires a great postural and neuromuscular control and could increase the chances of error and dysfunction (Steele *et al.*, 2015). Therefore, single support movements test the participant to a greater degree and in novel ways that differ from that experienced during double support movements. One such example is the presence of a non-level pelvis which is categorised as a hip drop, where the presence of such during double support movements would be highly unlikely due to both feet being in direct contact with the floor. Whereas, the ability of an individual to maintain a level pelvis while stood on a single leg would represent a substantial test of gluteal activation and control (Distefano *et al.*, 2009). Therefore, although the deep squat has been shown to significantly contribute to injury prediction models, a double leg support movement may not be as effective in this pursuit as single leg support movements for cohorts that run a great deal.

An additional advantage of the single leg support movement is the apparent sex-based movement control differences. Drop-jump tests are commonly used to assess landing technique; however, adapting this movement by reducing the number of contact points during landing would likely increase the difficulty and highlight movement dysfunction to a greater extent. During Zazulak *et al.* (2005)

study, surface EMG data from a single leg drop landing movement, demonstrated that females exhibited lower levels of gluteal maximus activation while also generating greater rectus femoris activation. Therefore, the study demonstrated a sex based difference in muscle activation during single leg movements. The study continues to state that this difference would likely result in a greater valgus knee movement within the female cohort due to the role the gluteal maximus plays in lower-limb movement control. However, the study failed to examine movement kinematics, and therefore was not able to confirm this hypothesis. Moreover, greater EMG peaks do not necessarily indicate muscle contraction strength, or amount of movement control (De Luca, 2006). If a single muscle contracts over a second, and in the middle 0.2-seconds of this contraction the peak appeared, it can be clearly stated that this is when the greatest amount of muscle force was applied. However, if two corresponding muscles are assessed simultaneously and a greater peak was seen in one muscle, the study cannot state that this would have shown a greater muscle force. Although this may seem that such a conclusion could be made when assessing muscle contraction of the dominant and non-dominant muscles of any given limb, the separate EMG data cannot be inferred to mean force. What this does highlight though, is that the participants used within the study were able to be significantly separated by sex according to their peak EMG traces for muscles vital to bipedal locomotion.

A similar study assessed EMG muscle activation alongside kinematic data between sexes during a single leg squat. The study demonstrated that sagittal plane movement discrepancies were observed in the form of significantly greater peak hip flexion and lower knee flexion in female participants (Dwyer *et al.*, 2010). Moreover, they confirm that rectus femoris peak activation was higher for females, although they also show that gluteal maximus peak muscle activity was also higher, which is in contrast to findings from Zazulak *et al.* (2005). The individual movements within the FMS have shown to deliver two main movements that significantly contribute to the injury prediction models (Rusling *et al.*, 2015), while also highlighting its lack of ability to accurately predict injury rates in females (Gibbs *et al.*, 2014). Therefore, if a more appropriate movement is available that can deliver greater contribution to prediction models while also identifying the movement quality differences between male and females, such a movement should be adopted for further movement quality testing. As Dwyer *et al.* (2010) and Zazulak *et al.* (2005) both demonstrate a sex based difference while adopting a single leg stance, single-leg support movements may prove to be this movement. Therefore, if a single movement screen is to be used in mixed sex cohorts, it may prove important to include movements that highlight differences between the sexes in the pursuit of an answer to the injury risk difference observed between males and females.

3.2.5 The difference between a single leg squat and a small knee bend

Bilateral evaluation tools have been used previously to analyse lower limb movement control and quality. Earl et al. (2007) demonstrated that a single leg step down test is an appropriate evaluation tool for hip and lower limb movement quality. However, there are small but important differences between the movements used. The step-down test allows the participant to position their non-weight bearing leg in front of them, much like one would do while walking down stairs. However, the small knee bend positions the unsupported leg behind the participant, which would more accurately mimic a portion of a running gait. Although this seems a small difference, this could be of great significance to their movement quality due to position specific muscle activation. Holding the non-weight bearing leg in front of oneself will encourage the pelvis to rotate under the participant's centre of mass (CoM), resulting in greater gluteal activation (Lewis *et al.*, 2015). The gluteal muscle group are responsible for rear hip extension and rotation of the upper leg and increased activation would likely result in increased hip and knee stability. When assessed against one another, the step-down movement, with a front held unsupported leg, demonstrated greater amounts of knee abduction. Whereas, during the small knee bend , with a rear held unsupported leg, the participants displayed higher levels of dynamic valgus knee movement (Lewis *et al.*, 2015). In ordinary settings reducing dynamic knee movement would be beneficial, and therefore would suggest that the front held unsupported leg movement should be adopted. However, when attempting to observe a person’s movement quality, having the gluteal muscles unintentionally activated by the position of the non-weight bearing leg could result in a less effective movement quality scoring tool. As the intention of a movement quality screen is to identify limitations or irregularities in a person’s movement (Bahr, 2016) artificial manipulation of this would result in errors in observations and therefore, errors in the injury likelihood score. This then again suggests that the movement selected for movement quality assessment should be based on the specific nature of activity undertaken by the cohort in question. Therefore, when assessing cohorts that undertake large volumes of bipedal locomotion, such as military recruits, a single leg support movement with a rear held unsupported leg would likely result in a more effective movement screen score.

Using a single leg support movement that better represents bipedal locomotion would give a better understanding of what mechanisms of injury are present in such movements. Botha et al. (2014) demonstrate that in footballing cohorts a single leg squat is able to identify movement dysfunction in those with symptomatic femoroacetabular impingement (FAI) by using movement markers such as level pelvis, knee valgus movement and trunk flexion. Although the study does not give an indication of the position of the non-weight bearing leg, knowledge of this may prove important. Subsequent correspondence with the research team confirmed that the non-weight bearing leg was positioned behind the participant. This better represents the stance and contact phase of a run, where a single leg in in contact with the floor while the other is unsupported and in the “swing” phase. However, this does have other consequences to the movement. The unsupported leg influences the rotation of the pelvises, which, in turn, influences the activation of the gluteal muscle group. Specifically, a rear held unsupported leg could increase the likelihood of an anteriorly rotated pelvises. This can result in a reduced gluteal muscle activation. As the gluteal muscles are the primary muscle used to articulate the lower-limb, this would likely result in a reduced ability to control the movement. If this were the case, this would also be present during the participants running technique. Thus, the movement used within the study was appropriate for the cohort based on a rear held unsupported leg being more indicative of, at least part, of the running technique. The study was able to identify specific movement dysfunction in male football players that presented with FAI. Furthermore, the study suggests that FIA is a strong predictor of developing hip osteoarthritis (OA). Therefore, this study demonstrates that while using a movement that is specific to population, potential mechanisms of injury can be identified.

What is clear is that not all movements within a movement screen contribute evenly to the injury prediction model. Consequently, there is likely to be some movements within all movement screens that are either not contributing to the prediction model, or that actively reduce the predictive ability of the prediction model. Moreover, movements such as the deep squat and press-up have all shown individual significant contributions to prediction models within specific cohorts (Rusling *et al.*, 2015). However, what is not clear is whether these movements will emerge in all or even most cohorts, or if there are types of cohorts that require specific groups of movements in order to generate a more appropriate movement screening tool. Further understanding of this topic will increase the efficiency of all movement screens as well and injury prediction, mitigation and intervention development. While attempting to further understand the most effective movements to use within a movement quality assessment tool, it would also be prudent to ensure that those cohorts at greatest risk of injury have preferential treatment. Namely, those who undertake activities that have higher rate of injury, such as military populations. Alternatively, those who seem to be at greater risk of injury regardless of activity or cohort, such as females.

3.3 Neuromuscular exercise interventions

One of the foundational reasons for evaluating and researching any movement control screens in active individuals is to inform interventions and to document movement control changes. In some cases, interventions have been specifically designed to increase movement control in the hope that this will lead to a reduction in injury. A systematic review and meta-analysis by Emery *et al.* (2015) state that neuromuscular training interventions can substantially reduce lower-limb injuries in youth team sport cohorts. The study continues by highlighting that most of the RCTs targeted improvements in balance, agility and strength. Although the study was not able to identify to what degree each variable contributed to the injury reduction, the study claims that a combination of balance, agility and strength has consistently demonstrated their effectiveness. Thorborg *et al.* (2017) state that specific injury prevention training can reduce injuries in youth football players by 39% and represents a substantial reduction, which would affect the physically active participants. Marshall *et al.* (2016) predicted that if a 38% reduction in injuries could be achieved in the Alberta youth soccer cohort (n=58100), this would result in a $2.7million health care saving. This would result in a 43% reduction in health care cost in Alberta. As the military are reportedly estimated to spend £1.2bn over the next 15 years due to injuries sustained during military service and training, excluding the costs of rehabilitation and return to training (Mgt Accountancy Services – Army., 2016), reducing this cost by 43% could result in a £516million saving. Although, this is predicated on a neuromuscular injury reduction intervention proving viable within other physically active populations, such as military cohorts.

Kiesel et al. (2011) created and undertook a strength and conditioning intervention based on the post-season results of the FMS during the off-season with a group of 62 healthy professional American football players. The study created an intervention based on, and designed to improve, the participants' FMS scores. The study showed that FMS scores can be increased with interventions designed to increase FMS scores. Therefore suggesting movement control can be altered. They also show that asymmetry in FMS movements can also be reduced across a cohort. However, the study did not follow the participants through the following season and neither injury, nor performance, data were collected. Consequently, there was no way of ascertaining if this change in FMS score and movement quality resulted in a change in injury likelihood or performance output. However, as previously stated in section 3.2.7, O'Connor *et al.* (2011) and Lisman *et al.* (2013) have demonstrated that FMS score is correlated to injury risk. Consequently, this change in FMS score, may suggest a change in injury risk.

3.3.1 Examining movement quality change after movement quality interventions

One of the roles of any movement screen is to inform musculoskeletal training programmes and injury reduction interventions (Bahr, 2016). The FMS, being the most commonly used movement screen, has also informed and created the FMS-intervention (FMS-I) which has been used in several studies. Bodden et al. (2015) used the FMS-I during an 8-week intervention to increase FMS score in a cohort of 25 semi-professional male mixed martial arts (MMA) athletes divided into intervention and control groups. The intervention included corrective movement training specified in the FMS advanced corrective exercise manual performed four times per week. Results show that the intervention group increased FMS scores from 13.2±0.8 to 15.2±1.2 at week-4. However, there was no significant increase in FMS score after week 4 of the intervention (15.33±1.43 at week-8). As previously stated, although the FMS is employed as a movement quality tool, the manner in which it is designed lends itself more to movement performance tool. Therefore, although the study showed that the FMS can detect movement quality changes instigated by an intervention, this may not be accurate. A more likely conclusion is that the FMS is able to detect changes to the movements in the FMS based on the criteria of the FMS after an intervention whose design was to do just this. As no other outcome measure was used within this study, the study may simply have shown that one can change their FMS score by using an intervention based on the FMS.

The adaptation seen in the initial 4 to 6 weeks of any training intervention would most likely result in adaptation due to neuroplasticity (Beck et al., 2007). Therefore, the apparent lack of movement quality change after week-4 would suggest that the FMS-I relied heavily on neuroplasticity adaptation. Moreover, improving movement quality past the initial neuroplasticity adaptive stage would require progressive challenges, intensity, problem solving, sufficient motivation, and focused attention (Winstein et al., 2014). However, the intervention used within Bodden *et al.* (2015) study did not allow for any progression, repeating the same movements through all weeks while maintaining the level at which they were conducted. Therefore, the study may not have shown a change past week-4 because of the lack of progression that represented the advancement from neuroplasticity adaptation to neuromuscular adaptations. Consequently, the study is unable to state that the FMS-I used, is capable of improving movement quality past the initial neuroplasticity adaptation stage. Moreover, the study was also limited with the use of the FMS to assess the effect of the FMS-I. Both the intervention and outcome tool use similar movements. By performing movements in an intervention that will be repeated to assess the influence of said intervention, one could argue that any observed improvements were the result of a learning effect rather than a genuine movement quality improvement. As such, the present research programme suggests two possibilities: research into the ability of the FMS to identify movement quality improvements in other intervention studies is required. Or that the FMS is not an appropriate tool for assessing movement quality and movement quality adaptations to interventions.

Frost et al. (2012) used a different intervention to assess the ability of intervention protocols to change FMS scores in a cohort of 60 firefighters from the same precinct. The study does not specifically state what the intervention contained, but it does state that it was 90-mins per week and that those considered for post-intervention analysis had to be present for more than 80% of all intervention sessions. Participants were asked to maintain current training regimes outside of the intervention, but observations and data of this was not recorded. FMS scores were recorded pre and post intervention, and participants were assigned to either a 12-week intervention 1 or intervention 2 or a control group. Intervention 1 and 2 actually completed the same movements and exercises; however, they differed in their approach of delivery. Intervention 1 was primarily focused on the quality of movement and whole-body coordination; whereas, intervention 2 focused on increasing the fitness of each participant; and the control group were allowed to continue their own typical physical training. Results show that neither intervention was able to significantly modify FMS scores, however, they state that 85% of participants who were in the control group had presented with different post scores compared to the pre scores. However, the study highlighted that this was not systematic, and showed as many reductions in scores as increases. This suggests that individuals were unable to reproduce their previous score. This led the researchers to suggest that FMS scores could be unstable and therefore unsuitable to use in pre-post intervention analysis with such small cohorts. Again, this suggests that the FMS may not be an appropriate tool for assessing movement quality and movement quality adaptations to interventions.

Bodden *et al.* (2015) explain that the purpose of the study was to better understand the appropriateness of movement screens to predict injury, and to understand if movement quality can be changed. Bodden et al. (2015) demonstrate that FMS total score is subject to modification, however, in a similar vein to Kiesel et al. (2011), the study did not continue to assess injury risk in the following season. Therefore, the study was unable to determine what effect of the change in FMS score had on injury risk. If the change in FMS score were not to present with a reduction in injury rate in the subsequent season, it would likely suggest that the FMS would be an inappropriate measurement tool for improvement in movement quality and injury risk. Additionally, although the study was able to demonstrate that the FMS total score is malleable through intervention; the study was unable to define the mechanism of change, nor was it able to explain the reduced rate of change seen after week-4. Not understanding the mechanism of movement change will likely lead to inefficient future interventions and therefore, greater emphasis on gaining a better understanding of the reasons for the observed movement changes are required. Moreover, this then questions the FMS's ability to indicate movement quality at a given time. As such, the present research programme will refer to FMS score and movement quality as linked, but not indicative of one another from here out.

Minthorn et al. (2015) conducted a literature review of research using interventions to improve movement quality measured by the FMS score, and concluded that there is little evidence to show that this change in the FMS is indicative of movement quality changes. Although papers such as Kiesel et al. (2011) and Bodden et al. (2015) showed, to varying degrees, that the FMS score can be changed and improved after movement quality interventions in professional sporting cohorts, no such evidence is presented to categorically state that this interacts with movement quality changes. Moreover, there has been no research on the impact of such FMS score changes, on injury likelihood post intervention. A cut-off point of ≤14 is well-established as the point at which injury likelihood significantly differs, and therefore an intervention that demonstrated predictable ability to move a person from ≤14 to >14 would indicate a reduction in injury likelihood, there has been no evidence to support this relationship. An increase in FMS score after an intervention may only be an indication that one's FMS score had improved. The underlying mechanisms behind injury may still remain, resulting in a similar injury likelihood as pre-intervention. Until such research into an intervention's impact on injury risk has been conducted, there will be no clear answer. Additionally, most intervention studies that utilise the FMS as the primary outcome measure either do not include women, or do not analyse the effect of a person's sex on intervention success. As such, conclusions from such studies must assume similar movement quality changes regardless of sex. As this may not be the case, more research into interventions based on women is required.

3.3.2 The 11+ programme

The FIFA 11+ is a set of warm-up exercises and movements that specifically target hip and lower-limb muscles to increase the likelihood of reducing movements associated with lower-limb injury. The intervention is split into running exercises, strength, plyometric and balance exercises followed by additional running exercises and typically lasts 20-mins (Appendix D). Soligard et al. (2008) demonstrate that 1,892 female football players between 13-17 participating in the FIFA 11+ as part of a warm-up significantly reduced total injury, overuse injury and severe injury likelihood over a competitive season. Moreover, Soligard et al. (2010) demonstrated that in a cohort of 1055 female football players, those who completed the FIFA 11+ warm-up more frequently had an additional 35% reduction in injury likelihood. This shows that not only does the FIFA 11+ have an effect on injury likelihood, but that this relationship seems to be positively affected by intervention exposure. Such findings prompted research in the mechanisms of change in similar cohorts.

Thompson et al. (2016) used musculoskeletal modelling using anatomically located marker sets, and inverse dynamics to record for kinematic assessment of four movements before and post-intervention. A planned cutting movement, unplanned cutting movement, double-leg jump and single-leg jump was analysed to assess peak knee valgus movement before and after the FIFA 11+ injury prevention warm up in 51 adolescent female football players. The study showed that the intervention significantly reduced knee valgus moment during double leg jump landing compared to the control group and pre scores. Therefore suggesting that knee valgus movement may be linked to injury likelihood. However, they did not follow the group through a full season to assess the resultant effect on injury risk. The study concluded that this decrease in knee valgus movement would likely result in fewer injuries, as knee valgus movement is highly linked to ACL and knee injuries (Hewett *et al.*, 2005; Quatman and Hewett, 2009). However, until injury likelihood is established in a longitudinal study post intervention, this research is unable to state categorically that this intervention and the resultant reduction in knee valgus movement, would have an effect on injury risk.

Women are 1.7 times more likely to sustain lower limb injuries in general and are said to be 3.5 times more likely to sustain an ACL injury (Voskanian, 2013). Therefore, it would be reasonable to assume that women would be specifically targeted for lower limb movement control interventions to reduce injuries. Mandelbaum et al. (2005) developed a warm-up intervention based on education of movement control, stretching, strength, plyometric and specific agility drills and assessed this against a standard warm-up. Although not purely a movement control intervention, foundations of movement control were integrated into each element of the intervention. Female football players were split into intervention group (*n*=1041) and control group (*n*=1905) and injuries throughout the season were collected by the 52 participating teams. During season 1, the intervention group demonstrated an 88% lower rate of ACL injuries compared to the control group. During season 2, players were age and skill matched to better control for such variable and resulted in the intervention group demonstrating a 74% lower rate of ACL injuries compared to the control group. Although the study did not report other lower limb injuries, the intervention used had a significant impact on ACL injuries. However, as no pre and post movement control screen was used, there is no clear way to assess if any movement quality changes occurred, nor does it allude to the underlying mechanisms that resulted in such a marked injury reduction.

Earlier chapters (Chapter 1 & 2) demonstrate that injury rates in military recruit cohorts are high, while also highlighting that females are at a greater risk of injury than their male counterparts. Therefore, the current research programme has sought to understand this difference in injury risk. However, military training is conducted in mixed sex groups. This then dictates that any intervention strategy used must be appropriate for both males and females. Therefore, if the FIFA11+ is to be effectively implemented, it must at least, not increase injuries for males. However, it would be beneficial if the singular intervention had positive effects on both sexes. Quatman and Hewett (2009) used the FIFA11+ to reduce injuries in specifically male youth football players in the Lagos premier league. Quatman and Hewett (2009) used a cluster RCT that used the FIFA11+ over a 6-month intervention period. The study showed that those in the intervention group sustained 41% fewer total injuries and 48% fewer lower-limb injuries compared to the control group. Similarly to that of Soligard et al. (2008), intervention compliance was not 100%, but Quatman and Hewett (2009) demonstrated that the intervention was performed before 60% of all training and game situations, while an average of 74% of the players completed the scheduled interventions. Thus adding weight to the suggestion that the FIFA11+ reduces injury likelihood with a lower than optimal dose. However, the study did not assess pre or post-intervention movement quality. Therefore, it is unclear what mechanism was primarily responsible for the reduction of injury risk. Such findings suggest that the FIFA11+ is appropriate for male and female cohorts, however, it is not clear that the intervention will affect males and females to a similar degree. Consequently, this may present favourably for a single sex within mixed sex cohorts. As such, it is still important to better understand the effect the FIFA11+ has on mixed sex cohorts from a movement quality perspective.

The FIFA 11+ has yet to be researched in military populations; however, it shows a strong ability to reduce the likelihood of injuries within active female populations. As the UK military have recently reduced restrictions of female recruit application, and that this increased cohort of females has shown to be at greater risk of injury, the use of the FIFA 11+ could prove useful in UK military cohorts. One main difference between the FIFA 11+ and the FMS intervention, which is more commonly used in military populations, is the use of single stance movements. As football players spend a large proportion of training and gameplay in single leg stance, running and kicking, it would seem relevant to assess their movement control during single leg stance. However, military populations also spend a great deal of time marching and running, and as such, assessing single leg stance may also lead to increased injury preventions. As such, colleagues from the University of Southampton have modified the FIFA 11+ to focus on movement control and have proposed it for use within this study.

3.4 **Load carriage**

The previous sections in this chapter have identified that movement quality can be recorded and modified through intervention. However, movement quality can also be more acutely modified via external factors. One such factor is an external load exerted on an individual. Lee *et al.* (2009) explains that biomechanical models can accurately identify (92.5%) the differences in gait between those loaded and unloaded participants. Within this study, the researchers were unaware of who was carrying the 12.5kg weight. However, the linear discriminant analysis model correctly identified those carrying the load. This demonstrates that there must be some systematic changes instigated by carrying an external load. Moreover, Liew *et al.* (2016) demonstrated that frontal and sagittal plane lower-limb kinematics are affected by load carriage during gait. Participants carried 0%, 10% and 20% of body weight (BW) and both loaded conditions differed from that of 0% BW. This is evidence of the influence external load carrying has on movement quality. Therefore, if movement quality is important to a cohort, greater insight into the exact effect of carrying load, and if these can be mitigated should be investigated. Military recruits are expected to carry loads of ~16kg during Phase-1 and 2 training. Although there is varied anthropomorphic data available for military recruits, Gibbs *et al.* (2014) showed that this load would represent ~ 23% of BW for participants in their study. This exceeds that of either previously highlighted paper. Thus, it is likely that while exposed to the loads typically used in military recruit training, the movement quality of the recruits will present with different kinematics.

Every time a person carries a load, their functional mass increases. This impacts their ground reaction force, centre of mass (CoM) (Devroey et al., 2007) and the force required to maintain an upright position on any joints and skeletal framing below the carried object. The ground reaction force experienced during carrying, and muscular force required to carry said object, is in direct proportion to the mass of the load being carried (Birrell *et al.*, 2007). There are multiple factors that affect the effectiveness of carrying, such as the mass, distribution, time under load and the method of carrying (Knapik *et al.*, 2004). There are various ways in which to assess the effectiveness of carrying, such as energy expenditure per minute, muscle activation, performance outputs such as speed of carry and movement kinematics and kinetics. However, as this next section will explain, there has yet to be a clear mechanism of injury established, or a definitive answer to the sex-based injury rate difference.

A person's posture adapts in direct response to specifics of the load carrying being undertaken. For example, if a weight is supported on the shoulders, and held behind the person, the CoM of the total person and load has now moved backwards (Birrell *et al.*, 2007). Consequently, the back, hip and lower-limbs are all contributing to the increased support required and will likely show kinematic changes to maintain the CoM over the base of support. During 7-mins standing trials, Devroey et al. (2007) demonstrated that compensatory strategies are used to adapt to the added weight in conditions above 10% of body weight. Devroey et al. (2007) did not offer a reason for such a difference in adaptation strategy, but noted that this would have an impact on specific cohorts that are required to walk or stand for long periods of time with load. Devroey et al. (2007) also found that EMG and discomfort scores increased with load.

Birrell and Haslam (2009) also assessed discomfort but specific to skeletal discomfort, rather than soft tissue. They used 1-hour marching trial, which was therefore 53-mins longer than that used by Devroey et al. (2007), while exposed to an external load of a 24kg backpack. The trials were used to assess the effect of prolonged exposure to load carrying, and to examine if a difference between sexes would present itself in such a trial. Discomfort was scored on a five point scale (1=comfortable, 5=extreme discomfort) across the lower back, hip, knee, ankle, foot and body. Their results indicate that females reported a significantly higher mean perceived skeletal pain and discomfort overall and for each specific body segment, including the hip (Table 3-3). This is particularly relevant as hip stress fracture, or neck of femur fractures, are three times higher in female military cohorts (Ministry of Defence, 2016). Birrell and Haslam (2009) did not collect injury data, nor did they assess the impact of load carrying on movement quality. However, findings from their study seem to suggest that the skeletal structure of females in their study were under a greater amount of stress which; mirrors injury rate data and perhaps suggests a link between load carrying during marching, skeletal discomfort and hip injury rates. Moreover, it suggests that marching with load may be a movement or exercise that is likely to show sex based differences in outcomes.

Table 3-3: discomfort data from Birrell and Haslam (2009).

	Male	**Female**
Body section	**Mean ± SD**	**Mean ± SD**
Lower back	1.64 ± 0.83	1.93 ± 1
Hip	1.4 ± 0.81	1.66 ± 0.81
Knee	1.5 ± 0.76	1.79 ± 1.08
Ankle	1.64 ± 1.01	1.66 ± 0.86
Foot	1.86 ± 1.1	2.45 ± 1.35
Body	1.57 ± 0.88	1.8 ± 1.01
Average	**1.60 ± 0.90**	**1.88 ± 1.02**
Sum	**9.61 ± 5.39**	**11.29 ± 6.11**

3.4.1 Gait

A person's posture and movement are adapted to compensate for an external load during static and gait trials. Polcyn *et al.* (2001) state that this is likely to aid in maintaining stability and to absorb the increased forces associated with increased external load during movement. Therefore, these changes may be necessary to maintain balance, rather than injury inducing. This suggests that it may be preferable in the given circumstance. However, they may also deviate from movements that are best suited at the joints at which the movement occurs. Therefore, a movement that aids in the performance output, in this case, the movement of an external load over a given time or distance, may be in contrast to that which is best for the joints and bodily structures involved in the activity.

Polcyn *et al.* (2001), Birrell and Haslam (2009) and Majumdar *et al.* (2010) all reported that greater load was associated with greater stride length, frequency and double support time. Polcyn *et al.* (2001) elaborates that load and stride frequency were negatively correlated (r = -0.14) when velocity of the gait was maintained. This also resulted in a load to stride length relationship where stride length increased with load. Moreover, double support phase positively correlated (r = +0.37) with load. Thus increasing the distance between each foot during double support, and reducing the amount of time between double support phases. This may be an attempt to increase the base of support and therefore stability during gait movements and the double support phase. This interaction with load would suggest that the participants are attempting to accommodate for the additional load by adopting a more stable gait style.

To understand the fundamental changes in movement brought about by load carrying, kinematic and kinetic data must be assessed. Polcyn *et al.* (2001); Birrell and Haslam (2009) and Rice *et al.* (2017) all state that increased load during gait trials was associated with an increased knee flexion during ground contact and a greater ground contact time. However, Polcyn *et al.* (2001) elaborates by stating that there was a significant (p,0.01) correlation between load and the joint angle at heel contact for the ankle (r=0.13), knee (r = -0.09), hip (r=-0.52) and trunk (r=+0.82). This would not only increase the amount of stability and double support time but would reduce the impulse of force on the associated joints. Moreover, Rice *et al.* (2017) states that their participants were able to maintain similar kinematics during pre and post marching testing while unloaded, but were not able to do so throughout marching where they were loaded. This suggests that the load conditions had greater influence on movement changes than time under load or fatigue (Rice *et al.*, 2017).

As previously stated, findings from Birrell and Haslam (2009) show that males and females demonstrate significantly different self-reported discomfort at the hip joint post loaded marching. They showed that the highest level of discomfort was measured at the foot (1.99±1.19) for both sexes. This was followed by the ankle (1.65±0.98), knee (1.57±0.85) and then hip (1.46±0.81). This seems to suggest a distal to proximal relationship with discomfort, with the most protected joints situated further along the kinetics chain. However, Rice *et al.* (2017) shows a greater ground contact time and knee flexion. Therefore, this protective mechanism may not be evenly distributed between the lower-limb joints. During a heel to toe walking action the ankle is only able to distribute a small amount of the total force typically experienced in such an action. The ankle's primary movement are classed as plantar and dorsi-flexion. However, the subtalar joint allows some degree of eversion and inversion that contribute to force distribution. The remaining force travels more proximally where this must be distributed by another joint. The first joint that is capable of articulating and accommodating this remaining load is the knee. This may have to present as exaggerated movement with an increased load and may be linked to levels of discomfort.

As the changes to kinematics are to reduce load and potential for injury, the movement adaptations are also likely due to the change in Centre of Mass (CoM). Most external mass increases are achieved by wearing a rear loaded backpack, however, as Loverro *et al.* (2019) state, this is becoming less pronounced in military service with the implementation of front loaded load in the form of weapons and webbing. Therefore, the removal of asymmetrical load (anterior / posterior) may result in fewer movement adaptations. Loverro *et al.* (2019) stated that with a symmetrically loaded vest, movement adaptations in both frontal and sagittal planes were still present. They also showed that males and females differed in their accommodation techniques for the increased load. In order to ensure that this difference was not due to body weight differences, which were significantly different between the two sex-based groups, body weight was used as a covariate and movement was normalised to both body weight and total weight. The results showed that knee abduction was greater in the heaviest load condition and that this was significantly greater for females. Therefore, this suggests that movement adaptation, although somewhat influenced by CoM changes, is highly susceptible to load variation. Additionally, this demonstrates that sex is an influencing factor in movement adaptations strategy.

3.4.2 Functional military movements

During military training and deployment, military personnel are expected to be able to perform all tasks associated with combat with additional load. Therefore, a person may also adopt adaptive mechanisms to adjust for the additional load during these more functional movements as well. Phillips *et al.* (2015) performed an analysis of the impact of a symmetrically distributed 10kg load on the ability to perform basic tasks such as a toe-touch movement and a basic squat. Participants were asked to perform 45mins of treadmill walking at 6kph in between pre and post-movement quality assessments. They found that those who wore the weighted vest took 18% longer to perform the toe-touch and a squat movement. No kinematic differences occurred but the movement quality tests were performed without the additional load. Therefore, all changes observed were most likely due to fatigue rather than the additional load. A further study by Phillips *et al.* (2016), which seems to employ the same 45min walking tasks in between unloaded movement analysis sought to assess the kinematic changes to drop landing, and prone to standing tasks. As previously stated, these movement were again not performed with any additional load and therefore the study seems to be assessing fatigued movements rather than loaded movement. Similarly to the previous study, only the speed at which the tasks were performed changed between the load groups, with those in the loaded gait trails showing a 7% increase in time to achieve the set movement parameters, such as “total foot strike” and “impact to maximum knee flexion”. Both studies demonstrated that loaded marching increases the time it takes to perform “marching gait” and “prone to stand” movement while unloaded.

However, it is more likely that these changes were a result of fatigue brought on by load carrying that the load itself.

Although squatting is a movement conducted by military personnel, this is typically a controlled and slow, closed chain movement. However, the fundamentals of the movement are relevant to other movements, such as drop landing tasks (Earl *et al.*, 2007). The key difference in the two movements is that landing typically results in a greater amount of force required to counteract the downward trajectory of the body's centre of mass. Military personnel, such as paratroopers must perform this movement during parachute landings, while others may be required to drop from heights or jump over obstacles. In each case, in order to reduce the risk of injury in either movement, the participant would be recommended to adopt a double leg landing (Wang, 2011). This would double the amount of musculature and joints used to absorb the landing force and disperse the load. Sell *et al.* (2010) state that although previous studies had suggested that 33% of body weight is enough to adapt movement during gait, a smaller amount of additional weight may result in movement modifications in more dynamic and explosive movements such as a drop landing. Participants with the Sell *et al.* (2010) study performed a two-footed landing tasks from a 50cm platform with and without body armour based on the participant's height. Average additional load was 15±3.7kg and was symmetrically loaded. Their results concluded that max knee angles, time to maximal knee angles, maximal ground reaction force and time to maximal ground reaction force were significantly greater in the body armour condition. These results mirror those of Polcyn *et al.* (2001); Birrell and Haslam (2009) and Rice *et al.* (2017) and suggest that the squat movement and drop landing tasks demonstrate similar adaptations to additional load. However, Sell *et al.* (2010) only used loads of 15kg during the drop jumps landings, whereas the other studies mentioned used loads much greater (12-50kg, 32kg and 35 kg). Therefore, it is likely that the dynamic nature of the landing task reduces the amount of external load required to generate significant kinematic and kinetic differences.

All the previously mentioned studies explained that knee angle, time to knee angle and time to peak ground reaction increased. As, if the maximum angle achieved had increased, it would likely have required a greater amount of time to achieve this increased angle. However, Sell *et al.* (2010) did not assess this link between these variables. Therefore, the current study used the average data given by

Sell *et al.* (2010) to assess the degree of movement per millisecond to achieve the max angle. The data showed that those in the body armour condition moved through the knee flexion 12% faster than those in the non-body armour condition. Moreover, the same assessment was conducted on GRF and found that the body armour condition was 2% faster to max GRF. As the only data available were mean data, the current study cannot assess statistical relevance of these new data. In order to fully explore if these data demonstrated a statistically relevant difference, the total dataset would be required as the range of the data, outliers, and the difference between mean and mode would influence the likelihood of returning a significant difference. However, it would suggest that there is a greater likelihood of the time to peak knee flexion being influenced by the load condition.

It is clear that load affects movement kinematics in movements such as gait as well as double leg landing. However, less evidence is available for more fundamental and functional movements that have been shown to be linked to injury likelihood. Ugalde *et al.* (2015) explains the link between single leg squats and injuries. While, Shirey *et al.* (2012) demonstrates the evidence that indicates that lower-limb muscle activation intervention could improve movement quality and reduce injury. Although a single leg squat has the same outcome parameters as the double leg squat, achieving these is more complex and therefore more difficult while adopting a single leg stance. As such, it would seem relevant to examine these movements under load to assess if this load increase changes kinematics and if these movement adaptations are linked to percentage of body weight or absolute load.

3.5 **Summary**

Movements are subject to gradation in terms of performance, but there is now evidence to suggest that movement quality can also be graded (Botha et al., 2014). There is also evidence that movement quality is not static and can be influenced by external factors (Majumdar et al., 2010). However, it is not clear if these changes are subject to influence from a person's sex and if this modification would have an influence on injury likelihood. Kiesel *et al.* (2011) suggests that movement quality interacts with sporting performance and injury. However, more recent and robust studies have found contradictory evidence suggesting that the screen used to quantify movement quality (FMS) is not able to predict either and that the predictive ability shown is nothing more than chance (Dorrel et al., 2015). Moreover, the FMS shows an inability to identify the location or severity of the predicted injury (Bushman et al., 2016). Consequently, any predictions made on the evidence of the FMS would likely result in falsehoods, and interventions developed from FMS output would likely be ineffective. Moreover, the FMS is unable to accurately identify the likelihood of injury for females (Gibbs *et al.*, 2014). As females are at greater risk of injury in cohorts that undertake similar physical activities, being able to accurately assess movement quality, from which to potentially accurately predict injury rates is very important.

An important role of a movement screen is to inform intervention creation, rehabilitation programmes and to analyse the effectiveness of interventions. Therefore, having movement screens based on, and screening for, common injury inducing movements would likely result in more effective interventions and accurate analysis of interventions. As the FMS, was not intended nor designed to predict injury risk, it would be naive to think that this set of seven tests would be able to do so with no alterations. Moreover, the FMS was never developed to inform injury prevention programmes. Which again would suggest some level of naivety in believing that it would be able to do so with no modification. Based on the evidence provided in previous sections of this chapter, this research programme suggests that research practices should change and move away from the FMS and attempt to create and design a new, specific movement screen that is able to better inform injury prevention interventions.

In military cohorts, bipedal locomotion, in the form of walking, marching and running, is common practice to improve physical fitness and during drills. As such, movement screens that assess movement quality during such movements would prove appropriate. However, as such a mixed-sex cohort has yet to be assessed for movement quality, there may be variations in the individual contributions of each movement within any given movement screen that would result in a subset of movements being the most appropriate movement from which to use in future mixed-sex military cohorts.

The FIFA 11+ has shown that adherence to a specific lower limb warm-up can improve movement quality in female cohorts while also showing an ability to reduce injuries of female and male football players separately. Additionally, there seems to be reasonable evidence of a dose response. As women in military Phase-1 and Phase-2 training have been shown to be disproportionately affected by injury, an intervention that has been shown to work for similar populations should be investigated and researched in military cohorts. However, any intervention adopted by the military must also demonstrate a positive effect on male recruits. As the FIFA11+ has shown injury reduction in both male and females, it is likely that the same intervention given in a mixed cohort would also demonstrate such a response. However, as male cohorts have not demonstrated movement quality improvement, questions remain over the appropriateness of the FIFA11+ to be employed within mixed sex cohorts.

3.6 Aims

The principal aim of the present research programme was to gain an understanding of the movement quality of military recruits, with specific emphasis on female recruits.

Objectives

1. To examine the ability of the FMS to significantly contribute to an injury prediction model with, either the total score or the individual movements within the FMS.
2. To examine if movement screens can identify significantly different skeletal kinematic data.
3. To better understand the influence load has on movement quality
4. To better understand the influence a person’s sex has on movement quality.
5. To assess if males and females present with significantly different movement quality prior to military training.
6. To assess if males and females present with significantly different movement quality after military training.
7. To assess if a pre-exercise neuromuscular intervention can influence movement quality

Chapter 4: Assessing injury risk prediction of Royal Navy recruits: A retrospective evaluation of the Functional Movement Screen (FMS)

4.1 Introduction

The UK military has a high incidence of musculoskeletal injuries (MSKI) in young (aged 16–21 years) military trainees (Kaufman et al., 2000; Gemmell, 2002; Blacker et al., 2008). These injuries account for a high number of working days lost during initial training, and significantly contributes to training attrition (Almeida et al., 1999; Gemmell, 2002; Blacker et al., 2008). This high rate of injuries brings with it a great financial burden for the military, but also a great quality of life burden on those likely to suffer an injury. Although many of the injuries suffered will not result in further complications after rehabilitation, some of those will suffer an injury that will change future everyday life for that individual. Injuries such as stress fractures, hard tissue breaks, cartilage and ligament damage are all documented as injuries sustained during military training for Phase-1 and 2 recruits which have lasting consequences. However, Anderson *et al.* (2011) claim that serious ligamentous or capsular injury will increase the risk of osteoarthritis (OA) to ten times that of a previously uninjured person; whereas, articular fractures increase a person's risk of OA by twice this. Therefore, reducing the likelihood of any injury during military training will likely result in fewer acute or chronic injuries.

During initial training, 25% of male and 55% of female recruits require medical attention for MSKI (Sarah *et al.*, 2017). This demonstrates that a greater proportion of females are injured. However, this results in a lower total number of injuries sustained by females as they only represent 12% of military populations. The current population split is likely to change as legislation was removed in 2014 to allow females to serve in ground close combat roles for the first time in UK military history. Therefore, the military can expect a greater number of female recruits and with it, a greater number of females seeking military employment. As there is no clear single variable attributed to an increased in injury likelihood in females, any increase in the percentage of a military population represented by females would result in an increase in the number of injuries seen in such cohorts. Being able to identify those at greater risk of injury accurately will reduce the financial cost of rehabilitation and time out of work for the military, while also reducing the risk for those most likely to sustain an injury as well as improve the quality of life for those individuals.

Movement dysfunction, measured by the FMS, has been shown to generate accurate predictive models and identify those at greater risk of injury within military and active working populations (Sarah *et al.*, 2017). However, Whittaker *et al.* (2017) state that there is inconsistent evidence that lower levels of movement quality, as measured by the FMS, is associated with an increased likelihood of sustaining lower-limb injuries in physically active populations. Furthermore, Dorrel *et al.* (2015) state that the FMS is inappropriate as an injury identification tool as it is more specific (85.7%) than it is sensitive (24.7%). Such identification properties would result in a high number of those unlikely to sustain an injury being correctly identified, but a lower number of those likely to sustain injuries being correctly identified. Moreover, the study also demonstrated that area under the curve was 0.58, which reveals the predictive ability of the FMS to be little more than chance. Rusling *et al.* (2015) claim that this lack of predictive ability may be due to the propensity for certain injuries in specific sports and/or professions and the comprehensive and broad movement screens employing non-injury specific movements. For example, in the military, over 70% of all injuries are of the pelvis or lower-limb. Therefore, screening movements specifically used to identify dysfunctional movements in the upper-body will be less useful. This could therefore dilute the total score system employed by such movement screens. Rusling et al. (2015) suggest adopting specific movements for specific populations and cohorts based on typical or historical injury types. While exploring the implications of such assessments they found that with a cohort of adolescent male football players that only deep squat and core press-up significantly contributed to the injury prediction model. As such, the introduction of the other five movements within the FMS would have rendered the FMS total score less efficient and potentially less accurate.

4.2 Aims and Hypotheses:

4.2.1 Aims

1. To investigate the predictive validity of the FMS with respect to injury risk in Royal Navy (RN) recruits.
2. To examine the ability of the FMS to predict time, type and onset of injury.
3. To further investigate the mechanisms of prediction by analysing the individual components of the FMS and their contributions to the injury prediction model.
4. To investigate the correlation between a single point difference in score and injury likelihood.
5. To investigate the link between asymmetrical movement and injury.

4.2.2 Hypothesis

H_1- The study expects to concur with previous research and show that the FMS is capable of predicting injury likelihood.

H_0- The FMS will not accurately predict injury likelihood.

H_2- The individual movements more associated with lower-limb movement will give a significantly greater contribution to the predictive model than upper-limb movements.

H_0- No individual movement will contribute significantly differently to another.

H_3- The study expects to show that FMS score can predict injury onset, time and type.

H_0- The FMS score will not accurately predict injury onset, time or type.

H_4- The study expects to show that FMS asymmetrical score will influence injury prediction models.

H_0- FMS asymmetrical score will not influence injury prediction models.

4.3 **Methodology**

4.3.1 Study design

Primary data, previously collected and analysed by Gibbs *et al.* (2014), was subjected to secondary data analysis. The current study intended to subject the data to more detailed analysis to provide a greater understanding of the mechanisms that significantly correlate movement quality, as defined by the FMS, and injury in Royal Navy recruits.

4.3.2 Ethics

Approval for the evaluation of the predictive validity of the Functional Movement Screen (FMS) for identifying injury risk in Royal Navy recruits was submitted via an amendment of the original application to the Ministry of Defence Research Ethics Committee (Ref: 217/Gen/11) in September 2011. The amendment request was submitted that pertained to an additional researcher and the retrospective use of data. Specifically, a request was made that an anonymous version of the data set collated under the previous protocol could be subjected to further analysis as part of the MOD/academia collaborative research programme, and that these secondary analyses would be reported in a doctoral thesis. The amendment was approved in September 2015.

4.3.3 Participants

A cohort of 957 Royal Navy (RN) recruits (male, n=862, 90%; and female, n=95, 10%) volunteered to participate in the study. All participants were recruited from the training population at HMS Raleigh, Torpoint, United Kingdom.

4.3.4 Protocol

Participants completed the FMS prior to undertaking Phase-1 training. The FMS was administered by five accredited FMS raters and comprises the individual exercise tests of: deep squat with overhead handhold; in-line lunge; forward hurdle step-over; press-up; shoulder mobility; active straight leg raise while supine; and rotator stability while prone on all fours; for greater detail, refer to section 3.2.2. Each of the 7 movements were completed three times, and 6 of those movements were scored per side to identify dominant vs non-dominant differences. Movements were scored on a scale from 0 representing “pain during movement” to 3 representing “perfect movement”, depending on how well the participants performed the movement against the predetermined criteria. Hand and foot dominance was also recorded on the FMS scoring sheet. Study participants also completed a health history questionnaire, smoking and alcohol histories questionnaire, as well as information describing general levels of exercise undertaken during the previous year.

Data describing the occurrence of injuries were recorded prospectively during training. Recruits participating in the study, who reported to the Medical Centre, had the ‘Week of Training’ (Time) and the details of their injury coded on the Defence Medical Information Capability Programme (DMICP) system by the reviewing doctor, nurse or medical assistant. Injury was defined as a musculoskeletal condition causing the recruit to lose two or more days of physical training; acute injuries were those conditions sustained from a traumatic event, and overuse injuries were those conditions with an insidious onset.

Data were also collated from the RN physical fitness assessments undertaken in week 1 and week 7 of training. These assessments comprised the Multi-Stage Fitness Test (MSFT) as an estimate of maximum oxygen uptake (VO2max), a press ups test, a sit up test and an anaerobic shuttle running test.

4.3.5 Data Input Transfer for Secondary Analysis

The data in the current study were originally collected and used by Gibbs *et al.* (2014) to study the ability of the FMS total score to predict injuries in Royal Navy recruits. However, the current study aimed to investigate aspects other than total score. Therefore, a secondary analysis of the original data was permitted. To gain access to these data, the principal researcher travelled to the Institute of Naval Medicine (INM). The data were not permitted to leave the military base in its existing form and therefore had to be transferred to a digital copy. Paper copy of the original scoring sheets were stored at the INM and made available for replication and storage at the University of Southampton (UoS). Replication was only possible through manual transfer from paper copy to digital data, which was completed by the principal researcher and overseen by military personnel. Data transfer was completed within a single day, after which time, a duplicate copy was created on CD and stored in a locked storage compartment at the University of Southampton.

4.3.6 Quality assurance of Data Input and Transfer

Manual transfer of data increases the risk of errors and omissions, therefore, measures were established to increase accuracy and highlight errors during input. The original data were handwritten on data sheets and therefore, reading and understanding the writing may have increased error. To ensure this had as little impact as possible, if the principal researcher was unsure of the recruit number, those observing the data transfer were asked to clarify. Additionally, those data sheets under question were put to one side until data transfer had been completed, to check against those the principal researcher was certain about. This left very few recruit numbers left from which to identify the missing or unclear recruit numbers. Therefore, if a recruit number was written in a way that could be interpreted as multiple different numbers, some of these potential recruit numbers could be ruled out because they had already been allocated to a participant. This would then result in fewer numbers from which to distinguish between as a group.

As the FMS includes 7 movements, one can expect to have recorded 7 scores. However, 6 of the movements in the FMS are performed and scores bilaterally. This then gives 6 left scores, 6 right scores and 7 total movement scores, which totals to 19 individual movement scores and a total screen score. This imposed two potential errors: one stems from the potential for the movements completed on left and right being scored independently and therefore may present with different levels of movement quality and therefore different scores. This is not an issue for accuracy of data transfer, but may have resulted in an incorrect total score initially. To calculate the FMS total score, one must use the lowest, or worst of the bilateral scores to generate the total screen score. The purpose of a movement screen is to observe and highlight movement dysfunction, even when this is only observed in a single limb. The FMS could average the bilateral scores, however, this would not represent the actual movement quality for the given movement, and fractional scores would be generated. As the FMS is not structured as to allow such scores, this would seem more problematic. Therefore, if a person demonstrates perfect movement on their right shoulder range of motion test, but pain on the left, the correct score to give for the combined score is '0' as this score denotes pain during movement. In the case of the retrospective data analysis, it was unclear if the higher or lower score was used to calculate the final total score. Also, if a rule had been applied, such as the lowest bilateral score should be used to generate the total FMS score, it was unclear if this had been used for every participant's data. Therefore, the newly created data sheet had the FMS proposed rule embedded, which was the lowest score counts towards the total score. This allowed for correct data to be present for further analysis, but also to identify errors in the previously generated data which allowed for error correction and subsequent analysis to be performed on more accurate data (Table 4-1 or Figure 4-1).

Table 4-1: Difference between original and calculated FMS scores.

Difference between original and calculated FMS score	**-3**	**-2**	**-1**	**0**	**1**	**2**	**3**	**4**
Number of participants with errors of the size indicated	2	15	10	897	11	2	0	1
Percentage	0.2	1.6	1.1	95.6	1.2	0.2	0	0.1
Total score (-27)	-6	-30	-10	0	11	4	0	4

A negative number shows that the original FMS score was lower than the new calculated FMS score.

A positive score shows that the new calculated FMS score was lower than the original FMS score.

The calculated FMS total highlighted a small number of participants whose FMS total score had been originally calculated incorrectly (n=41). However, this error was not systematic as 66% of the incorrect values underestimated total FMS score, while 34% overestimated FMS score. In total, the cumulative score of the errors was -27. This would have reduced the overall FMS mean value, however, mean data shows that the difference between the two FMS totals was 0.03 FMS scoring points. Therefore, although it is better to have progressed with more accurate data in any situation, the realistic effect of such an error reduction would likely be negligible.

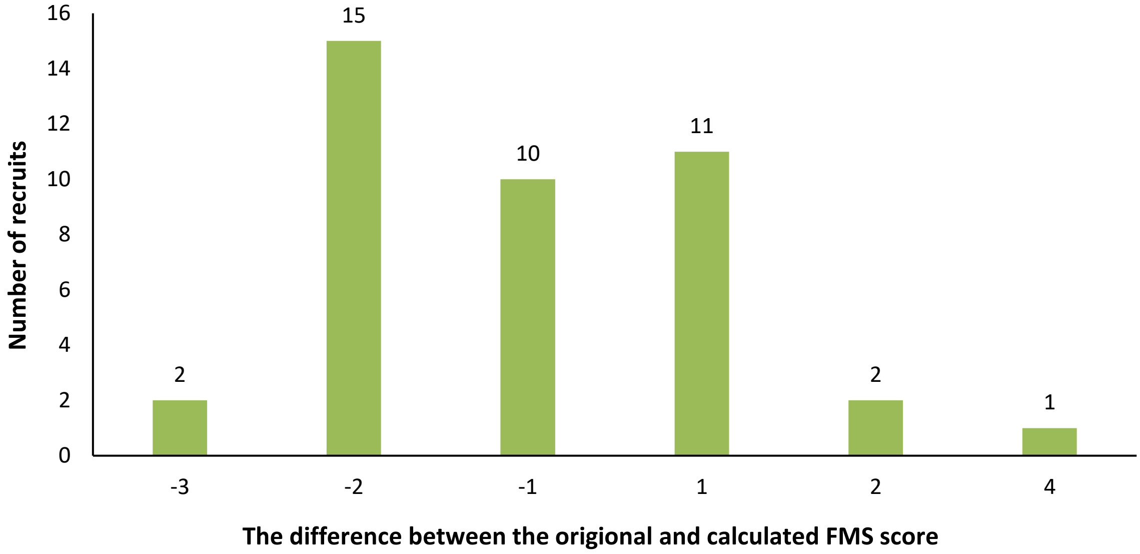


Figure 4-1: The difference between the original and calculated FMS scores

The second potential source of error was that the total score was calculated at the time of assessment and may have been calculated incorrectly. Therefore, another column was created to calculate the total score more accurately. To identify if an error had been made, the original screen total was subtracted from the calculated total. If anything other than '0' was presented, this would raise awareness of input error. If such a difference was seen, the original document was scrutinised to establish whether the error originated from the original document, misinterpretation of the original document, inaccurate data transfer from original document to digital form or from an error in the calculated total formula. During input and subsequent analysis, errors with the original data were discovered and therefore, the newly created calculated total was substituted in place of the original total.

To further ensure correct data transfer, a member of military research staff was tasked with transferring 10% (n=96) of the total data transfer in the same manner and with the same rules and data sheets as the principal researcher. This was conducted independently and post transfer comparisons were made to assess accuracy. Post transfer comparison shows 100% agreement and therefore indicates low probability of data mismanagement. Although this does not guarantee 100% accuracy throughout the total data set, it does show that the means of transfer were appropriate.

4.3.7 Specifics of the regression analysis

Regression analyses were used to establish the strength and direction of the relationship between the dependent (injury, injury onset type, injury type) and independent (FMS score, individual movement score, sex) variables. This would then allow the study to establish a hierarchy of relationships based on the gradation of contribution to the predictive model in terms of Alpha (p) and R^2 values. The collected data was a mix of continuous and categorical data; therefore, a variety of regression analyses were used, which are detailed in the following paragraphs.

In order to highlight the variables that significantly contributed to the regression model, the variables were removed in a systematic pattern. Firstly, all independent variables were entered into the model and the regression was completed. At this stage, the variable that presented with a non-significant contribution to the model was removed and the regression was completed again. If multiple variables presented with non-significant contributions, only the variable with the lower contribution was removed at this stage. Although it is likely that those variables that presented as non-significant at stage one would remain non-significant, regression models are influenced by the number of and level of contribution of other variables. Therefore, there was some possibility that after removing the lowest contributing variable, the remining variables would present with different regression model contribution. This process continued until only variables that significantly contributed to the regression model were remaining. The reason that this process was chosen was based on the changeability of regression output based on the number and type of independent variable. If the process were to have been completed the other way round and independent variables were to have been added until only those who generated significant contribution were present, the process would have taken longer, and would have been more likely to generate errors or inaccuracies. Not only would there have been a greater chance of statistical error, but bias of the person entering the data and variables could also have influenced the final output. Based on previous research, explained in section 4.1, lower limb movements are likely to generate a greater prediction contribution than upper limb movements. Although this has been shown in previous papers, if such a process would have been followed here, data that countered this point may have been influenced or changed to the point that they would not have been highlighted. For these reasons, a variable removal process was used instead of a variable addition method.

4.3.7.1 Relationship between total FMS score and injury occurrence during training

To re-establish the predictive ability of the FMS, injury was defined as either yes or no and a binary regression was completed. However, to establish a score cut-off, each potential FMS total score, from 0 – 21, were categorised separately and the binary regression was repeated.

4.3.7.2 Relationship between FMS and injury onset type

To establish the link between FMS total score and injury onset type, injury onset was categorised as non-injury (0), chronic onset (1) and acute onset (2). As the data were count data, Poisson regression (count regression) was completed with FMS score as independent variable and injury onset as dependent variable.

4.3.7.3 Relationship between individual FMS test scores and injury occurrence.

To establish individual contribution to FMS score predictive ability of injury, the individual movement scores were individually categorised and a binary regression was completed. FMS score represented the independent variable whereas the injury occurrence, defined as yes or no, acted as the dependent variable.

4.3.7.4 Relationship between Functional Movement Score and time in training

To establish links between time and injury, the 12 weeks of training were individually categorised and a binary regression was completed. FMS score represented the independent variable whereas the injury occurrence, defined as yes or no, acted as the dependent variable.

4.3.7.5 Possibility of a relationship between movement asymmetry and injury likelihood

To establish the association that asymmetry has on injury occurrence, the five FMS movements scored bilaterally had their left side score deducted from the right side score. This created a new data set of the differences between left and right side movement quality. As the analysis was not aimed at determining the direction of the difference, all differences were subjected to root mean square (RMS) calculations and all positive numbers were used within the statistical analysis. Analysis of asymmetry highlights that most recruits showed at least 1 point of difference between left and right. To assess links between asymmetrical movement and injury likelihood, asymmetrical scores were categorised and a binary regression was completed. Asymmetrical score represented the independent variable whereas the injury occurrence, defined as yes or no, acted as the dependent variable.

4.3.7.6 Relationship between Sex and injury

To establish the effect of sex on injury likelihood, Data were initially assessed for normality by measuring skewness and kurtosis, and descriptive statistics were determined. Median split transformations were used on continuous variables (Age, Height, Body Mass, FMS Score, 1.5mile run time) to create categorical variables. These categorical independent variables were cross-tabulated with Injury occurrence and any association analysed (Chi-Squared tests).

Variables shown to be significantly correlated with injury occurrence, identified from previous research, were further analysed by logistic regression (forward stepwise, conditional method) to evaluate relationships. Injury occurrence was defined as either 'yes' or 'no'; therefore, a binary regression was completed with FMS total score as the independent variable and injury as the dependent variable. Analyses were also undertaken to establish if there was a relationship between injury occurrence and a specific FMS score, or with those under/over a specific score. To do this, the

FMS score was set as separate categories and binary regression was repeated. Regression analyses of the relationships between injury type (i.e. chronic or acute) and FMS score were also completed.

All movements were then assessed for their individual contribution by categorised step-wise regression analysis against the independent variable, FMS total score. Additionally, aspects such as age, a person's sex, smoking and alcohol consumption were assessed as covariates. Further investigation into injury rates included assessing the relationship between time and injury by assessing total injuries per week by an independent variable, FMS score, again using regression analysis. Finally, five of the seven FMS movements are scored for both sides of the body to allow consideration of asymmetry. Using the FMS to establish asymmetrical movement differences, an examination between a calculated asymmetry score and injury likelihood was completed. Statistical significance was set a priori at $p<0.05$.

4.4 Results

4.4.1 Participants characteristics

957 RN recruits, split between male (n=862, 90%) and female (n=95, 10%) were recruited. Participants mean height, body mass and age were:[$\overline{x}$ (SD) male, 179 (0.7)m, 75 (10.9)kg, 22 (4)years; female, 1.66 (0.7)m, 64 (8.7)kg, 22 (4)years]. Of those who completed training, most recorded no injury at all (n=667). While those who were injured (n=265), most sustained lower-limb injuries (n=206) (Figure 4-2)

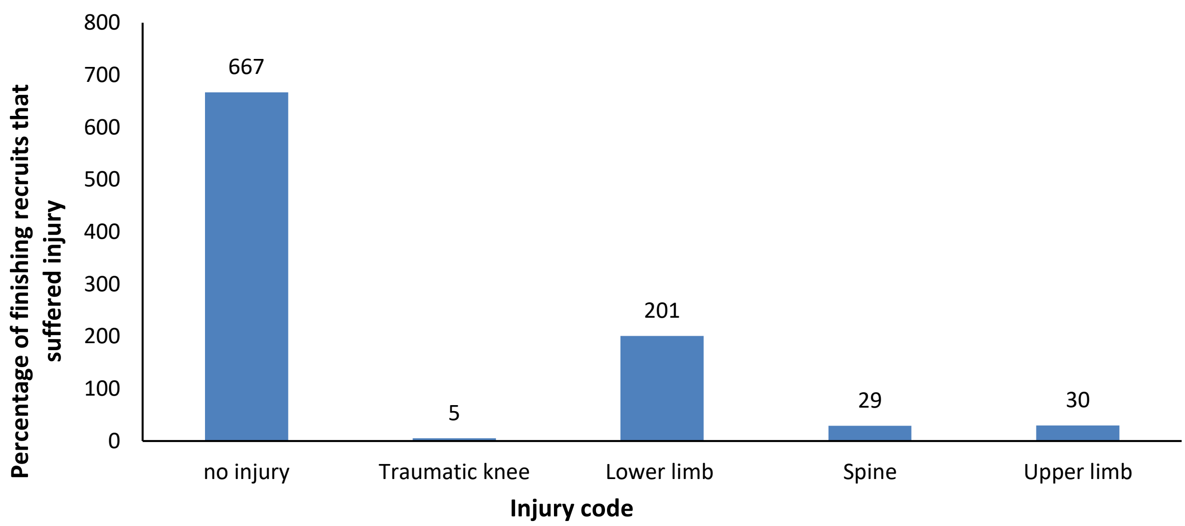


Figure 4-2: The distribution of injury type.

4.4.2 Relationship between total FMS score and injury occurrence during training

The results of the binary regression between FMS total score and injury occurrence concurs with the previous paper (Gibbs *et al.*, 2014) and shows a significant, (R^2 = 0.085) but very weak predictive ability of calculated FMS Total for injury (Y/N) (p≤0.000). Additionally, the categorised results show significant predictive ability ≤13 (p≤0.005), which suggests that a cut-off is more able to predict injury likelihood rather than a singular score (Figure 4-3).

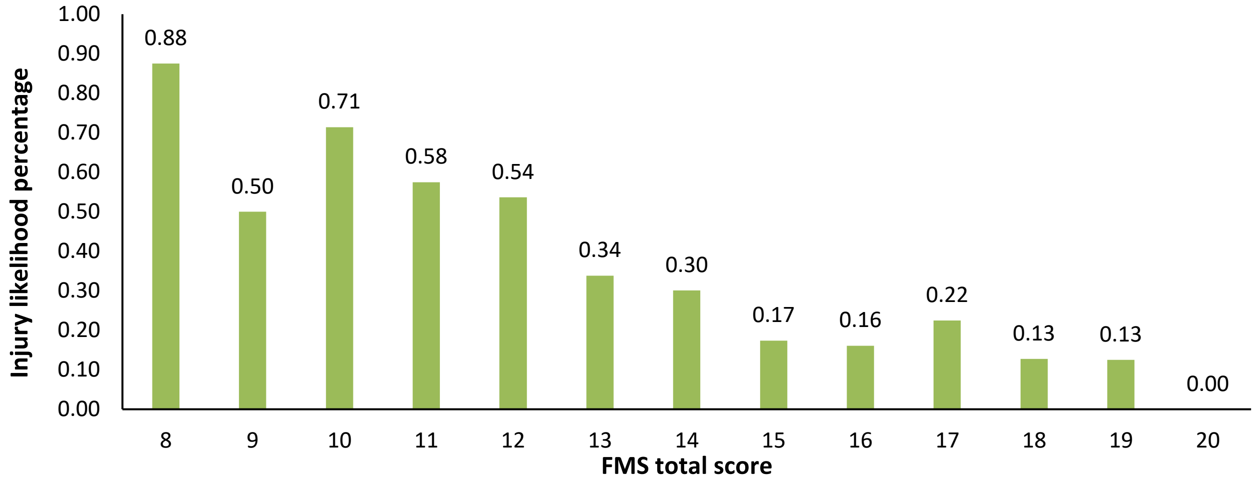


Figure 4-3: Average injury score categorised by FMS total score

4.4.3 Relationship between FMS and injury onset type

Poisson regression showed a positive relationship between FMS total score and reduction in chronic injury likelihood. However, only FMS totals between 13 and 19 gave a significant ($p=0.013$) reduction in risk of chronic injury (Figure 4-4). For every unit increase between 13 and 19, chronic injury likelihood reduced by a factor of 1.0 - 1.6 and demonstrated that those with lower FMS scores had a greater chance of sustaining a chronic injury ($p \leq 0.005$). FMS score had no significant effect on acute injury likelihood. This presented with a marked increase in the percentage of those completing military training with no injury (Figure 4-4).

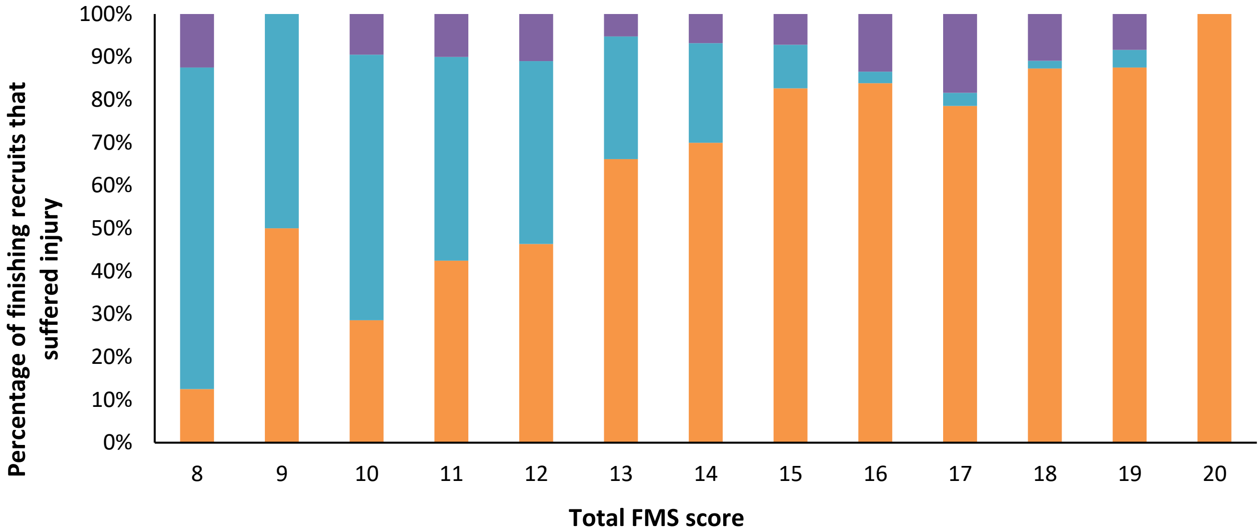


Figure 4-4: The percentage of acute and chronic injuries. (Orange = Finished with no injury, Purple = Finished with acute injury, Blue = Finished with chronic injury)

4.4.4 Relationship between individual FMS test scores and injury occurrence.

Assessment of the relationship of individual test scores to injury shows that of the seven FMS movements, only shoulder mobility and trunk stability showed significant ability to predict injury occurrence (Table 4-2). For every unit increase in movement score, the likelihood of injury decreases by a factor of 1.3 from the constant given during the regression. This then shows that better movement, as considered by the FMS guidelines, in these two movements can result in a reduction of injury likelihood.

Table 4-2: Regression coefficients from individual FMS movement that significantly contributed to the prediction of injury.

FMS movement	FMS Score	Coef (SD) =	P value	95% Confidence interval
Shoulder mobility:	2	-1.334 (0.589)	0.024	(-2.49 / -0.179)
	3	-1.963 (0.584)	0.001	(-3.107 / -0.82)
Trunk stability:	3	-1.424 (0.47)	0.002	(-2.334 / -0.504)

4.4.5 Relationship between Functional Movement Score and time in training

Results showed that for every unit increase in week total, risk of injury reduced for all FMS totals. However, only FMS scores of 13–19 show significant reduction in risk (Table 4-3). Additionally, regardless of FMS score, there was an increase of injury risk in week-4. When examining the time of peak injury occurrence, the highest rate of injury occurrence was in week-4 regardless of FMS score (Figure 4-6).

Table 4-3: Regression coefficients from calculated total (category) and week of training.

FM score	Coef (SD)	P value	95% Conf =
13	-0.892 (0.21)	≤0.005	-1.304 / -0.481
19	-2.054 (0.372)	≤0.005	-2.783 / -1.324

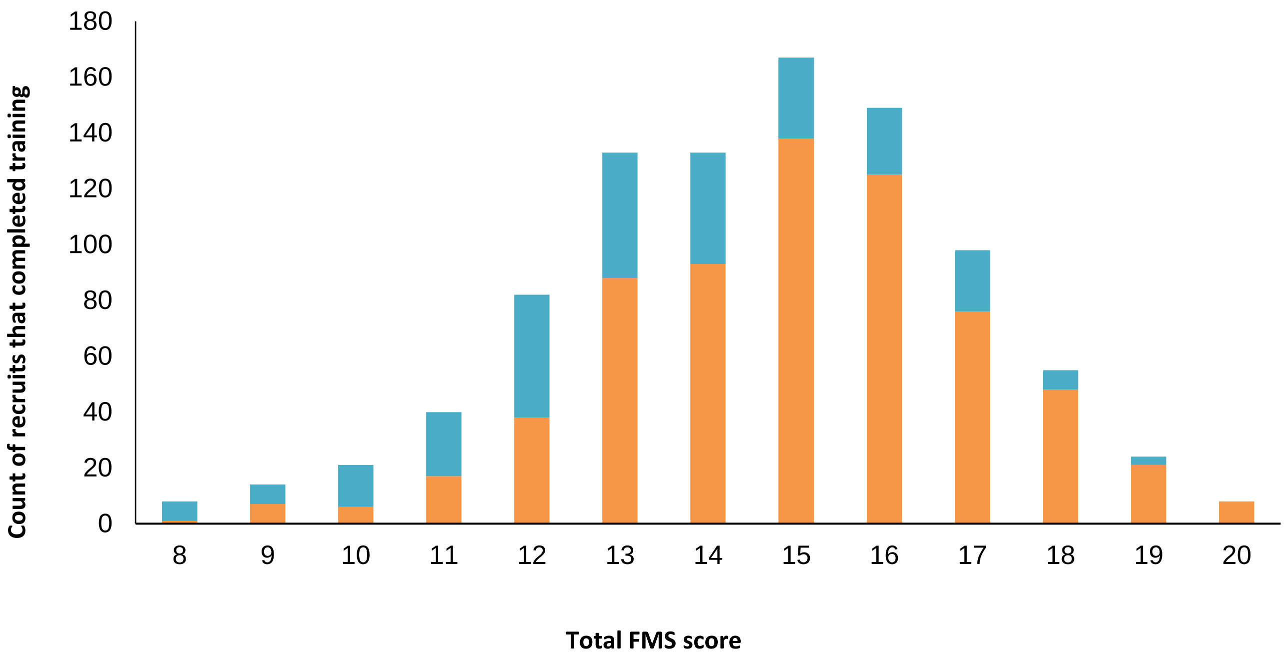


Figure 4-5: Total FMS score of injured (Blue) and non-injured (Orange) recruits that completed Phase 1 training.

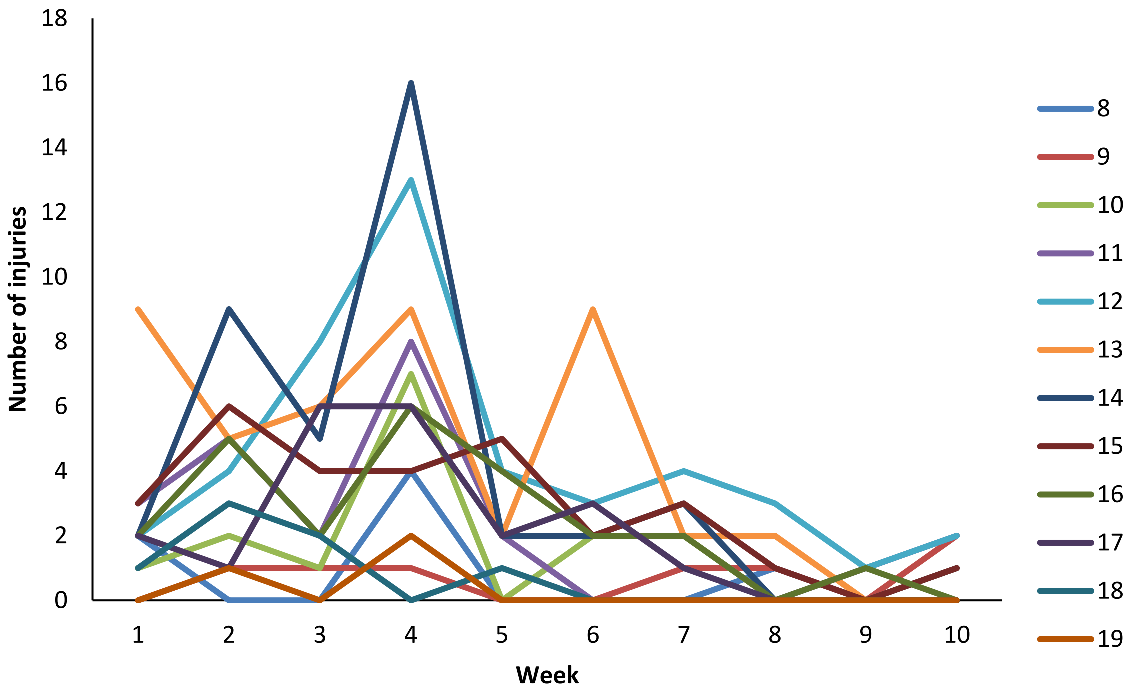


Figure 4-6: Injuries per week sorted by total FMS score.

4.4.6 Relationship between movement asymmetry and injury likelihood

Results showed that 61% of the recruits demonstrated at least one asymmetrical movement (Figure 4-7). Further analysis indicated that an increase of asymmetrical movement was linked to injury rates (Figure 4-8). Statistical analysis demonstrated that for every unit increase in movement asymmetry, injury likelihood increased by a factor of 0.4 (Coef (SD) =0.423 (0.08) P ≤0.0005, 95% Conf = 0.259 / 0.586). However, only 2.36% of the variation in the data was explained by this relationship.

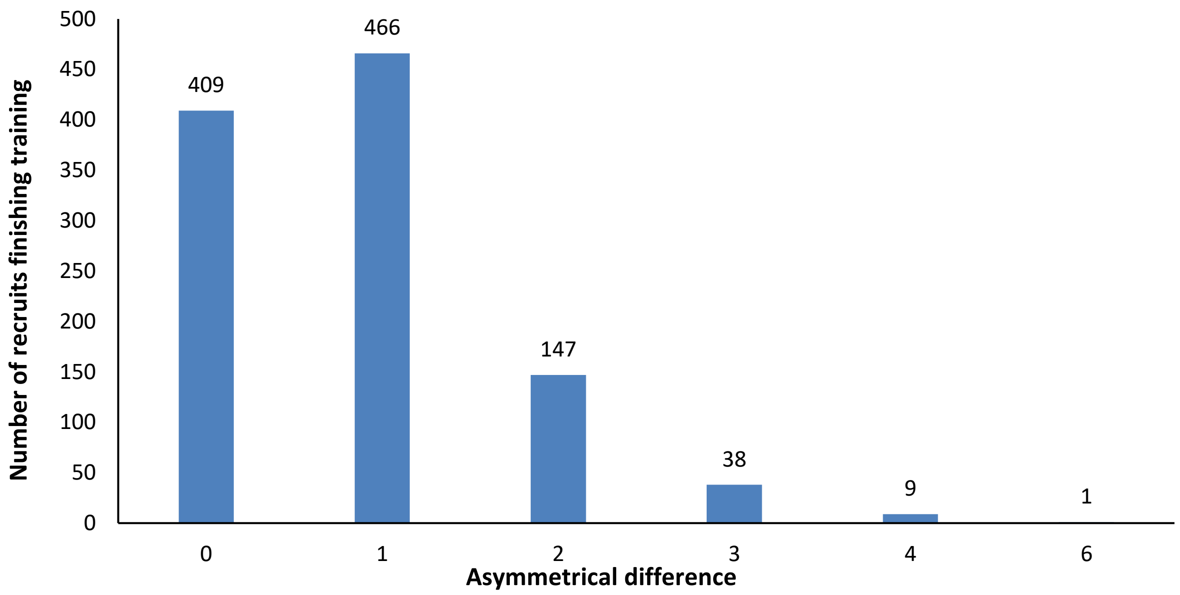


Figure 4-7: Total recruits by amount of movement ability differences shown between left and right.

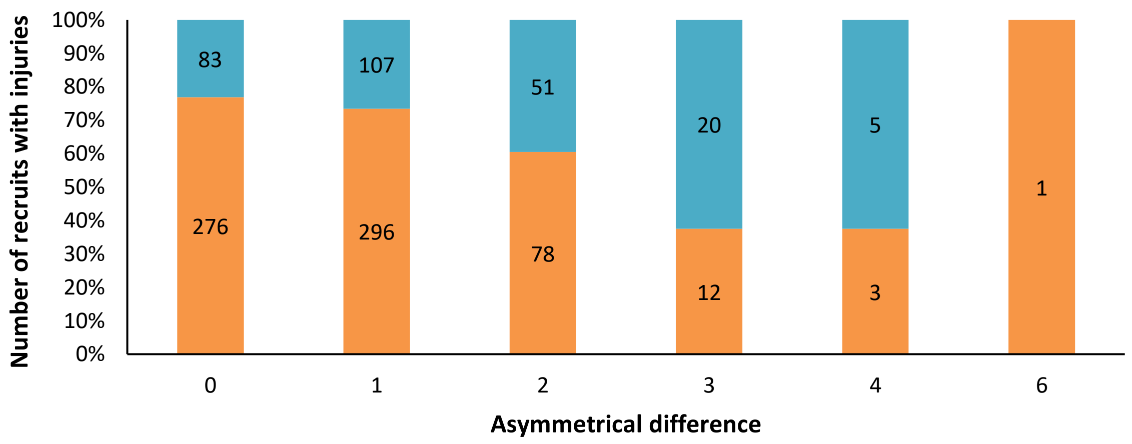


Figure 4-8: Percentage of injuries (Blue) according to asymmetrical differences.

4.4.7 Relationship between a person’s Sex and injury

When expressed as percentage of passing recruits, a greater proportion of females were injured compared to males (34% and 27%, respectively). Logistic regression analysis of injury outcome, including those variables significantly associated with injury, demonstrated that only FMS total score and a person’s sex significantly contributed to the prediction model ($p \leq 0.005$). The model explained 17% of the variance in injury outcome. The Odds Ratio (OR) values for sex and FMS score were 1.7 and 0.7 respectively. This indicated that the risk of injury increased by a factor of 1.7 for females, compared with males, and by 0.7 for each unit decrease in FMS (i.e. a 7 fold greater risk of injury for a score of 5 compared to 15).

Chi squared test show that Pearson chi^2 (1) = 4.99, Pr = 0.025

Equation 1: The final prediction model from variables extracted in the current study if coded with males=1 and females =2.

Probability of injury = 1 / [1+e – (4.1 + 0.535 Sex – 0.359 FMS score)]

Once the predictive model was established (Equation 1), the effectiveness of the classification to accurately assign recruits into the injured or non-injured categories was assessed (Table 4-4). The model only correctly classified 23% of injured recruits when the model was applied to the study cohort.

Table 4-4: Classification of injured and uninjured RN recruit participants using the derived logistic regression model (n=948)

	Predictive		
Observed	**Non-injured**	**Injured**	**Percentage correct**
Non-injured	655	26	96
Injured	206	61	23
		Overall percentage	76

4.5 **Discussion**

4.5.1 The FMS is not predictive of injury in RN recruits

It is clear from the present data that the lower the FMS total score, the more likelihood there is of injury, which confirms findings from Kiesel et al. (2007), O'Connor et al. (2011) and Gibbs et al. (2014). However, the ability of the regression model to accurately predict those who did sustain an injury was poor. This corroborated findings from Dorrel et al. (2015), in that the FMS demonstrated higher levels of specificity (96%) than it did sensitivity (23%) in military cohorts. Overall, there was a weak relationship between FMS and injury risk in Royal Nay (RN) recruits, where this relationship was unspecific and would not inform injury mitigation. Therefore the FMS seems limited in its ability to accurately predict individuals that are likely to sustain injury, confirming the conclusions from two systematic reviews (Moran *et al.*, 2017; Whittaker *et al.*, 2017).

4.5.2 Injury risk cut-off score

This current study initially identified that recruits with an FMS score of ≤13 or less were at a greater risk of injury. This is similar to Kiesel et al. (2007), O'Connor et al. (2011) and Lisman et al. (2013), who reported a threshold score of ≤14 to be predictive on injury likelihood. However, further inspection of the present results showed that the relationship was weak, with only 8.5% of the variance in injury risk being explained by the FMS score. Thus, in this military population, specific FMS scores demonstrated a small but significant ability to predict injury occurrence. As the present study found similar relationships between FMS score and injury likelihood to those in previous studies, it is likely that further examination of data in the previous studies would have found similar strengths of relationships if they had given the data further scrutiny.

4.5.3 Injury rate differs between males and females with the same FMS score

The current study demonstrated that females sustained a greater percentage of injuries compared to males (Table 4-5). Additionally, the study confirmed previous findings (Shaffer et al., 2006; Finestone et al., 2008; Anderson et al., 2015) that the sex of a group significantly contributes to the prediction of injury in RN recruits during phase-1 training, with females being 1.7-times more likely to sustain injury. However, the amount of variance in the data that was explained by the regression model was low (17%). After using the regression model to retrospectively predict those who would go on to sustain an injury resulted in only 23% accuracy.

Table 4-5: Pearson Chi^2 output for injury and Sex.

Injury	**Sex**		**Total**
	Female	**Male**	
Non-injured	58	609	667
	61.7%	72.7%	71.6%
Injured	36	229	265
	38.3	27.3%	28.43%
Total	94	838	932
	100%	100%	100%

The present study attempted to detect such a difference with the use of movement quality tests in the form of the FMS, however, there was no significant difference between the FMS score of males: 14.6 (2.3) and females; 14.4 (2.4). Consequently, this indicates that movement quality did not differ between sexes (p=0.000). As such, variables other than movement quality, as measured by the FMS, are likely to have influenced differences in injury occurrence between male and female RN recruits. Hence, the FMS demonstrates another limitation to its utility in injury likelihood detection within mixed sex cohorts.

One aspect of difference between male and female recruits within the current study was body mass. Males were on average, 11kg heavier than their female counterparts. This alone would not warrant further exploration, however Rice *et al.* (2012) has demonstrated that the percentage of body weight carried over time contributes significantly to injury prediction models. Therefore, further exploration of such variables in military cohorts may be valuable in explaining the sex based injury difference.

4.5.4 The relationship between lower FMS score and chronic injury

Although there was no significant relationship between FMS and injury location within the current study, FMS total score was linked to injury onset type with recruits with lower FMS scores being more likely to sustain chronic injuries. Initially it was thought that this relationship might be due to the increased numbers of injuries sustained by those achieving an FMS score of ≤13; however, when expressed as a percentage of total injuries the trend was still apparent. There were no significant differences in the percentage of acute injuries sustained by the recruits, regardless of total FMS score. This then suggests that for acute injuries, movement quality is not a predictive variable and that other factors are responsible for acute injuries. Moreover, the current study shows that the poorer a person's movement quality, as recorded by the FMS total score, the greater the likelihood of sustaining a chronic injury.

A major theme of this thesis, previously discussed in chapter 2.1, is kinesiopathology. This process explains that a person's bodily structures set the parameters of movement, in the form of limits and direction of movement. Moreover, any deviation from this would stress these structures in ways in which they are not specifically capable of dealing with. Over time, it is hypothesised that, under the right conditions, these structures will adapt to allow for the commonly undertaken stress. However, this same process may also lead to failure of the structure. In muscles we understand that stress and rest must be used to create adaptations in size and strength. Hard tissue may require the same process. Therefore, if the stress is applied too fast, or over a period of time allowing for less than sufficient rest, this may cause failure of the structure. This then may give an insight into why the FMS total score was able to predict chronic injury and not acute injury. If chronic injury is the result of continued and repetitive movement, it may be the result of performing these movements with less than optimal movement according to the person's bodily structures. Whereas, acute injuries are more likely the result of individual and one-time inaccurate movements.

4.5.5 Time in training and injury risk

Assessment of injuries over time demonstrated that with every passing week of Royal Navy training, the likelihood of injury reduces and fewer injuries are observed. This may represent that those in training are becoming more adapted to the physical requirement of Phase-1 training and therefore are more capable of undertaking the tasks set. However, another interpretation may be that those who are at greater risk of injury are injured and removed from training. Thus making the cohort less likely to be injured by way of omission. As the study only contained information about those who completed Phase-1 training, this is still unclear.

The single deviation from this downward trend was in week-4, within which, injury rate increased regardless of FMS score. While attempting to identify why this spike in injury occurrence was present during week-4, it was acknowledged that the first fitness test was conducted within this week. This, therefore, suggests that the physical exertion generated by this test was likely the predominant cause of the increase in injuries. However, injury identification and time of injury was set by weeks rather than day. Consequently, the study was not able to categorically demonstrate that the injury spike occurred before, during or after the examination. One explanation might be that the recruits were injured during the fitness test as they were pushed to their physical limits. Conversely, recruits may have sustained an injury prior to the examination which they did not report. Although it would seem counterintuitive to keep an injury secret from a training team during training, the recruits had a large incentive to pass week-4 with no injuries.

If a recruit were to be removed from training prior to week-4 examination, they would be returned to week-1 training post rehabilitation. This resulted in every recruit who sustained an injury prior to week-4 physical assessment having to repeat the initial 4 weeks of training. However, if a recruit were to successfully pass the week-4 examination and then sustain an injury, they would be removed for rehabilitation and be allowed to return to week-5 training. Initial training is extraordinarily tough, and one could argue, this is enough motive for a recruit to work through an injury until they successfully pass the week-4 examination. As the study did not record the day of injury reporting, nor is it possible to identify exactly where some injuries were sustained, it may suggest that injuries were reported after the examination, but were sustained prior. Therefore, this spike may not be as revealing as initially thought.

4.5.6 Asymmetry and injury risk

The FMS gives a single score for movement conducted bilaterally. However, movement asymmetry has also been suggested as a factor in injury prediction (Lisman et al., 2013). This variable can be extracted from the FMS, and in cases that previous research has done this, the results have shown that asymmetry is linked to an increased injury risk during a sporting season in junior male players (Chalmers *et al.*, 2017). Additionally, the study also identified a potential dose response. When the cohort were categorised into a dichotomous groups of no asymmetry, and asymmetrical movements ≥1 this gave a significant contribution to the prediction model. Moreover, when these categories were expanded to include no asymmetry, 1 asymmetry and ≥2 asymmetries, there was a greater contribution to the prediction model. The study continues, by also explaining that although asymmetrical movements were recorded using the FMS, the FMS total score did not significantly predict injury or contribute to the prediction model. Unfortunately, the study does not state how many of their 237 participants presented with ≥1 asymmetries, however, the current study identified that 61% of recruits presented with at least one asymmetry. Moreover, the current study concluded that a greater asymmetrical score was linked to a greater likelihood of injury, and therefore concurs with Chalmers *et al.* (2017). Further analysis demonstrated that asymmetry made significant contributions to the injury prediction regression model ($p \leq 0.000$). However, this contribution only accounted for a small amount of the variance in the model (2.36%). Chalmers *et al.* (2017) recruited participants around 16 year of age, and suggest that asymmetrical score may be more pertinent to younger sports players, and that the older a person gets, the less valuable this score will become. As such, it may be that those entering recruits Phase-1 and 2 training at 18 years old and above, are less affected by this asymmetry and may correspond to the small amount of the variance contribution in the model (2.36%). Therefore, although movement asymmetry as assessed by the FMS, may be useful in certain cohorts, it is unlikely to be an important predicting factor in determining injury risk in RN recruits.

4.5.7 Shoulder/trunk contributions to the regression model

Although the FMS total score was confirmed as having a significant contribution to the injury prediction model ($p \leq 0.000$) in sports and occupations that have high rates of specific injuries or injuries associated with a single segment of the body, the comprehensive approach taken by the FMS may render some movements redundant and leave the FMS total score less appropriate and/or accurate (Rusling *et al.*, 2015). Therefore, a better understanding of the individual contributions of the movements within the FMS may lead to greater predictive accuracy for certain populations. For example, 76% of injuries sustained by military personnel in the current study were lower-limb injuries (Figure 4-2). As stated in the introduction, Rusling et al. (2015) suggested that movement screens would be more appropriate if they adopted specific movements that are more relevant to the population, in either movements that replicate typical activities or informed by typical or historical injury data. Therefore, it would be likely to expect that FMS movements that are predominantly lower-limb specific, such as the deep squat and in-line lunge, would present with greater contributions to the injury prediction model. However, as explained below, this was not the case.

The current study shows that, of the seven movements in the FMS, shoulder mobility and trunk stability were the only movements to contribute significantly to the injury prediction model (Table 4-2). This was consistent with Rusling et al. (2015), who demonstrated that core stability significantly contributed to injury prediction models within a cohort of male football players. Moreover, a recent systematic review has stated that there is a clear association between core musculature and lower limb injuries (Emami *et al.*, 2018). However, the study stated that this relationship is based on the deconditioning and reduction in size of specific muscles, such as the Multifidus and quadratus lumborum, while also stating that this direction, or causality of the relationship has yet to be identified. The review, found no papers able to establish if the impaired muscle characteristics lead to increased lower-limb injury risk or vice versa. Although this suggests an interaction between core movement ability and lower-limb injury, the link between the high rates of lower limb injury sustained by those in the study, and shoulder movement quality seems less clear.

The test for shoulder mobility could be, and often is conducted while seated, showing a direct separation between lower-body movement quality and the shoulder mobility test. Additionally, the movement is very basic and involved practically no input from the lower body. One potential link might be that the shoulder joint could be representative of the full body movement quality due to the flexibility, coordination and joint structure of a ball and socket. However, if this were true, the same could be said for the hip joint. Therefore, a deep squat, which is also used within the FMS, would have also shown significant contributions to the injury prediction model. The deep squat involves a greater number of joints and muscles than the shoulder movement and does so under loaded conditions (Clifton et al., 2015). Therefore, the notion that the shoulder could represent total body movement control in a single movement would seem less likely than the deep squat being such a representative movement. Therefore, the underlying mechanism responsible for there being a significant relationship between shoulder mobility and injury likelihood in RN recruits is yet unclear. Moreover, the individual movements contributed to the injury prediction model was small (10.5% of the variance in the data). This suggests that the ability for two FMS movements to accurately detect injury likelihood is limited and potentially inappropriate in military Phase-1 recruit cohorts.

4.6 **Limitations of the study**

The current study demonstrated a limitation in the interpretation of the time of injury. As the current study purely recorded the week that the injury was reported to medical staff, it is unclear when the original onset of the injury actually occurred. This is less than optimal for a number of reasons; firstly it limits ability to identify an accurate cause of injury. Moreover, this limits the utility of this information to identify injury risk factors in such a cohort. Consequently, this reduces accuracy of future predictions of injuries. Having a more specific injury onset time would allow for a more accurate identification of cause of injury and therefore rehabilitation practices. However, the likelihood of being able to identify the exact causality of injury of every recruit is low, as many of the overuse injury onsets are built up over a period of use and time. Therefore, regardless of the recording style, there would be some naturally occurring omissions of data. However, recording the day of injury reporting would likely result in less subjectivity in data interpretation, post study.

The current study identified that males were on average 11kg heavier than females, and that this may have impacted the sex based injury difference. However, the study did not record any information on the loads each recruit had to carry specifically, such as weight, duration of carrying or carry method etc, nor did it record body mass index (BMI). Finestone *et al.* (2008) recorded that BMI was the only variable that was associated with difference in the number of stress fracture observed between those who did and did not sustain stress fractures. Males in the study recorded with no stress fractures at all, but females who did sustain such an injury were shown to have a lower BMI (19.2±2.6 injured, 22.5±3.3 uninjured). That being said, this relationship was seen as non-significant, and there was a body mass difference between males and females (60.8±10.5kg females, 67.8±10.8kg males) which was significant different. whereas, the current study has demonstrated much greater differences in body mass. There are typical loads used in military training that would have likely been used and there are average times in which certain courses or distances would have been completed. However, without accurate and individual data, analysis of such data would be mere speculation. Further examination of such an effect on injury or movement quality through load manipulation does seem relevant and should be investigated further.

Statistical analysis is more accurate when groups within the data are of equal size. In the current study, the groups (male vs female) were divided 90%:10% respectively. Although the mean differences still displayed enough variance to be classified as significantly different, if males and females are to be examined against one another in future studies, using cohorts that are more equally divided, or artificially selected into equal groups, would be preferable.

Whittaker *et al.* (2017) state that a major limitation of studies examined in their systematic review was the lack of characteristic data reporting of those who did not submit to follow-up screening due to injury or dismissal. The current study also did not collect data on those who left Phase-1 training due to injury. Consequently, the study cannot state that it is free from selection bias, and the results may differ due to the influence of such a bias. Those who do not complete Phase-1 military training through injury are, by definition, injured. This means that the number of injuries recorded by the study was lower than that which actually occurred during training. However, as those who were removed had their data also removed, there is no way of knowing any specific details of the injury or their injury risk prior to Phase-1 training. Pre-existing conditions and previous injuries would have influence injury risk alongside variables such as FMS score and training level. However, such information was not available and therefore no indication can be given as to the likely directional impact these omissions would have had on the data and subsequent analysis and interpretation.

4.7 Conclusions

Preliminary analyses of the association between the total FMS score and injury occurrence indicated good predictive ability. However, the FMS total score contributed very little to the predictive model and accounted for a very small amount of variance within the data. The study identified the FMS as having good specificity (96%) and therefore was able to identify a large proportion of those that did not sustain an injury. However, the FMS demonstrated poor sensitivity (23%) which shows an inability to accurately identify those most likely to sustain injury. This confirms findings and conclusions from Dorrel et al. (2015), as well as three systematic reviews (Bonazza *et al.*, 2017; Moran *et al.*, 2017; Whittaker *et al.*, 2017) and suggests that the FMS in its current form is not an appropriate tool for identifying injury likelihood.

The differences in FMS total score between male and female recruits were non-significant. However, females were significantly more likely to sustain an injury. Therefore, something other than that recorded by the FMS must be responsible for this disparity. Additionally, the FMS shows an insensitivity to the difference in injury rates between male and female RN recruits.

The majority (76%) of all injuries sustained by the military personnel in the current study were lower-limb injuries. As such, it was hypothesised that the individual movements within the FMS that focused on lower-limb movement dysfunction would demonstrate a greater contribution to the injury prediction model. However, the only movements to significantly contribute to the injury predictive model were upper-limb and core movements. At this time, the current study is unable to give a definitive answer as to why this is the case. However, these findings demonstrate that the full seven movements within the FMS are not required in all populations and gives further justification to cohort specific movement assessment in future injury screening tool and assessment development.

In conclusion, the findings from the current study challenge the use of the FMS in military cohorts as a tool for identifying a person's risk of injury.

4.8 Impact of study

Since the completion of the study, the results have been distributed to military services. The conclusion of the study is that the use of the FMS is not fully justified as an injury identification tool in military cohorts. Consequently, the FMS has been removed from training institutes as a military endorsed assessment tool.

Further investigation into injury identification is still required, and as the military has removed their previously endorsed assessment, a replacement is now required. Therefore, one impact of the current study is that further laboratory experiments have been approved to better understand movement quality and the impact certain external and internal variables have on it. Subsequently, a laboratory based study was approved as part of the present PhD, to examine the effect of external load carrying on movement quality, using specific movement screening tasks as well as military specific movements.

Moreover, as the current study has identified high rates of injury in both male and female recruits, the military training institutes have expressed interest in developing intervention strategies to reduce this risk. Consequently, an intervention study has also been approved by Ministry of Defence Research and Ethics Council (MODREC). The study will explore the ability of a movement quality based intervention, which specifically targets the hip and lower-limbs, to improve movement within military Phase-1 recruits (Chapter 7).

Chapter 5: Methodology of the Hip and Lower Limb Movement Screen.

5.1 Introduction

During the literature review (Chapter 3), a number of different movement screens were identified and used to classify various factors within movement such as output, performance and quality. The most prominent of those reviewed was the FMS. However, the reviewed literature suggested that the FMS may not be appropriate for use within the military. Study 1 (Chapter 4) highlighted that the FMS total score was not sensitive to the injury risk difference between males and females while also demonstrating lower contribution to the injury prediction model than two movements from the FMS used independently. Consequently, the FMS was removed for subsequent testing within the current research programme. However, an appropriate screen was required for further testing. Rusling et al. (2015) claims that movement quality tools are more appropriate when designed for specific cohorts, due to the specific physical demands and specific injuries sustained by said cohort. Many cohorts share similarities in terms of the types and location of injury, as well as movement types and load. Many sporting and active cohorts rely heavily on bipedal locomotion, which contributes to high levels of lower-limb injuries (Ministry of Defence, 2016). Therefore, using a movement screen that focuses on the lower-limb movements during single leg support may prove to be appropriate across multiple cohorts. One such cohort that adopts high loads of bipedal locomotion, as well as high levels of lower-limb injuries, is the UK military Phase-1 and 2 recruits.

The current research programme aimed at identifying whether or not the hip and lower-limb movement screen (H&LLMS) could be used within mixed sex military cohorts. The movement screen was originally developed for use with male football teams and was specifically designed to inform the generation of intervention strategies to improve pelvic and lower-limb movement quality. The current cohort of mixed-sex military recruits required a movement screening tool applicable for females and males, and those undertaking high physical workloads that predispose them to injury. Study-1 (chapter 4) identified that the most common injury location for military personnel is the hip and lower-limb. Although different in terms of the goal of each profession, professional football and military recruits show similarities that both groups spend a high number of hours undertaking physical training, with a high proportion of that time spent in bipedal locomotion. Moreover, both groups show higher than normal levels of lower-limb injuries. Therefore, screens used in football may be relevant to use in military recruit cohorts.

During the next three thesis chapters (study 2 - laboratory study, study 3 - pre-intervention analysis of sex-based movement quality differences and post-intervention analysis of changes to movement quality), the studies will employ the Hip and Lower-Limb Movement Screen (H&LLMS) as the principal movement quality screen. The H&LLMS was created by the University of Southampton as a way of identifying individuals with abnormal movement patterns (Booysen, 2013). The H&LLMS was developed as validated by researchers other than the principal research for the current research programme. Details of how these auxiliary research programmes influenced the current thesis, please see Chapter 1 (Figure 1-1). The H&LLMS uses seven movements to determine a person's movement quality (Figure 5-1). These range from single stance, double stance and side lying movements, and all movements are specifically orientated around the hip, groin and lower-limb. From these movements, faults have been characterised that relate to specific movements required by the participants. For example, during a small knee bend in single leg support, if the knee of the standing leg moves medially and demonstrates valgus knee movement, this would be considered a fault. The medial movement of the knee shows an inability to maintain alignment of the leg and indicates some dysfunction in some aspect of movement quality. As study 1 (chapter 4), and the previous stated systematic reviews have shown (Dorrel *et al.*, 2015; Bonazza *et al.*, 2017; Moran *et al.*, 2017), total score is unlikely to accurately predict specific injuries, it has been suggested that moving away from total score would benefit movement analysis and subsequent prediction models (Rusling et al. (2015), which would lead to better informed interventions. Therefore, the H&LLMS does not use the total score (Booysen, 2013). Each fault is scored dichotomously with either a yes or a no, and the total for each of the seven tests is used separately to identify where faults are located. However, as each movement contains multiple faults, the scoring system allows for a multi-level data analysis. For example, one can assess the dichotomous score of each separate fault through all the movements. Furthermore, one can look at the total number of faults per movement if the primary goal of a movement screen is to identify dysfunction and inform treatment, using scores for each test or even each criterion enable treatment to be more targeted and increase the likelihood of effective treatment.

Figure 5-1: Illustrates the seven H&LLMS movement screening test.

Photographs courtesy of Nadine Booysen. Movement name (left to right, top to bottom) Small knee bend, small knee bend with rotation, Standing hip flexion, Sitting hip flexion, Hip abduction with lateral rotation, Hip abduction with medial rotation, Squat. For greater detail see Appendix A.

The movements used in the H&LLMS relate to functional movement but in a low load condition. An example of this is the small knee bend (SKB). The SKB is a single leg support movement where the support leg is flexed so that the knee protrudes past the toe and the unsupported leg is raised off the ground and held behind the individual with the knee flexed to approximately 90°. Such a movement is typical of the action required during bipedal locomotion such as walking and running, which is a commonly used movement in military training and employment. Riley *et al.* (2008) states that during over ground running males and females produce similar sagittal knee kinematics. Moreover, they demonstrate that during the stance and swing phase of a running gait, knee RoM peaks at ~60° and ~90° respectively. Therefore, both the supported and unsupported leg angle of the SKB replicates the position and joint range of motion experienced during the contact, propulsive and swing elements of the running gait. However, during the landing phase of a run, the landing leg can experience loads of 1.2 – 1.5 times their body weight (BWs). As well as having to distribute the landing forces the participant would also have to then generate a propulsive force in order to again initiate the flight phase of the run. This would all take place in a period of time typically less than a second. Therefore, the single leg stance during a run requires a great deal of coordination, and physical exertion. Using the SKB test allows for analysis of the 'running action' without subjecting the participant to the high demands experienced during the landing and take-off elements of the run. Although the mechanics of the SKB and running gait differ greatly in their muscle activation patterns, range of movement and generation of shear forces, the SKB does replicate the knee RoM during the landing position. Therefore, if a movement dysfunction is observed during this SKB movement, it is highly likely that when exposed to the actual running action, the dysfunction will not only also be observed, but that the movement dysfunction will present to a greater degree. Therefore, the SKB may prove relevant in cohorts that undertake high loads of bipedal locomotion.

FMS guidelines state that in movements that are completed on both left and right sides of the body, the lowest, and therefore worst score, should be used to generate the total screen score. This suggests that the FMS recognises that a movement screen should identify movement dysfunction and use tests that are more likely to highlight such dysfunctions. If a movement were to artificially rotate the pelvis as to more fully engage the gluteal muscles and therefore increase the stability of the lower-limb prior to screening for movement dysfunction, this would artificially lower the likelihood of detecting a movement dysfunction. However, if a movement were to more accurately represent a movement more likely to be performed by the participant, and for that movement to be more technically taxing, this would give a greater chance of accurately identifying movement dysfunction more typical of the participant's movement patterns. Moreover, the conditions in which the movement screen is conducted represent the most controlled environment in which these participants would likely conduct such movements. Therefore, this would represent the best chance for them to produce their best movement. Any deviation from such conditions would increase the likelihood of producing a lower quality movement. The H&LLMS has adopted a similar approach. The H&LLMS uses the more challenging movement, which would likely result in a lower movement quality. In the case of the H&LLMS small knee bend test, the unsupported leg is held to the rear, rather than in front of the body.

5.1.1 Study cohesion

As stated in chapter 1, this thesis is based on a singular epistemological view, that states that movement dysfunction can and will lead to injury. The previous chapter (Chapter 4) explains the analysis of the Functional Movement Screen (FMS) and concluded that the findings do not support the use of the FMS as a movement dysfunction identifying tool in military cohorts. As such, the subsequent research comprised in this thesis used the H&LLMS.

The next study will be a laboratory study aimed at better understanding the differences in loaded kinematics and the effect this has on both male and female Phase-2 military recruits, as well as understanding the mechanisms behind movement dysfunction. The aims of the third study are two-fold. Initially, the study will ascertain if movement control differs according to a person's sex for Phase-1 military recruits on initial intake. Secondly, the study will establish whether movement control can be modified with a physical exercise intervention while also accounting for sex differences in movement control adaptation and injury occurrence. Study four will examine the buy-in from military Physical training instructors (PTIs) and recruits in order to highlight areas of improvement for subsequent movement quality intervention within military cohorts. All four studies aim at answering a global question of how to decrease injuries within military training cohorts, but do so from different vantage points. With this style of approach, this thesis aims to provide greater insights of mechanisms for injury, sex differences in injury rates and advise on the most effective methods of modifying movement control to reduce injury rates in military populations.

5.2 Changes to the H&LLMS

The H&LLMS has been subject to reliability and validity studies by colleagues in the author's department during the period of time in which the research in this thesis was conducted. These data are in preparation for publication (Booysen, 2013) and were made available to the present author. Although this is not currently published, the research occurred within the University of Southampton, which allowed the author of the current thesis to have access to the reliability data. As such, some modifications were made to the H&LLMS that resulted in two versions of H&LLMS being used within this thesis: one version for the laboratory study and another for the prospective intervention study. Changes were made to the H&LLMS due to a number of factors, such as redundant faults, ambiguous language used and ensuring the screen used an appropriate scoring system. The changes aimed to create a more reliable and valid screening tool while maintaining the basic principles of the original screen. This section will give details on how and why the changes were adopted, and the implications of such changes on the results and conclusions of this thesis.

5.2.1 Redundant faults criteria:

Reliability studies within the school of health science examined the contribution of each individual fault criterion within the H&LLMS (Booysen, 2013). Some criteria were found to overlap and report similar aspects of movement dysfunction. Other criteria demonstrated low repeated agreement. Therefore, those faults that were identified as redundant were removed from the relevant movement test. For example, "Does the trunk side-bend?" and "Do the toes claw or any loss of balance?" were removed from the Small knee bend with rotation test. The faults were removed because they were seen to both record the participant's ability to balance throughout the small knee bend and that the fault of "Is there an increase in dynamic valgus from the start position?" captured the participant's balance more efficiently. Additionally, a valgus knee movement has been shown in previous literature (Dwyer *et al.*, 2010) to be of greater importance to the identification of movement dysfunction due to its relationship with knee and hip pain. Moreover, some faults, such as "Is there axial rotation of the pelvis?" and "Does the pelvis hitch?" were combined due to both reporting similar aspects of movement dysfunction. This produced the criterion, "Does the pelvis rotate or hitch/hike?", which resulted in a more efficient screen in both the amount of time required to complete it, and the accuracy of scoring.

Reliability and agreement testing were also conducted to better understand if the fault scoring could be trustworthy. However, no faults were removed due to low reliability or agreement. Although, the fault, “Do the toes claw or any loss of balance?” demonstrate low reliability (AC1 / %: 62 - 75), this was not the principal reason for its removal. As stated previously, this was due to its overlap with the fault “Is there an increase in dynamic valgus from the start position?”.

5.2.2 Ambiguous language:

Booysen (2013) consulted with practising physiotherapists and sports coaches to gain feedback on the wording used within the screen. It was suggest that some of the criteria used language that was ambiguous, which made identifying the fault difficult. This was either due to not fully understanding the scoring system or the most commonly used terminology in the literature and/or practice being used. The scoring system was set so that if the fault was observed the scorer could answer “yes” and if the fault was not observed the scorer could answer “no”. This made analysis more efficient. However, it did make some fault questions negatively worded. For example “Does the knee fail to move 2cm past the toes?” and “Does the hip fail to bend (flex) just beyond 90 degrees (approximate 110 degrees)?” some of those who used the screen had raised concerns that this type of questioning would confuse those less practised in the screen and therefore give misleading or perhaps false outputs. As such, these were removed where possible.

The changes made to specific terms used in the literature or practice were done so due to the terms not being specific enough, or not used or not known by those outside academia. For example, “does the pelvis hitch/drop?” was changed to “does the pelvis stay level?” in an attempt to remove specific language that is not clear. During discussions with practicing and researching physiotherapists, the term “hitch” was deemed as unclear; additionally, it was also unclear which side of the hip the rater should be concerned with. For example, if the participant were to complete a small knee bend while standing on their right leg and the left side of the hip was to rise, would this be considered differently to the left side of the hip lowering. Are these two movements both categorised as hip hitching, and if so, do they attain the separate and different H&LLMS scores or simply the original dichotomous rating of 1. In this case both hip movements were considered equally dysfunctional, and therefore resulted in a change in term and a simplification of the scoring system in which any deviation from level would result in a fault score.

5.2.3 Fault order changes

The original H&LLMS required the rater to observe faults from sagittal and frontal planes. For ease of use, the H&LLMS ordered the faults to reflect this and would prompt the rater to look at faults from the same area at the same time. For example, the small knee bend with rotation shows faults observed from the front “does the pelvis follow the trunk?”, “Does the trunk side-bend?” and “Does the pelvis hitch/drop?” together. However, some of the faults were deemed more important than others and prompted a discussion on the order of faults listed. As previously stated in chapter 2.1, a movement can be said to have occurred if the main aspect of that movement was achieved. For example, a movement in the H&LLMS asks the participant to raise one leg, so to flex their hip to 90°. Therefore, if the participant were unable to attain 90° of hip flexion during this movement, the movement was not successfully achieved and not completed. However, in the case of the H&LLMS, the participant may not have been able to flex their hip to 90° but, during the course of the movement, did not present with any of the other movement dysfunctions assessed within the movement. Subsequently, they would score a single fault for the total movement. This presents the study with a problem for a single use movement screen and the accuracy of the screen. In this case the study does not know if the participant would have demonstrated other movement faults, if they had been able to attain a greater hip RoM limitation. For example, their restricted hip RoM may represent the first movement dysfunction to manifest in the movement, rather than the only one. If this was removed, they may find that additional movement accommodation would manifest in other areas. But during the restricted version of the movement, these dysfunctions were not stressed, and therefore did not manifest. Therefore, the study and the H&LLMS cannot conclude that the participant does not have other movement dysfunctions. Instead, the study can simply conclude that the participant did not present movement dysfunction during a movement with a restricted range of motion. However, the bigger issue presents itself during intervention studies.

If a participant were to be screened prior to an intervention, and present with a failed test and therefore a single fault for a specific movement, this could result in an improvement in movement ability, but be recorded as a worsening. For example, if we take an instance where a participant failed to attain 90° in the hip flexion test explained above, and therefore is given a single score for the fault. The participant may not present with any other fault; however, as the full range of motion was not achieved, it may have not have required the participant to resort to compensatory movements. If a person with structural adaptations at the shoulder were asked to raise their hands as high as they can, you may observe a lack of height achieved by the participant. However, if at such a point you ask them to attempt to reach higher, you may find that they resort to compensatory movements to allow them to achieve such a movement, such as raising their shoulders. Similar movements may be present at the hip, but if the range of motion is not sufficient to require compensatory movements, these would not be observed.

Therefore, the participant may have demonstrated movement dysfunction had they been able to achieve the actual movement criteria of 90°. However, pre-intervention testing did not observe this. After an intervention, if the participant's RoM had increased and now is able to achieve the desired 90° of movement, but now present with movement dysfunction as the greater RoM is stressing the movement ability of the participant to the point that they require movement modification in order to achieve the total movement. In such a case, the post-intervention score may be higher than the pre score, showing a worsening of movement quality. However, in such a case, this conclusion cannot be made. Therefore, the screen was modified to rectify this issue. A change in the order of the faults, as well as the scoring system, was introduced. For all movements, the fault that most effectively represented the completion of the movement was elevated to the initial question and fault. If the participant were unable to attain this criterion, they would receive a single fault as well as a "failed test" grade. This approach was adopted to ensure that the movement was actually completed, after which, the movement could then be subject to quality analysis and scoring.

Thereafter the movement would be scored the same and each subsequent fault observed and graded as normal. The reason that each fault was scored regardless of the initial total movement fault was that this would allow for a more detailed post-intervention comparison. If a person were to fail a test completely because of the initial criteria the score displays no information about the subsequent criteria. Consequently, any pre to post-intervention analysis is limited. It would be inaccurate to state that the individual who failed the full test but had passed all other criteria had improved by the full test score after an intervention when they had actually improved by a single point. However, removing the fail component would suggest that all criteria were of equal value when this is not true. Therefore, scoring the full set of criteria despite the pass / fail nature of the initial fault allows for greater depth and accuracy of pre to post-intervention analysis and adds to the multiple levels of data review approach.

Although changes were made to the screen throughout the current PhD, this does not mean that the initial version was an inappropriate movement observation tool. What this continual progression demonstrates is the constant pursuit of a more robust tool derived from scrutiny and examination of the H&LLMS. Any observational tool is set on a gradable scale of accuracy and appropriateness. In this case, the tool required alteration, but the main aspects of the tool such as the dichotomous scoring system, rather than the extended gradation used in the FMS and others, were maintained. Additionally, the fact that a person could fail an entire movement based on a single movement criterion is novel to the H&LLMS and was also maintained. Additionally, although not entirely, comparisons can be made between the two versions of the H&LLMS which means that data from the two versions and two studies are also comparable. Ultimately, the changes to the H&LLMS during this thesis have improved the screen while maintaining the aspects of the screen that sets it apart from previously used screens.

5.3 **Training process for developing skill in movement screening**

To ensure reliable and repeatable measures were recorded during the following studies, the researcher continually undertook supervised training to use the H&LLMS reliably. Training included: demonstrations of the H&LLMS by one of two qualified practitioners, observations of the H&LLMS in use with research participants, pre-recorded video-based learning sessions alongside a qualified practitioner and live supervised scoring. The training team consisted of one therapist (NB) with over 14 years of experience as a physiotherapist and six years working with movement control assessments. NB had attended multiple training courses; such as, the Performance Matrix: Movement and Performance Screening and FMS course and led the development of the H&LLMS. The second therapist (DW) had over 16 years' experience as a physiotherapist and seven years using movement control assessments including the H&LLMS. Additionally, the lead researcher in the current study (CP) had access to a manual of the H&LLMS to use and refer to during and after training. These processes were stage-based and were only progressed once competence had been shown in each phase, culminating in real-time scoring. To show competency, reliability testing was conducted at each stage (See below).

5.4 **Reliability testing**

The only rater formally assessed for reliability was the principal researcher (CP). However, the training that was given to the principal researcher was also given to all members of the extended research team prior to, and throughout the intervention study. Once initial training with the principal researcher was completed, reliability was established by counter scoring with other trained practitioners. For this, two raters would screen the same person at the same time. This allowed the two raters to converse over the more ambiguous, or less obvious movement faults. These pairs were randomised and altered during the training day. This section will document the progression through the stage-based reliability testing undertaken by the principal researcher. Three stages were completed prior to the H&LLMS being used within this thesis. These stages were:

- Inter-rater video screening
- Intra-rater video screening
- Inter-rater live screening

5.4.1 Stages of reliability

5.4.1.1 Video screening – inter-rater reliability

Initial inter-rater reliability testing utilised videos of participants completing the H&LLMS against one of the two aforementioned expert physiotherapists. This allowed the raters to pause and rewind the screen, which allows those learning to identify movement faults to do so at a pace suited to their ability. Additionally, this method was very time efficient as the screen could be conducted at any point the researcher was using a computer. However, as the videos were static during their recording, this restricted the view from which the researchers could identify a participant's movement dysfunctions.

As both the novice and experienced raters were screening identical videos, any variations in their screening score would represent either their ability to recognise a fault, or their definition of the fault. Therefore, this would identify any biases the researchers had towards specific faults and allow them to address these prior to progressing to the next reliability testing phase.

5.4.1.2 Intra-rater reliability screening using video

Once inter-rater agreement was tested and established, intra-rater reliability needed to be confirmed in order to gain confidence in repeated testing such as that employed during intervention studies. Similarly to inter-rater agreement testing, the same pre-recorded videos of participants performing the H&LLMS were used. This again gave the same advantages and disadvantages in ease of use and time efficiency and lack of viewing options. As a single rater was assessing their individual reliability, any differences in the scoring would likely be due to the rater identifying the faults incorrectly in one of the instances. However, if high agreement were to be shown during intra-rater testing, this would indicate that they were consistent, although would not be an indication that they are accurate in their observation and scoring. Therefore, results from inter and intra-rater testing should be addressed in culmination to ensure accuracy and repeatability.

5.4.1.3 Inter-rater reliability screening. Real-time screening (practice)

The final stage of reliability testing was to use the H&LLMS during live screening of participants. Live observation and screening removed any advantage specific to video, such as the ability to pause and rewind. However, this allowed the researchers to move about the participants during movements to better see the particular fault or movement based on their own observational ability.

5.4.2 Method

Twenty participants had been screened and the video recording made available for reliability testing on digital recordings. The participants were not known to the inexperienced rater to ensure no previous knowledge of the participant could influence their scoring. The raters scored the videos independently and were given new recording sheets for each recording so that they would not be able to refer to other rater scores. Each screening was conducted on a single day and scores were digitised into a blank excel spreadsheet. The recordings were part of the original H&LLMS reliability testing, and not recorded specifically for this research programme. Both the experienced and inexperienced rater used the same blank recording and excel sheet. This simplified data integration, while ensuring a low likelihood of error. Two sets of scores were then assessed to ascertain agreement between the raters through the use of AC1 and percentage agreement by the principle researcher (CP).

The same videos used for inter-rater reliability scoring were again used to assess intra-rater reliability. Re-using the same videos, in this instance increased the chance of the rater remembering the scores given in previous viewings, thus reducing the reliability of the results. However, as the screen has 64 total faults, over 7 independent movements scored on both left and right, it is unlikely that one can remember the exact score from all 20 recordings, and thus 1280 individual scores. However, in order to ensure that memory did not affect the results, the videos scoring sessions were separated by at least 14-days. Moreover, the videos were randomised and a separate data recording spreadsheet was used to reduce the chance of the principal researcher remembering or being able to look up each participant's original score. All data from video recording were collated and analysed in Excel.

The live H&LLMS screening was performed over two separate sessions with separate populations. The initial session was performed with male football players (n=8) during data collection for the expert physiotherapist's study (NB). At this time, the data collected by the principal researcher was not used in the study conducted by the expert (NB) but was collected alongside the expert to establish inter-rater reliability of the principle researcher (CP) of the current research programme only. The second session was with military recruits (n=12) during data collection for the pre-intervention study within this thesis. The collected data were used within the study and the data from the expert was for comparison to clarify the reliability during the first instance of actual data collection conducted by the principal researcher.

While screening the football players, the raters conferred, at times, to either clarify points or to highlight individuals with specific and sometimes, hard to identify faults. However, during the military data collection, both raters observed and scored independently so to establish an uninfluenced score from which to assess final inter-rater agreement.

5.4.3 Data analysis:

Initially, Cohen's Kappa was considered for agreement assessment due to prominence in research (Wongpakaran *et al.*, 2013). However, this test is adversely affected by the imbalance in the table's margin totals and referred to as the "Kappa paradox" (Gwet, 2014). If a movement or fault were to be recorded with no disagreement across the total numbers of participants, it would reduce the Kappa ratio (k) to nothing. Therefore, k tends to underestimate the agreement of cases that are rare (Wongpakaran *et al.*, 2013). Preliminary reliability testing of the H&LLMS demonstrated occasional 100% agreement, and therefore subsequent reliability testing cannot be completed using the Cohen's kappa k ratio. Therefore, another reliability method would be required for subsequent testing.

Gwet (2014) adjusted for chance agreement by using the AC1 reliability test. The AC1 score between two or more raters is defined as the probability that two randomly selected raters will agree, given that no agreement will occur by chance. Gwet (2014) concluded that Cohen's Kappa ratio gives an elevated value when there are high levels of agreement. However, Kappa paradox presents itself when Kappa ratio is low despite a high level of agreement. Gwet (2014) suggested that AC1 would work as a "paradox-resistant" alternative to the Kappa coefficient ratio. Therefore, AC1 and percentage agreement were used for the reliability studies within the current study.

Wongpakaran *et al.* (2013) give a consolidated framework from three sources, which establishes a benchmark of quality of agreement (Table 5-1). Although there is a difference between the three guides, a score over 0.61 would be seen as "good", above 0.75 would be classed as "excellent" and above 0.81 is the highest classification given.

Table 5-1: Benchmark scale for Kappa's value, as proposed by different investigators. First presented in Wongpakaran *et al.* (2013)

Landis and Koch	Altman	Fleiss
<.0; Poor		
0.00 – 0.2; Slight	<0.2; Poor	<0.4; Poor
0.21 – 0.4; Fair	0.21 – 0.4; Fair	0.4 – 0.75; Intermediate / Good
0.41 – 0.6; Moderate	0.41 – 0.6; Moderate	
0.61 - 0.8; Substantial	0.61 – 0.8; Good	>0.75; Excellent
0.81 – 1.00; Perfect	0.81 – 1.00; Very good	

5.4.4 Results:

Results from the inter-rater analysis of the video data suggest an agreement between the two raters. If 0.81 is the benchmark of “perfect” or “Very good” reliability set by both AC1 and percentage agreement, then the results demonstrated in Table 5-2 show that only sitting hip flexion, Hip abduction with medial rotation and deep squat had a total score below such a grade and demonstrated less than this standard of agreement. Moreover, the average total agreement shown for AC1 of 80 and percentage agreement is 88% which again sits above the threshold of what is classified as “perfect” or “Very good” agreement.

Table 5-2: Demonstrates the AC1 and percentage agreement scores of each individual H&LLMS screen test.

	Inter-rater	
Movement	**AC1**	**% agreement**
Small Knee Bend	81%	89%
Small Knee Bend Rotation	83%	89%
Stand Hip Flexion	82%	89%
Sit Hip Flexion	77%	87%
Deep squat	77%	86%
Hip Abduction Lateral Raise	88%	92%
Hip Abduction Medial Raise	71%	83%
Total average	**80%**	**88%**

The results from intra-rate analysis of the video data demonstrate that only one movement had a total score that would be considered less than good agreement. Moreover, the average total agreement shown in Table 5-3, demonstrates an AC1 of 82 and percentage agreement of 89% which is above the threshold classified as “perfect / very good / excellent.

Table 5-3: Demonstrates the AC1 and percentage interrater agreement of H&LLMS scores.

	Intra-rater	
Movement	**AC1**	**% agreement**
SKB	82%	89%
SKB Rotation	83%	89%
Stand Hip Flex	91%	94%
Sit Hip Flex	87%	87%
Deep squat	62%	79%
Hip Abd LR	84%	91%
Hip Abd MR	82%	89%
Total average	**82%**	**88%**

Data from the live screening shows that after the first session, both sitting hip flexion and deep squat showed agreement levels below the set boundary (Table 5-4). Moreover, AC1 scores for small knee bend, small knee bend with rotation and hip abduction with medial rotation were below the set boundary in the first round of live screen reliability.

During the second phase of training and reliability testing, results, Shown in Table 5-4, demonstrate that only the AC1 score for deep squat showed lower than the required agreement. Additionally, between the initial and secondary live screening testing, the total score increased on average by 16% (AC1) and 8% (%agreement).

Table 5-4: Demonstrates that AC1 and percentage agreement for H&LLMS live scoring (Session 1 and 2)

	First testing		Second testing		Change	
Movement	**AC1**	**% agreement**	**AC1**	**% agreement**	**AC1**	**% agreement**
SKB	68%	81%	82%	89%	14%	8%
SKB Rotation	74%	83%	95%	95%	21%	12%
Stand Hip Flex	81%	85%	90%	93%	9%	8%
Sit Hip Flex	60%	77%	87%	87%	27%	10%
Deep squat	55%	75%	78%	84%	23%	9%
Hip Abd LR	88%	91%	99%	99%	11%	8%
Hip Abd MR	78%	86%	82%	88%	4%	2%
Total average	**72%**	**83%**	**88%**	**91%**	**16%**	**8%**

5.4.5 Discussion and conclusion:

The initial agreement between the two raters was, on average, higher than the suggested benchmark. However, three of the individual movements demonstrated lower than such an agreement. This means that the two raters showed high levels of agreement in most individual movements and the total screen score, and there are specific areas in which the agreement must improve. Given that the agreement was assessed between a novice and experienced rater, it is more likely that the errors in the agreement were due to misidentification of fault/no-fault by the inexperienced rater and therefore the inexperienced rater was advised at this time to continue training. The goal at this stage of the reliability training was to assess if the novice rater was accurate enough to continue to the next stage of training, the researcher could be confident that their scoring was not dissimilar to that of an experienced physiotherapist. Therefore the principal researcher was deemed competent enough and encouraged to progress to live scoring with the likelihood of subsequent scoring improving with experience.

Assessing repeatability of fault/no-fault identification identified that the only movement that did not meet the 80% agreement standard was that of the deep squat. This movement was also shown to be under the 80% standard for inter-rater reliability. As such, this does suggest a systematic inability to accurately distinguish faults during the deep squat movement. Consequently, greater emphasis should be taken in further training to improve accuracy in the deep squat movement. Intra-rater agreement demonstrated that the researchers two independent scoring sessions did not completely agree. However, the level of agreement achieved is greater than that required to be classified as "excellent" by Wongpakaran *et al.* (2013) (Table 5-1). Therefore, the researcher demonstrated high levels of intra-rater reliability. This consequently indicates that their scoring is stable and consistent and that the researcher can confidently progress onto the next phase of screen training.

Data from the live inter-rater screening suggests that there was a worsening of the primary rater's reliability or scoring stability from video to live scenarios. However, this may be explained by the additional factors at play during live scoring such as not being able to pause and rewind the movement. During the secondary session of live screening the data show that there was an improvement in percentage agreement and AC1 scores between the initial and secondary live data collection sessions (Table 5-4). Therefore, this indicates the presence of a learning effect between the two sessions. These data show a fairly constant and stable AC1 and percentage agreement between an experienced physiotherapist and the primary researcher. As such, the primary researcher is confident in their subsequent scoring and therefore data collection in future data collection.

5.4.6 Reliability of H&LLMS

Prior to the intervention study, rater training and reliability testing had been conducted to ensure data integrity. However, week 1 of testing for study 3 (Chapter 7) provided the opportunity to assess interrater reliability against experienced H&LLMS raters during live testing. In order to assess interrater reliability, someone who had already established their reliability would be required to perform live recordings alongside the novice members of the study team. As the H&LLMS is a relatively new screen, there were only three people (CP, NB & DW) at the time qualified to perform such reliability assessments. Of these qualified, only two were available during pre-intervention testing (CP & NB). Consequently, their availability was the limiting factor. The first day of a person's military career, they are subjected to a variety of medical tests, such as eyesight, hearing and other such examinations. These are all tested during a single time slot that is referred to as the Initial Medical Assessment (IMA), and are typically scheduled for a single morning or afternoon for efficiency. The movement screen testing was also scheduled to be performed in this time, but no additional time was given to the IMA. This meant that only a single IMA morning would be available for interrater reliability testing. In order to maximise the likelihood of completing all required screenings in the given time, multiple screening would need to be performed at the same time. This would then mean that the raters would need to be separated as much as possible. Therefore, although all the raters could have been assessed against the experienced rater at the same time, this would have resulted in the smallest number of recruits screened per hour. Therefore, the study team allocated a single rater to be assessed for interrater reliability by rating alongside the experienced rater during live H&LLMS screens. A total of 12 participants were assessed by one novice and one experienced rater, where their individual movement scores were assessed for agreement.

Reliability testing was originally examined and established previously in this chapter using AC1 and percentage agreement. The same data analysis and interpretation was conducted for these reliability tests, using the same agreement boundaries expressed in Table 5-1. Data shown in Table 5-5**Error! Reference source not found.** shows that only AC1 for "Deep squat" was lower than 0.81 boundary defined as perfect. Consequently, the principal researcher (CP) had demonstrated high reliability during live testing with military cohorts in the exact setting in which subsequent testing would be conducted. However, as previously mentioned, the other raters were not subject to reliability testing due to time restraints, and therefore their reliability was an unknown.

Table 5-5: Initial IMA H&LLMS scoring interrater reliability

	Second testing	
Movement	**AC1**	**% Agreement**
Small knee bend	82%	89%
Small knee bend with Rotation	95%	95%
Stand hip flexion	90%	93%
Sit hip flexion	87%	87%
Deep squat	78%	84%
Hip Abduction with lateral rotation	99%	99%
Hip Abduction with medial rotation	82%	88%
Total average	88%	91%

In week 13 of military training, participants were required to attend their post-intervention screening. At pre-screening, the screener's initials were written on each recruit's screening sheet. Afterwards, this was included on the post-screening recruit list sheet. This was done so that pre and post screening would be completed by the same rater in an attempt to increase reliability. Data were all collected in the same location and the same researchers were present during all data collection sessions.

5.5 Summary

During the training process, the principal researcher demonstrated an improved accuracy in fault identification, which was highlighted in live rating data (Table 5-4). Moreover, the training culminated in the researcher achieving an interrater agreement level greater than that required to be classified as “excellent” by Wongpakaran et al. (2013) (Table 5-1) during the final live scoring session.

The agreement between the two raters was, on average, higher than the suggested benchmark. However, inter-rater reliability agreement between fault scores of the deep squat still show lower, but still high, levels of agreement. This discrepancy was shown at each level of training, thus suggesting a systematic difference in faults identification of the deep squat movement. Consequently, further training is required to improve scoring accuracy in the deep squat movement.

These results show a constant and stable AC1 and percentage agreement between an experienced physiotherapist and the primary researcher. As such, the primary researcher is likely to record accurate data in subsequent data collections.

Chapter 6: Laboratory study of movement under different rear loaded packs in males and females.

6.1 Introduction

6.1.1 Movement quality

Movement quality has been suggested as a potential factor for injury risk identification (Lisman *et al.*, 2013). Being able to effectively move within the limits of the structure and mobility of the joints could not only produce more efficient movement, but also reduce injury risk. Gibbs *et al.* (2014) demonstrated that navy recruits with an FMS score of less than or equal to 14 were 1.5-times more likely to sustain an injury, than recruits with a score greater than 14. Moreover, female recruits were more likely to sustain injury compared with male recruits, despite no difference in average FMS score. This indicates that something other than that observed and recorded by the movement screen must be responsible for this variance in injury risk.

6.1.2 Load carrying

Specific elements of military training and service are commonly implicated in injury occurrence (Knapik *et al.*, 1997). Of these, load, fatigue, terrain, footwear and distance travelled during marching have all been associated with increased injury rates. More specifically though, load carriage during bipedal locomotion tasks has been suggested to relate to lower-limb injuries (Majumdar *et al.*, 2010). The most common injury linked to this is stress fractures (Rice *et al.*, 2017), where females are twice as likely to sustain lower-limb stress fractures than males (Birrell and Haslam, 2009). Military personnel are required to carry load such as supplies and weapons in active service and are trained to do so during Phase-1 and 2 training. This has led some to suggest that injuries, and the sex-based difference in injury rates, associated with load carriage are a non-modifiable extrinsic risk factors during military training (Birrell and Haslam, 2009). However, many aspects of load carriage are adaptable, such as total load, load distribution, duration and load placement. Consequently, load may prove to be a modifiable risk factor to lower-limb injury in military personnel (Orr *et al.*, 2015).

Study 1, reported in chapter 5, demonstrated a mean difference in body mass of 11±2 kg between male and female recruits (male: 75±11 kg; female 64±9 kg). This demonstrates that females are on average lighter than their male counterparts. Although this alone does not suggest a link to injury rates, carrying loads above 33% of bodyweight is a strong predictor (Haisman., 1988 and Majumdar et al., 2010)). Thus, military recruits or service personnel with a lower body mass would be at a greater risk of injury given the same external carrying load. Calculating 33% of male and female average weight results in a 4kg difference in critical carrying load between males (25kg) and Females (21kg). Moreover, in military service, loads representing 63% of body weight have been recorded (Rice *et al.*, 2013).

Load carrying is a fundamental part of military training and active service, and yet it has also been linked to increased injury rates (Knapik and Reynolds, 2015). One such suggestion is that a person adapts their posture and movements to accommodate the load, and that these changes to the person's movement contribute to movement quality changes. By deviating from optimal movement quality, the risk of injury may increase and thus the externally added load may prove to be somewhat responsible for the increase in injury likelihood (Rice *et al.*, 2012). As load is a continuous variable, It is unlikely that the addition of external load would present as a dichotomous change in injury risk. Moreover, it is also unlikely that injury risk would be based on the net weight of the external load regardless of physical ability. It is more likely that the injury risk is more aligned with the percentage of body mass and/or physical ability. Therefore, those who are lighter, and /or less physically able, would be at greater injury risks. As the previous paragraph demonstrated that females recruited for the initial retrospective study were lighter than the males, this may help to explain the difference in injury rates observed between male and female Phase-1 military recruits. However, load or percentage of body mass load is not a mechanism for injury, merely a contributing factor. Therefore, it is vital that the biomechanical mechanisms leading to injury is more fully understood.

6.2 Aims and hypothesis

6.2.1 Aims

The principal aim was to further understand the movement quality differences between male and females military recruits during a set battery of movement tests. Moreover, the study sought to gain insight into the influence of external, rear-mounted load on recruit movement quality. Additionally, the study would establish if an interaction effect were present between sex, load and movement quality.

6.2.2 Hypothesis

H_1 There will be a significant difference in movement quality between males and females during unloaded movement.

H_2 There will be a significant difference in movement quality between unloaded and loaded conditions.

H_3 There will be a significant difference in movement quality between male and females during loaded conditions relative to body weight.

H_4 There will be a significant difference in movement quality between male and females and between loaded conditions.

6.3 **Method**

6.3.1 Study design and rationale

The current study deployed a cross-sectional repeated measures experimental laboratory based study. Data were collected in the Biomechanics Laboratory, at the University of Southampton within the Faculty of Health Sciences. The aim was to evaluate the effect of a relative (33% body mass) and an absolute (16kg) external load on movement control, during a battery of movement tests that included the Hip and Lower-Limb Movement Screen (H&LLMS) (see chapter 5), military-specific movements and bipedal locomotion, using biomechanical assessment. The loads were related to the Career Employment Group (CEG) of the study sample population, and did not exceed those experienced during the study. Study-2 examined the underlying biomechanical mechanism of movement control in male and female personnel when unloaded, and when exposed to loads typical of load carriage weights expected in military service. The specific relative movements of the joints and limbs during military-specific movements were examined to inform understanding of movement control, and how this might change during load carriage. The increase muscular strength required to perform movements under exaggerated external load has been associated with an increased risk of hand and soft tissue injury (Attwells *et al.,* 2006) such movement change data may also aid in understanding of injury risk, which in turn could inform future injury mitigation strategies. However, no injury data were prospectively recorded in this study.

6.3.2 Ethics

The protocol for this study was approved by the Ministry of Defence Research Ethics Committee (Reference: 781/MODREC/2019) and was conducted in accordance with the ethical standards of the Declaration of Helsinki. Specifically, various measures were established to maintain these ethical standards. This research programme was conducted in accordance with the Medical Research Council (MCR) Good Research Practice (GRP) guidelines. As such, the study team could have been subject to an independent GRP audit if required, under the direction of the RNSAC/MODREC, to ensure that the scientific approach, as well as the safety and ethical conduct of the study, were appropriate. Programme governance was under the authority of the Women in Ground Close Combat (WGCC) Research Team, and also the Defence Musculoskeletal Health Advisory Group (DMHAG) under the 1* Defence Injury Prevention Working Group, which is the MOD sponsor for an externally funded (Southampton University) doctoral programme.

Specific study numbers were used during the study to identify individual participant data. Participant names or service numbers were not used, nor were they identifiable at any stage of the write up of this study. Only members of the study team had access to raw data linked to the participants' names. This information was not available, or made available to anyone outside of the study team, including military command. Paper copies of recorded data were held by the lead investigator in locked cabinets within an office at the University of Southampton during the life-span of the study. Data were exported to and stored electronically, and this again was securely held on password protected computers in a locked room at the University of Southampton. On completion of the project, all data will be stored by the University of Southampton in an approved secure storage facility for 10 years.

6.3.3 Participants

A cohort of 30 (15 female, 15 male) military volunteers, were recruited from an Army Phase-2 training establishment within easy access to Southampton to participate in the current study. Male and female volunteers were not matched for age, height, body mass or physical fitness.

Participants were recruited from the training population at a Phase-2 unit close to the University of Southampton. All potential participants were aged between 16 – 34 years at the Start of Training, had successfully completed the Army physical and professional selection tests, and had been deemed medically fit and healthy following medical screening at the Army Selection Centre (ASC), and again at the training establishment if required. All potential volunteers had been deemed physically fit to undertake military training and specifically the load carriage element of this study.

6.3.3.1

Personnel were excluded from the study if they have been deemed unfit to undertake Phase-2 military training.

6.3.3.2 Recruitment

Potential participants were identified through liaison with the Colonel for Training Operations (SO1 Trg Ops) at the Headquarters for the Army Recruiting and Training Division. The Commanding Officers (CO) at the relevant Army Training Centre had supported this work being undertaken, and had liaised with the study team to identify the specific cohorts eligible to participate in the study. The CO then gave the initial introduction and information forms to the potential participants with the understanding that on arrival at the University of Southampton, participants would then have a more detailed description and introduction of the study.

Potential research participants were approached, as a group, during an initial study briefing. An outline of the study aims and requirements were disseminated through weekly and daily orders in advance of the brief. This has proved to be a more direct approach to advertising the study in comparison with posters, as all personnel are required to read 'orders'. At the study briefing, personnel were provided with a full description of the study, the measures to be taken, and any possible risks and discomforts associated with participation. It was also explained at this briefing that participation in the study is voluntary, and that non-participation would not adversely impact upon recruits' training outcome. At this briefing potential participants were provided with a Participant Information Sheet (PIS) (Appendix E) and had opportunity to ask questions of the study team. Written informed consent was obtained from each volunteer during the second study briefing (See Consent Form in Appendix F) and paper copies were stored at the University of Southampton, in locked cabinets.

6.3.3.3 Preparation

Prior to testing, all recruits wishing to participate in testing were given a new information form and asked again for volitional written consent. This also allowed the study team to have access to the participants' most recent fitness test, in the form of a 1.5-mile run. Although this is likely to have been from the end of Phase-1 training, this was still very recent and allowed the study to contextualise the study participants within the wider Army population. Participants were told about emergency drills and exit strategies from the building at the University, as well as general information about direction to toilets. The participants were again told that participation was voluntary and that they could stop or leave testing at any point without it effecting their standing in the military.

Participants had their anthropomorphic data collected (age, sex, height and weight) with no shoes prior to testing. They were asked to bring clothing that would allow the investigator to place reflective markers on their skin for motion analysis of both the upper and lower-body. The participants stood in a relaxed position whilst 53 reflective markers (Table 6-1) were taped into 23 bilateral positions and seven unilateral locations. The positions of the markers were marked with pen to allow for reliable placement and replacement of the markers for each assessment if some were to fall off. The lower-limb marker positions are shown in Figure 6-1. The study had already been explained to the participants prior to any data collection and at this point the participants were able to attempt the movements that were used for testing. Kinematic data was collected using 12 Vicon MX T-series cameras operating at 100Hz.

Table 6-1: List of markers and marker location

Rigid segment	Bilateral location	Marker name	Marker location
Torso	No	Sternum	
		Xiphoid proses	
		33% of ST and PX	33% of ST and PX
		Left rib	
		Right rib	
		T7	
		C7	
Pelvis	Left and Right	Anterior superior iliac spine (ASIS)	
		Posterior superior iliac spine (PSIS)	
		Iliac crest (IC)	
		50% between IC and PSIS	50% between IC and PSIS
Thigh	Left and Right	Superior thigh marker	Mid-point ASIS to patella on anterior
			Mid-point ASIS to patella lateral thigh
			Mid-point ASIS to patella on posterior thigh
		Inferior thigh marker	Mid-point between superior marker and patella on anterior thigh
			Mid-point between superior marker and patella on lateral thigh

			Mid-point between superior marker and patella on posterior thigh
		Lateral epicondyle of the femur	
		Medial epicondyle of the femur	
Shank	Left and Right	Superior tibia marker	Anterior tibia
			Lateral tibia
			Posterior tibia
		Inferior tibia marker	Mid-point between superior tibia marker and ankle on anterior tibia
			Mid-point between superior tibia marker and ankle on lateral tibia
			Mid-point between superior tibia marker and ankle on posterior tibia
		Lateral malleolus of the ankle	
		medial malleolus of the ankle	
Foot	Left and Right	Calcaneus	
		Fifth metatarso-phalangeal joint	
		Dorsal aspect of 1st metatarsal head.	

Figure 6-1: Lower-limb reflective marker placements.

6.3.4 Protocol

To assess movement quality and kinematics between males and females, and between loaded conditions, specific loads were first established. No load while barefoot (BF), no load while wearing shoes (Shod-no load), absolute load used in military training (16kg) and load relative to body mass (33% body mass) were chosen. Participants were asked to provide their own shoes for the conditions in which they would require shoes. These shoes, and the specific dimensions of these shoes were not recorded during this study. The primary outcome measure for the current study was the H&LLMS (See chapter 5.1). Specific movements were removed from the H&LLMS to negate the increased risk of injury imposed by the external load. Movements such as the small knee bend with trunk rotation were removed, as it was deemed a risk to acute lower back injury due to the torso rotation under load.

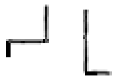
Additionally, tests that were unlikely to be modified by the increased external load were removed, e.g. where the test position was in sitting or lying down. Therefore the sitting hip flexion and side lying hip abduction movements were not completed under loaded conditions.

Although the study recruited both male and female military recruits, data collection sessions were arranged so that testing days would be sex specific. Due to the marker set used within the study, and to ensure the highest level of accuracy in data collection, participants were asked to wear clothing that would reveal the skin on their legs, arms and some areas of the torso. In order to maintain the participant's modesty and to increase their comfort levels, all testing days were separated into males or female only. Additionally, it was mandated by the military that participants be chaperoned by a senior military staff member. Therefore, these chaperones were also of the same sex as the participants.

6.3.4.1 Data collection procedure

Prior to testing, participants were required to perform calibration movements to determine joint centres and primary axis of rotation, which contribute to the determination of kinematic outputs. This calibration allowed identification of joint centres and axis using a functional approach (Corazza *et al.*, 2007). The Star calibration was followed by knee flexion and extension trials. The Star movement involved hip flexion, hip abduction, hip extension and hip circumduction to approximately 40 degrees. Knee flexion/extension movements were then performed through the full range of motion. The entire process was completed on a single leg in a single trial. The participant was asked to keep their moving leg off the floor between each iteration of the same movement, but could steady themselves between movements. Greater detail of the full calibration series can be found in Table 6-2.

Table 6-2: Table of the Star calibration on the right foot. Diagram represents the pathway of the participant's foot while observed from above the participant (hip) and from the side (Knee)

Diagram	Joint	Movement	Description
	Hip	T-swing	The participant swings a single leg forward and backwards with a straight knee.
		Star	The participant moves their leg, again straight knee, out from the body in several angles.
	Knee	Flexion / extension	The participant flexes their knee to ~90° and back to fully straight

As previously mentioned, the recruit's movement quality was observed and recorded using the H&LLMS, However, there were alterations to this based on the testing format and military specific cohort. After consultation with military researchers, it was suggested that including gait analysis and a lunge movement, intended to replicate the movement conducted by military personnel while taking a knee, would give greater insight into movement quality changes due to external load.

6.3.4.2 Randomised load

Each participant was asked to complete movements in four conditions, two of which were weighted. This could introduce fatigue which would manifest in the results. To minimise this effect on the movement quality of the recruits, the loaded conditions were randomised. This was achieved by numbering each participant 1-15 for both male and female. Each evenly numbered recruit completed the relative load condition first (Table 6-3), while those who were oddly numbered completed the absolute load condition first. Although this meant that 16 recruits completed the absolute condition first and 14 completed the relative condition first, every recruit completed both conditions. The lack of evenly distributed groups, was unlikely to result in the study producing data that was inappropriate to use for statistical analysis.

Table 6-3: Data collection protocol.

Order	Condition	Test
1	Calibration	Static
		Start
2	Bodyweight	Full H&LLMS
		Gait analysis
		Army specific lunge
3	Bodyweight / Shod	Full H&LLMS
		Gait analysis
		Army specific lunge
Randomised	Loaded / Relative	Single leg bend
		Standing hip flexion
		Gait analysis
		Army specific lunge
	Loaded / Absolute	Single leg bend
		Standing hip flexion
		Gait analysis
		Army specific lunge

Shod: refers to the participant performing the said tasks while wearing shoes.

6.3.5 Data collection

Anthropomorphic data were collected, such as body mass, to the nearest 0.1kg (Seca, Hamburg, Germany), and height, to the nearest 0.1 cm (Invicta, England). Participants were dressed in shorts and t-shirt and were asked to remove their shoes/boots

6.3.5.1 Outcome measures

The study was primarily assessing the interaction between load, sex and movement quality. To assess movement quality, the study used two movement observation tools. Firstly, the current study used a sub-set of the individual movements within the Hip and Lower-Limb Movement Screen (H&LLMS) (Chapter 5). Movements included in the current study deviate from the full set of movement's typically completed in the H&LLMS and removed those movements that were not completed in the standing position, and one was removed to reduce rotation under loaded conditions. The remaining movements are listed below.

a. Hip flexion movement control test (small knee bend with unsupported leg held posteriorly).
b. Standing hip flexion to 100°-110°.
c. Deep Squat.

The H&LLMS was administered, observed and scored by a researcher specifically trained to undertake the H&LLMS. For more information on the training of the research, please see chapter 5 (section 3 and 4).

The study was also interested in assessing the underlying mechanism of the movement screen scores. Therefore, kinematics data was also collected during these same H&LLMS movements. Kinematic data was collected using twelve Vicon cameras with a marker set of fifty three modified by Collins et al. from Hayes (Collins et al., 2009). The kinematics outcome measures were aligned with the faults of the small knee bend (Table 6-4).

Table 6-4: Kinematic of the small knee bend.

Fault	Details
Knee passed the toes (mm)	A measurement of how far the knee protrudes past the final big toe marker on the foot.
Pelvis tilt (°)	A measure of the difference between the level of the floor and the pelvic structure recorded in degrees
Trunk lean (°)	A measure of the difference between the level of the floor and the angle generate by the torso markers recorded in degrees
Medial knee displacement (mm)	A measurement of how far the knee moves medially from the static initial position.
Dynamic knee valgus (°)	A measurement that includes the hip, knee and ankle to establish lateral knee angle if the knee itself did not move. Recorded in degrees
Pelvis level Min (°)	The lowest measure of the difference between the level of the floor and the pelvic structure recorded in degrees
Pelvis level Max (°)	The greatest measure of the difference between the level of the floor and the pelvic structure recorded in degrees
Pelvis level Diff (°)	The difference between the lowest and greatest measure of the difference between the level of the floor and the pelvic structure recorded in degrees

6.3.6 Kinematic model and kinematic data processing

Non-invasive motion capture marker systems typically employ reflective markers attached to the participant's skin on specific anatomical landmarks. Using geometric regression relationships and anatomical norms, these markers are used to define the centre of rotation of joints, such as the hip. However, individual deformities, or group based differences in skeletal forms can lead to errors in joint centre estimation (Taylor *et al.*, 2010). Moreover, such marker sets are highly susceptible to soft tissue artefact movement induced error, which results in errors within the kinematic data. Stretching of skin tissue, location specific muscle dimension changes, due to contraction and muscle vibration due to impact all change the relative location of markers, even though the underlying skeletal structure may have not moved to the same extent. Consequently, the marker location errors are not static or systematic and are associated with phase of the movement.

Taylor et al. (2005) demonstrates that small and non-significant changes in recorded marker location can result in significant differences in joint centre estimations. Taylor et al. (2005) claims that marker based errors can be classified into two main groups that can contribute to separate, and potentially coinciding errors. Firstly, the movement of all the markers on a given segment in the same direction and to a similar extent. Such an error may occur during landing or impact, as the soft tissue surrounding the bone will continue to move in the pre-contact direction, while the hard tissue will have stopped. The second is where the markers move in relation to one another and generate differences in the distance between each marker. This may have been a result of location specifics soft tissue deformation, such that occurs during muscle contraction, skin elasticity and/or the amount of soft tissue artefact (STA).

In an attempt to increase the accuracy of skeleton location the Optimal Common Shape Technique (OCST) was employed (Taylor *et al.*, 2005). Such a marker set and system reverts a limb into individual segments (see Table 6-1) and assumes that the underlying hard tissue will not change shape during movement. The system uses the positions of a set of markers to generate a mean shape of the limb segment during a calibration trial through a Generalised Procrustes Analysis (GPA) (Taylor et al., 2005). These markers are located on either, specific anatomical landmarks such as the lateral epicondyle of the knee, or areas of a limb segment such as superior aspect of the anterior portion of the thigh. The average shape was then mapped onto the respective markers during the dynamic activity (i.e. the Hip and Lower Limb Movement Screening Tool) using an Ordinary Procrustes Analysis (OPA) (Taylor et al, 2005). The OCST assumes that the shape is rigid, and therefore it removes the soft tissue artefact error by ensuring the distances between each marker remain constant. Taylor et al. (2005) claims that this was due to the individual marker contributing a smaller overall impact on the joint centre estimation. As such, the OCST represents a joint centre estimation technique that is less likely to present with STA errors. However, the OCST employed by Taylor *et al.* (2005) was still liable to errors associated with all markers moving in the same direction, and would likely shift the joint centre in the direction of the unison shift of markers.

During the study, the three joint centre estimation techniques showed small differences in individual marker location and movement [9.36 mm (Point Cluster Technique), 5.0mm (OCST), and 4.9mm (Raw Average)]. However, they stated that these changes in individual marker location resulted in large errors in the calculated position of the hip joint centre. Although this shows that the OCST and the raw average are more aligned, the study highlighted that the errors within the techniques was greater than the differences between them.

The participant was asked to perform a set of calibration movements called the Star Calibration (Table 6-2) and maximal knee flexion and extension. The calibration employed joint specific movements, such as rotation and circumduction at the hip, and flexion/extension at the knee. All movements were completed three times on each leg. These calibration movements were then used to generate an average shape of the markers on each segment.

6.3.6.1 Joint centre of rotation / axis estimation

Observing and recording human movement is typically achieved by attaching reflective markers to an individual's skin. To assess movement, from these markers relies on being able to interpret the underlying structures, anatomical landmarks and joint centres although no direct measurement of these can be made in most cases. To do this, techniques, such as the geometric regression relationship, have been developed. This identified the location of joint centres based on the relative location of the reflective markers on joint specific anatomical landmarks. For example, the centre of hip rotation would be based on the markers location of the right and left anterior and posterior superior iliac spine. However, these methods are subject to error through marker placement variations, anatomical abnormalities as well as soft tissue artefact (STA) movement. Taylor *et al.* (2010) claims that other methods exist that minimise these errors and are therefore preferable for dynamic human movement observation and recording. To overcome these issues the Symmetrical Centre of Rotation Estimation (SCoRE) and Symmetrical Axis of Rotation Approximation (SARA) were employed to generate the centre of rotation of the hip and the functional axis of the knee. This was achieved by employing a functional approach where the movement of the markers, regardless of location, would identify the centre of rotation. During the Start Arc movement, introduced in section 6.3.4.1, each marker travels in an ellipse, which would continue through a full circle if the joint would allow. The Star Arc includes movement in the sagittal and frontal plane and consequently results in 3D elliptical movements. These similar movements performed in different planes highlight a singular centre of rotation or axis depending on the joint. This is performed twice in opposing direction during the calibration. Once established, these Centre of Rotation (CoR) and Centre of Axis (CoA) are mapped onto the dynamic trials. Taylor *et al.* (2010) demonstrates that the OCST, SCoRE and SARA, combined approach (OSSCA) is more repeatable and reproducible than the regression approach through 600 motion capture trials. This was demonstrated between trials and between days, which highlights the lack of influence the location of the individual marker has on the kinematics output. As the current study will be recording participant movements on different days, there is little likelihood of accurate replacement of markers through all participants. Therefore, the OSSCA approach may prove the most appropriate model for the current study.

6.3.6.2 Incomplete data

During data collection some markers became obscured and therefore are missing. When this occurs, the accuracy of the kinematics reduces and in some cases where multiple markers from the same segments are missing, kinematic data are unable to be generated. Therefore, these segments of missing data, or gaps, must be reconstructed in order to generate accurate kinematics. Either side of a gap created by a missing marker, there are data for where said marker was (x) and will be (y). Recreating this marker path could be as simple as generating a straight line from x to y, however, it is unlikely that the marker moved in such a simple straight line. Therefore, more specific estimations are required.

Vicon has integrated gap filling processes that allow for a single marker to be reconstructed based on markers in close proximity and/or on the same segment as the missing marker. These are “Spline”, “Pattern”, “Kinematic” and “Rigid body”. These use different mathematical procedures in order to estimate the location of the missing marker through a given set of frames which produces a marker pathway. The current study has chosen to use the OCST, which generates a rigid segment for each limb section using all markers on said limb section. Therefore, it would be most appropriate to use a gap filling algorithm that bases its estimations on total rigid limb section movement. Therefore, in all cases where available, the “rigid body” gap fill method was chosen. In order for this process to operate, two conditions must be met. Firstly, at least three markers that are near to and/or on the same limb section must be selected as donor trajectories. From this, the movement of the donor markers are used to estimate the location of the missing marker in each fame. Secondly, the missing marker must be visible in at least one frame during the recording.

This process is unable to know the specific movement based deformation to the location of the missing marker, there will be an amount of potential error when regenerating a marker for any length of time. However, as previously stated, the individual contribution of each marker to the kinematic model is very small. Therefore, if the regenerated marker is inaccurate, this would have a very small effect on the overall shape of the rigid segment, and therefore the estimations of joint centres based on this. However, this potential error increases with the length of gap. Therefore the current study only used the rigid segment gap filling process for gaps of less than 100 frames, or 1-second. If a gap was discovered over this limit the gap was not filled. This did result in a small number of missing kinematics data, however, as all pertinent movement variables remained accessible, this was not seen to be detrimental to the study.

6.3.7 Data analysis

During the current study, participants were asked to perform all tests within the load specific H&LLMS as well as military movements three times per load condition. Weight of load and sex were defined as independent variables, whereas all aspects of the human movement were considered dependent variables. Movement aspects such as joint angle, joint movement, movement speed, bilateral differences, and H&LLMS score were all measured, collected, and analysed to establish if a difference was present within and between the three load conditions. The variables were extracted based on research previously undertaken by the University of Southampton Research Group, where Matlab functions were used to automate the extraction of the variables at specific events (Table 6-5)

Table 6-5: Small knee bend event timing used to establish when specific kinematic data was collected from and until.

Event	Joint kinematics	Timings to identify
1	End of double support	When non weight bearing knee angular velocity > 10% of maximum angular velocity
2	Start of standing leg flexion	Angular velocity weight bearing knee > 10% of maximum knee angular velocity and non-weight bearing knee flex >60 degrees or event 1 if unsupported knee flexion not reach 60 degrees
3	End of standing leg flexion	Angular velocity weight bearing knee < 10% of maximum angular velocity
4	Peak knee flexion	Maximum weight bearing knee flexion
5	Start of standing leg extension	Angular velocity weight bearing knee < 10% of minimum supported knee angular velocity and after event 4
6	End of extension	Angular velocity weight bearing knee < 10% of minimum supported knee angular velocity and after event 5
7	End of single leg stance	When non weight bearing knee angular velocity > 10% of minimum angular velocity

6.3.8 Statistical analysis

An Independent samples T-test was initially used to establish differences in demographic data between the sexes, such as height and weight, as well as performance based differences. The study has previously stated that the use of movement screen totals is unspecific and potentially vague, however, here the H&LLMS total score was also assessed for a potential sex based difference. As the full screen was only conducted under unloaded barefoot condition, there was no assessment of total H&LLMS score between loads. Further analysis was split into two sections. One being the analysis of the H&LLMS scores between the load condition; while the other analysed the movement kinematics between the load conditions.

6.3.8.1 H&LLMS scores:

Only the small knee bend and standing hip flexion were conducted under all load conditions to reduce the risk to the participants. Therefore, these were the only movements assessed for an interaction between sex and load. Multiple mixed measures ANOVA tests were used to establish the interaction effect and main effect of sex and load, with H&LLMS movement score as dependent variable and load and sex as independent variables. Sex was defined as two separate groups of male and female, while load was separated into three conditions of: no load, 16kg load and a load that represented 33% percentage of the individuals body weight. The movement scores are compiled of multiple faults scored dichotomously. As such, these data are nominal or binary and therefore cannot be subjected to the same analysis. Therefore, Chi^2 tests were performed to assess the difference in frequency of the faults between the two dependent variables of load and sex.

6.3.8.2 Kinematics:

The only movement subject to kinematic analysis within the current study was the small knee bend. In the same way the H&LLMS score was analysed, multiple mixed measures ANOVA tests were used to establish the interaction effect and main effect of sex and load, with kinematic data as dependent variables and load and sex as independent variables. Again, sex was defined as two separate groups of male and female, while load was separated into the same three conditions stated previously.

During all mixed measures ANOVAs conducted in the current study, Mauchly’s test was used to test the assumption of sphericity. If Mauchly’s test yielded a p-value of less than 0.05, the assumption of sphericity had been violated. At such a point the Greenhouse-Geisser correction was used to establish a significant interaction or difference. Moreover, if a significant difference was established for any individual movement score, subsequent assessment of the constituent faults that culminate as the movement score were also subject to statistical analysis. Post-hoc analysis was conducted using a Bonferroni test and alpha levels were set at 0.05. Data were collected and stored using Microsoft Excel and analysed using SPSS 24. The null hypotheses were rejected if an alpha value of less than 0.05 was achieved.

6.4 **Results**

6.4.1 The comparison of males and females.

Anthropomorphic data, fitness data and screen total were examined for significant differences between male and females (Table 6-6). The only significant difference was found for personal fitness assessment (PFA), which was a 1.5mile run (p=0.015). The difference represented a 1min 15 second difference over 1.5 miles. This resulted in a 1.4kph higher run speed in males (Male= 13.8kph, Female=12.4kph). As this was the only significant difference between the sexes, any significant differences seen between movement kinematic or movement fault is likely to be influenced by variables other than anthropomorphic variables.

Table 6-6: Anthropomorphic and performance outcomes between male and females.

Outcome	Sex	Mean	Minimum	Maximum	Diff	P value
Height (cm)	Male	170.22±7.69	158.00	182.00	0.68	0.832
	Female	169.54±7.13	157.00	187.00		
Personal Fitness Assessment (sec)	Male	626.91±76.68	536.00	756.00	-75.16	**0.015 ***
	Female	702.07±65.88	583.00	789.00		
Body mass (kg)	Male	75.67±12.86	54.00	101.00	9.03	0.060
	Female	66.64±12.37	46.00	93.00		
Screen total	Male	19.27±5.61	8.00	29.00	2.8	0.194
	Female	16.47±5.90	7.00	25.00		

“*” refers to significantly different results

6.4.2 Interaction effect

The only H&LLMS movements that were conducted under loaded conditions were the small knee bend and standing hip flexion (Table 6-7). Both movements were scored as a total movement score as well as the individual fault components of these movements. As the individual components are recorded as dichotomous, ‘fault’ Vs ‘no-fault’ (1 Vs 0) these data were not subjected to parametric testing and instead were analysed separately once interaction was either established or not. Analysis of all the total scores revealed only two significant interaction effects. These were for both left and right legged small knee bend total. No interaction effects were found for the standing hip flexion. A post hoc analyses of the “simple effects” encompassed by the interaction were established using pairwise comparison (Table 6-9).

Kinematic data were also analysed for interaction effect. The only H&LLMS movement to be analysed for kinematic variables was the small knee bend, which produced eight variables per side (Table 6-8). Such analysis revealed that “cm passed the toe” was the only variable to presented with significant interaction effect. A post hoc analyses of the “simple effects” encompassed by the interaction were established using pairwise comparison (Table 6-10).

Table 6-7: Small Knee Bend and standing hip flexion movement screen data assessed for an interaction and/or main effect.

		Bodyweight		Percentage		Absolute		P-Values		
Side	**SKB component**	**Male**	**Female**	**Male**	**Female**	**Male**	**Female**	**Interaction**	**Load**	**Sex**
Left	**SKB total**	2.80±1.08	2.27±1.22	2.33±1.40	2.87±0.99	2.73±1.16	2.73±1.10	**0.014 ***	0.485	1
	SHF total	2.20±0.94	2.00±0.65	1.80±0.77	1.87±0.83	2.07±0.70	1.87±0.74	0.493	0.126	0.651
Right	**SKB total**	2.67±1.05	2.20±1.15	2.47±1.25	2.73±1.10	2.47±1.36	2.73±1.10	**0.029 ***	0.442	0.955
	SHF total	2.07±1.10	2.00±0.65	1.80±0.86	1.87±0.83	1.93±0.80	1.93±0.80	0.83	0.196	1

Data displayed in Mean ± SD.

* = Indicates significant P-value <0.05.

Table 6-8: Small Knee Bend kinematic data expressed as divided between load and sex to assessed for an interaction and/or main effect.

		Bodyweight		Percentage		Absolute		P-Values		
Side	**Kinematics**	**Male**	**Female**	**Male**	**Female**	**Male**	**Female**	**Interaction**	**Load**	**Sex**
Left	**cm passed**	65.54±11.76	72.59±7.06	64.48±9.21	63.91±6.75	64.25±7.22	65.30±11.13	**0.02 ***	**0.001 ***	0.393
	Pelvic tilt	10.79±6.89	13.47±7.02	8.38±6.44	10.30±6.32	11.72±10.38	12.69±5.84	0.721	**0.011 ***	0.438
	Trunk lean	10.27±6.96	12.81±8.16	8.83±5.29	11.67±7.37	10.43±6.39	11.75±7.32	0.532	0.192	0.367
	Dynamic distance	-13.22±31.91	-3.61±21.43	-7.42±24.89	-4.87±20.67	-3.52±21.90	-4.42±23.45	0.382	0.513	0.628
	Dynamic angle	-9.54±6.02	-9.40±5.05	-7.19±4.55	-8.99±5.88	-7.68±4.06	-8.29±6.94	0.524	0.162	0.672
	Pelvis level Min	-4.28±1.77	-4.55±1.56	-4.55±2.83	-4.62±2.47	-4.92±2.88	-3.77±1.75	0.058	0.731	0.719
	Pelvis level Max	2.25±1.98	3.09±2.47	3.05±1.73	3.73±2.06	3.26±3.22	4.46±3.30	0.843	**0.037 ***	0.248
	Pelvis level Diff	-6.53±2.50	-7.65±2.91	-7.22±3.37	-7.41±3.95	-8.71±3.67	-8.22±3.49	0.361	**0.037 ***	0.795
Right	**cm passed**	66.58±12.62	73.18±7.67	62.19±7.29	64.57±7.32	62.63±7.74	67.78±8.81	0.244	**<0.0005 ***	0.109
	Pelvic tilt	11.61±6.29	13.11±8.49	8.73±6.08	10.82±7.21	8.96±5.15	12.22±7.04	0.497	**0.004 ***	0.341
	Trunk lean	10.66±6.78	12.84±8.61	8.24±5.74	11.66±9.62	9.47±6.40	11.27±7.61	0.631	0.112	0.353
	Dynamic distance	8.70±17.96	-4.45±35.00	7.73±21.08	9.78±23.34	20.77±22.97	19.43±74.63	0.588	0.071	0.711
	Dynamic angle	-8.77±6.39	-7.42±4.85	-12.31±14.99	-18.57±35.76	-9.38±6.72	-13.05±13.76	0.682	0.255	0.483
	Pelvis level Min	-2.61±2.56	-3.72±2.07	-3.68±2.23	-3.81±2.83	-4.00±2.89	-3.55±2.35	0.154	0.239	0.738
	Pelvis level Max	4.95±2.56	3.70±1.77	4.83±2.25	3.98±1.73	4.03±2.08	4.04±1.94	0.13	0.465	0.299
	Pelvis level Diff	-7.56±2.51	-7.42±2.24	-8.51±3.41	-7.79±2.22	-8.02±3.13	-7.59±2.23	0.771	0.265	0.617

Data displayed in Mean ± SD and statistically significant results are indicated by the inclusion of "*" and bold numbering.

Table 6-9: Post-hoc pairwise comparisons of small knee bend total.

Side	Sex	Load		M Diff	SE	Sig	95% CI	
							LB	UB
Left	Male	1	2	0.467	0.322	0.507	-0.408	1.341
		1	3	0.067	0.284	1.000	-0.705	0.838
		2	3	-0.400	0.254	0.415	-1.092	0.292
	Female	1	2	-0.6	0.214	**0.042***	-1.181	-0.019
		1	3	-0.467	0.192	0.087	-0.988	0.055
		2	3	0.133	0.091	0.493	-0.114	0.380
Right	Male	1	2	0.200	0.262	1.000	-0.512	0.912
		1	3	0.200	0.223	1.000	-0.405	0.805
		2	3	0.000	0.239	1.000	-0.650	0.650
	Female	1	2	-0.533	0.215	0.080	-1.118	0.052
		1	3	-0.533	0.215	0.080	-1.118	0.052
		2	3	0.000	0.000	N/A	0.000	0.000

Data displayed in Mean diff ± SE and statistically significant results are indicated by the inclusion of "*" and bold numbering.

Table 6-10: Post-hoc pairwise comparisons of cm passed the toe kinematics.

Sex	Load		M Diff	SE	Sig	95% CI	
						LB	UB
Male	1	2	-4.113	2.775	0.486	-11.733	3.507
	1	3	-3.881	2.673	0.511	-11.221	3.458
	2	3	0.231	1.641	1.000	-4.274	4.737
Female	1	2	3.963	1.874	0.155	-1.086	9.012
	1	3	2.571	2.270	0.826	-3.545	8.687
	2	3	-1.392	2.070	1.000	-6.969	4.185

Data displayed in Mean diff ± SE and statistically significant results are indicated by the inclusion of "*" and bold numbering.

Small knee bend total score for both left (Figure 6-2) and right (Figure 6-3) show that females in bodyweight conditions produced the lowest score, whereas females in the loaded condition produced the highest score. Conversely, males are able to produce lower scores while under loaded conditions, with the percentage load of their left leg representing the male's lowest score.

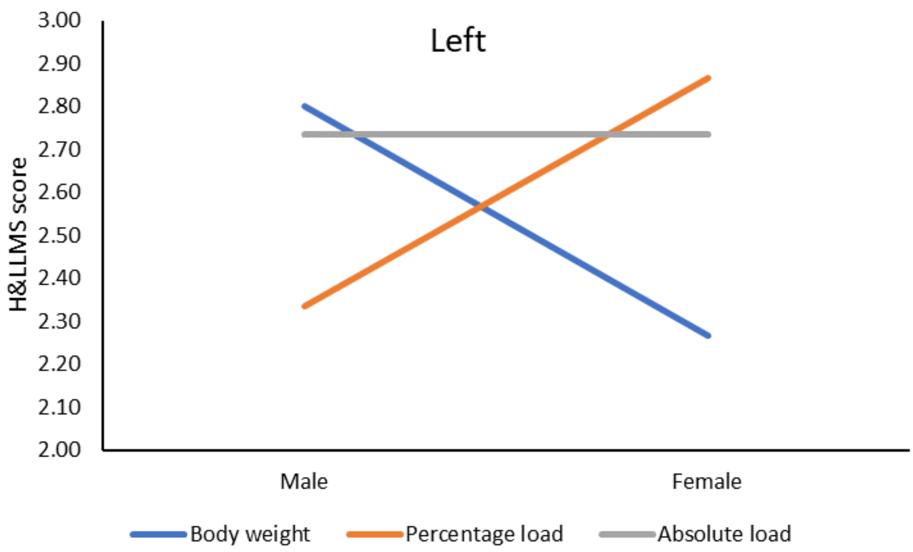


Figure 6-2: The interaction between sex and load on H&LLMS score during the small knee bend

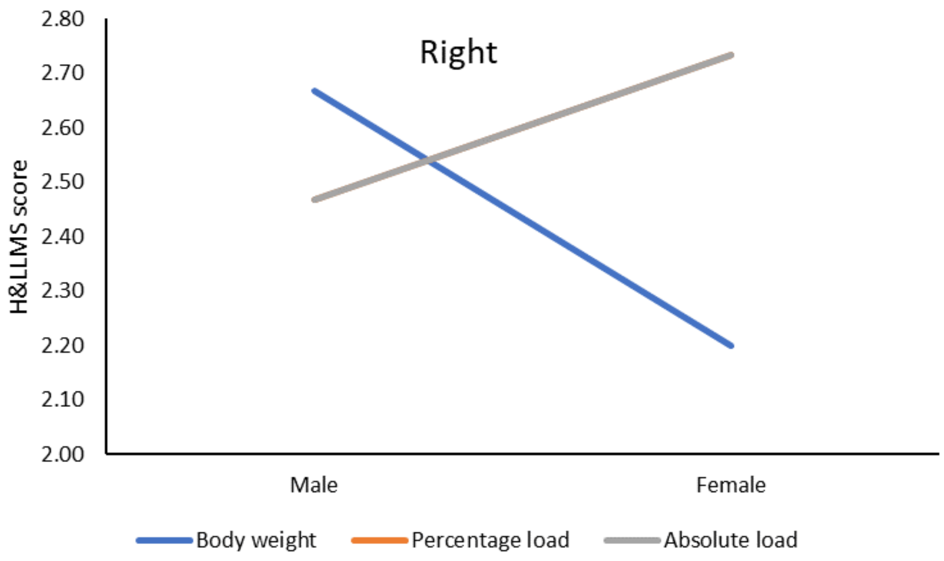


Figure 6-3: The interaction between sex and load on H&LLMS score during the small knee bend. The data line representing the “percentage” load is directly behind the “absolute” line as their mean data were almost identical.

Kinematics for the left legged variable “knee passed the toe”, showed that males present with similar anterior knee protrusion values regardless of load condition. Whereas females show greater values of anterior knee protrusion in the bodyweight condition (Figure 6-4).

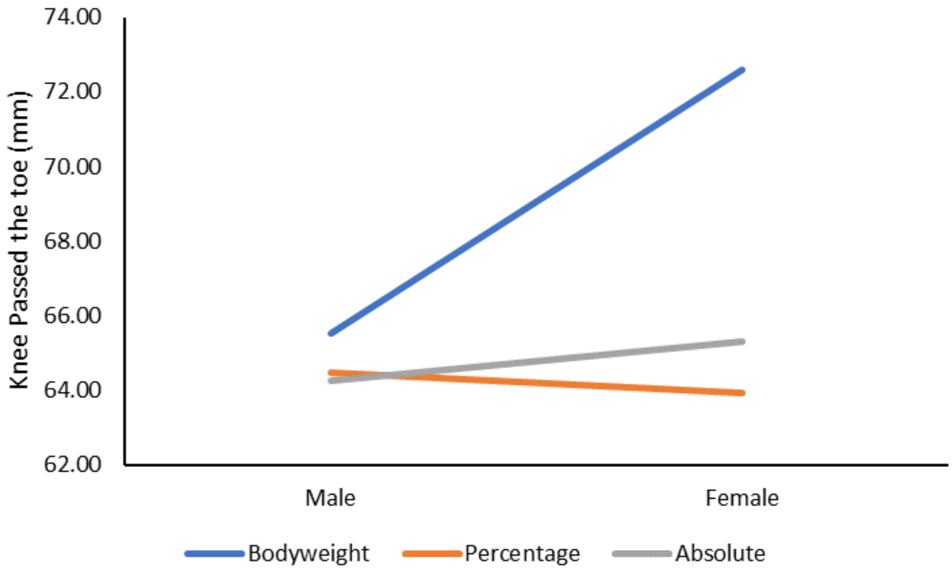


Figure 6-4: The interaction effect between sex and load on kinematics during the small knee bend left.

6.4.3 Between-load conditions

Variables that did not show a significant interaction effect but did show a significant effect of load are presented in Table 6-11. Chi^2 analysis highlighted that a greater number of faults was shown between the two loaded conditions than the other two conditions combinations. Of these significant results, 10 show significant results for both male and female in a single fault, 5 are significant for females only, and 1 was significant for males only. The data shows that the only fault to not show any significant difference between the load condition was “knee 2cm past toe”, which was also the fault with the lowest frequency.

Table 6-11: Small Knee Bend data presented as frequencies and assessed for Chi^2 significance by load and sex.

		Frequencies						Chi2 significance					
		Bodyweight		Percentage		Absolute		Bodyweight - Percentage		Bodyweight - Absolute		Percentage - Absolute	
Side	SKB component	Male	Female	Male	Female	Male	Female	Male	Female	Male	Female	Male	Female
Left	Knee 2nd toe	8	8	8	13	11	11	>0.05	>0.05	>0.05	**0.013***	**0.013***	**0.012***
	Pelvis hitch	13	11	12	13	14	13	>0.05	>0.05	**0.008***	**0.012***	**0.038***	>0.05
	knee 2cm past toes	1	0	1	0	0	0	>0.05	>0.05	>0.05	>0.05	>0.05	>0.05
	trunk flex	9	9	10	12	10	12	**0.025**	**0.018**	>0.05	**0.018***	**0.007***	**<0.0005***
	pelvis tilt	11	6	4	5	6	5	>0.05	>0.05	>0.05	>0.05	**0.004***	**<0.0005***
Right	Knee 2nd toe	8	7	9	11	10	11	**0.01**	**0.029**	>0.05	**0.029***	>0.05	**<0.0005***
	Pelvis hitch	13	12	12	13	12	13	>0.05	**0.02**	**0.002***	**0.002***	**0.024***	**<0.0005***
	knee 2cm past toes	1	0	1	0	0	0	>0.05	>0.05	>0.05	>0.05	>0.05	>0.05
	trunk flex	8	9	11	12	10	12	>0.05	**0.018**	>0.05	**0.018***	**0.001***	**<0.0005***
	pelvis tilt	10	5	4	5	5	5	>0.05	>0.05	>0.05	>0.05	**0.001***	**<0.0005***

Data displayed in Mean ± SD for continuous data and frequency for nominal data.

* = Indicates significant P-value <0.05.

Analysis of kinematic data demonstrated that “Knee passed the toe” and “pelvic tilt” presented as significantly different for males and female, while pelvic level and pelvic diff presented as significant for the left side only (Table 6-12). No data was collected on which leg was dominant for each participant which limits the interpretation at this point. In the general population there are less than 20% of people who identify as left footed (Carey *et al*., 2001). As stated previously, a military population can be seen as a subset of the general population for many variables. As dominant sidedness is unlikely to be affected by military training, there is no reason to suspect that these population would deviate from this percentage structure by any meaningful amount. The population assessed in this study (n=30) would have been predominately right legged (n=24) and therefore the greater number of significant differences on the left side may be appropriately assigned to their non-dominant leg.

Table 6-12: Small Knee Bend kinematic data between load to assess for a main effect.

		Bodyweight		**Percentage**		**Absolute**		**P-Values**
Side	**Variable**	**Mean**	**SD**	**Mean**	**SD**	**Mean**	**SD**	**Load**
Left	Knee passed the toes (mm)	69.30	10.03	64.18	7.85	64.81	9.37	**0.002***
	Pelvis tilt (°)	12.22	6.97	9.40	6.34	12.24	8.14	**0.013***
	Pelvis level Max (°)	2.70	2.26	3.41	1.91	3.90	3.27	**0.044***
	Pelvis level Diff (°)	-7.12	2.74	-7.32	3.63	-8.45	3.52	**0.041***
Right	Knee passed the toes (mm)	70.10	10.63	63.46	7.28	65.38	8.59	**<0.005***
	Pelvis tilt (°)	12.41	7.46	9.85	6.68	10.70	6.35	**0.004***

Data displayed in Mean ± SD and statistically significant results are indicated by the inclusion of “*”.

Examination of the main effect seen of load revealed that every fault except “knee 2cm passed toe” showed significant difference in movement screen score between the loaded conditions (Figure 6-5). The data show that there are 6 instances where the significant difference is between the two loaded conditions, 2 instances where bodyweight significantly differed from both the percentage load and the absolute load.

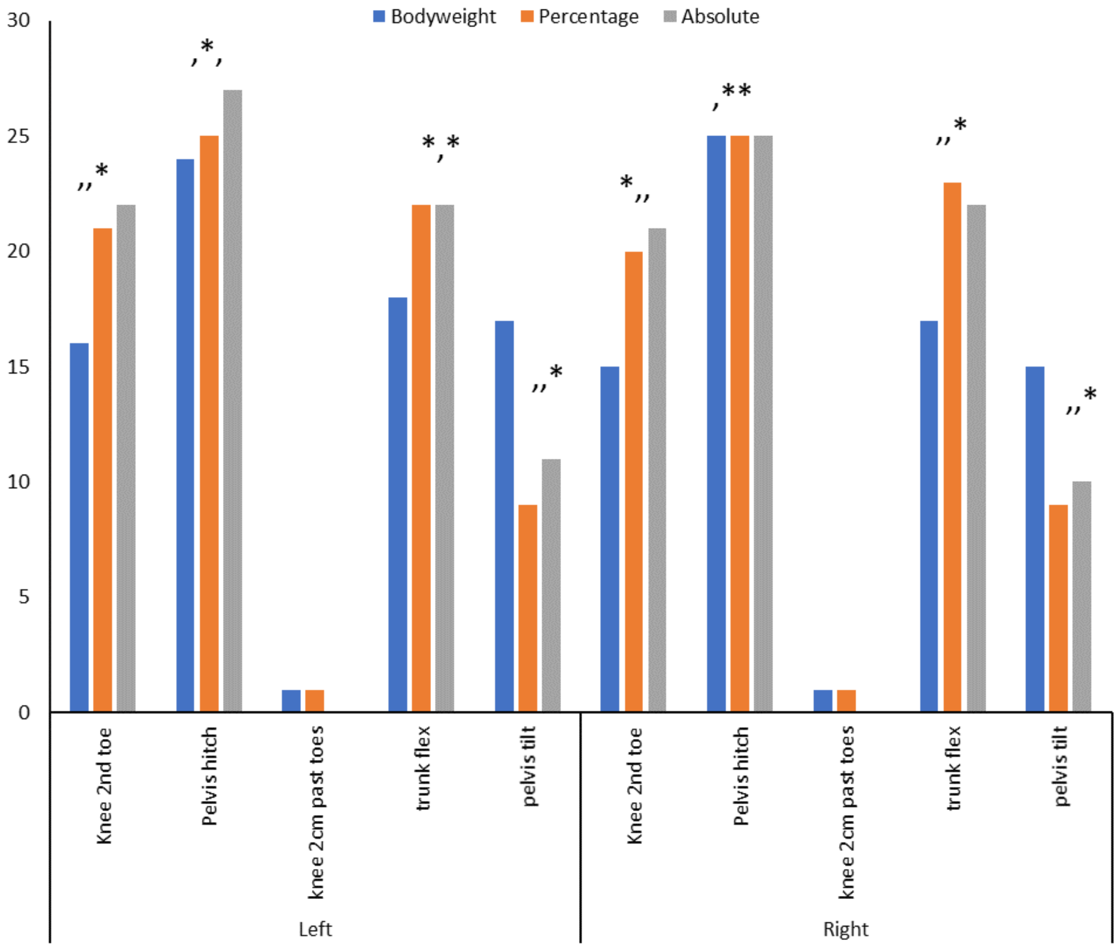


Figure 6-5: Hip and Lower Limb Movement Screen score output of the significant difference of the main effect of loaded condition in the small knee bend.

Key:

*,, = significant difference between bodyweight and percentage loads.

,*, = Significant difference between bodyweight and absolute loads.

,,* = Significant difference between percentage and absolute loads.

Further analysis was conducted on the small knee bend linear and angular kinematics. Of all variables extracted, only “Knee passed the toe” and “Pelvic tilt” demonstrated significant difference between the load conditions for both legs (Figure 6-6). However, “Pelvic tilt max” and “Pelvic tilt diff” showed significant differences between loaded conditions for left leg only (Figure 6-7).

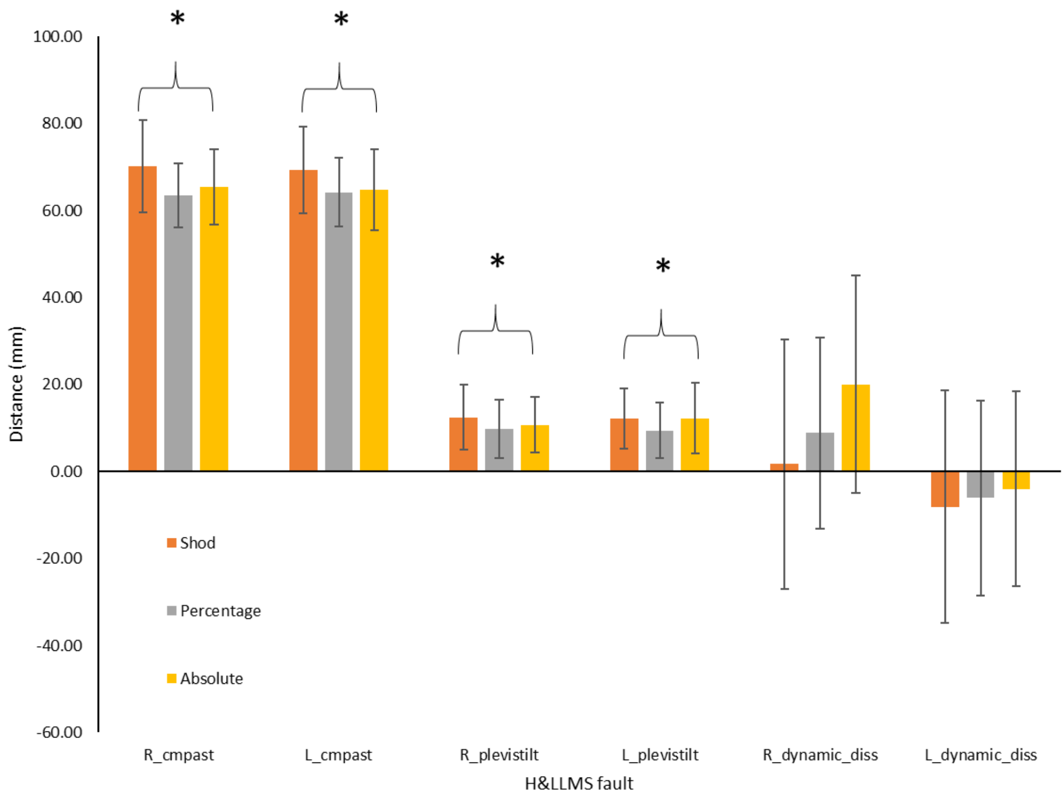


Figure 6-6: Linear kinematic output of the significant difference of the main effect of loaded condition in the small knee bend. “*” refers to significantly different results

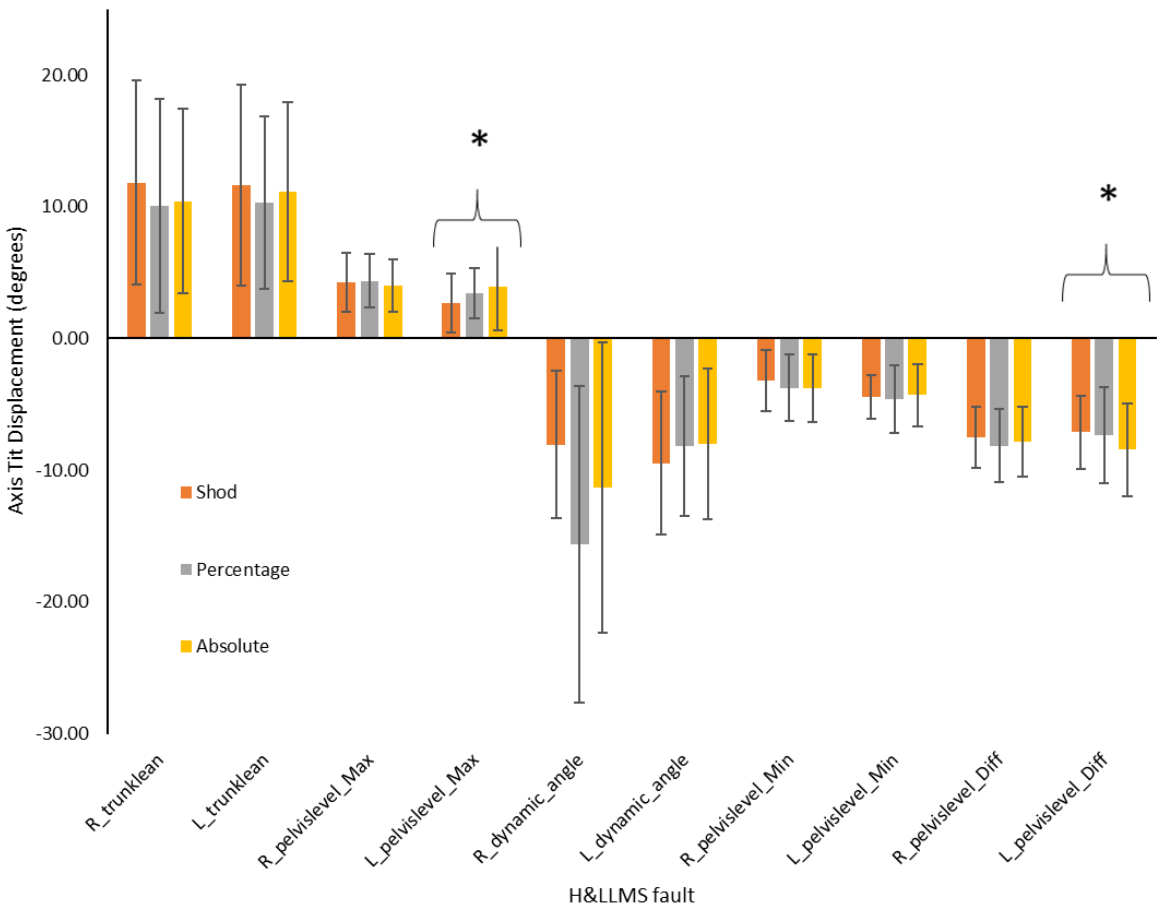


Figure 6-7: Angular kinematic output of the significant difference of the main effect of loaded condition in the small knee bend

The data show that participants in the bodyweight condition achieved a greater distance past the toes with their knee, while the loaded conditions showed similar results. This suggests that the load condition significantly reduced the distance the knee could travel forward over the foot. The data show that there was a significant difference for “Bodyweight – Percentage” and “Bodyweight – Absolute” for “knee passed the toe” kinematics. However, there were no significant differences between the two loaded conditions (Figure 6-8). For “pelvic tilt” only the comparison of “Bodyweight - Percentage” demonstrated a significant difference (Figure 6-9).

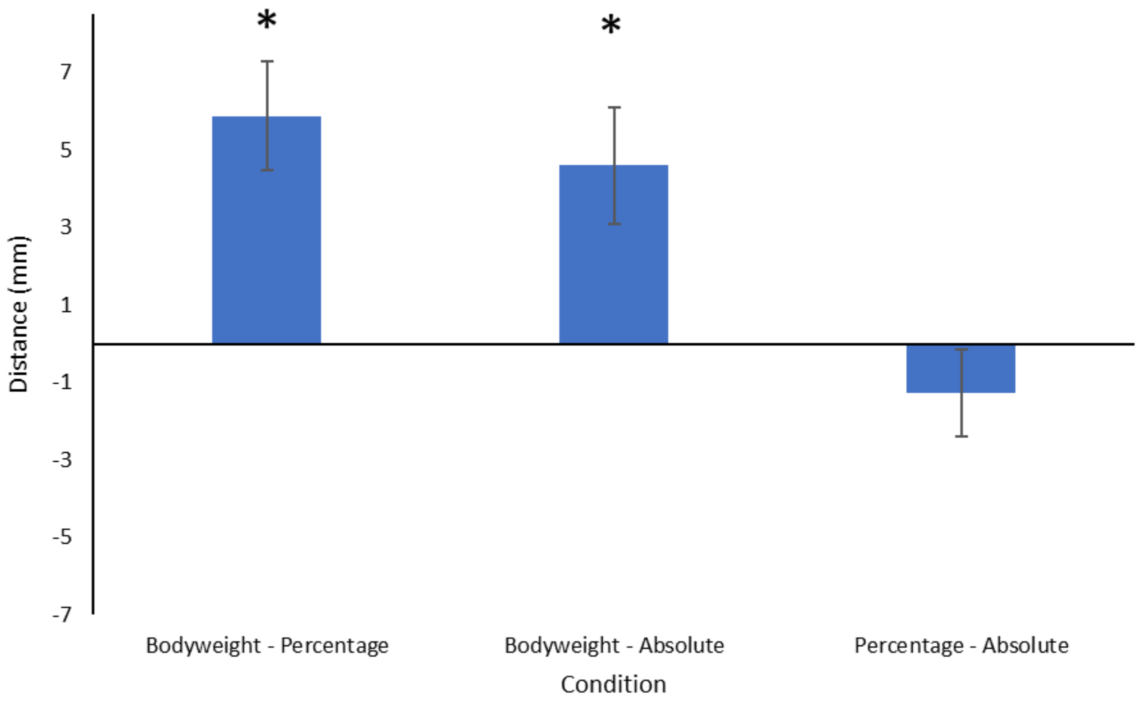


Figure 6-8: Post-hoc analysis of Knee passed the toe kinematics. The difference between the load conditions. * represents significant difference.

Knee passed the toe movement can be altered by squat depth due to the close-chain movement influence. Therefore, this squat depth was assessed based on hip joint centre vertical displacement (Table 6-13). Data shows significant difference between load conditions. However, these do not directly correspond to the "knee passed the toe" differences seen in Figure 6-8.

Table 6-13: Centre of hip joint vertical displacement (mm) between load conditions.

Pairwise comparison	Mean Difference	Standard Error	P value
Bodyweight - Percentage	-14.42	5.11	0.009 *
Bodyweight - Absolute	-9.03	4.81	0.071
Percentage - Absolute	5.39	2.47	0.038 *

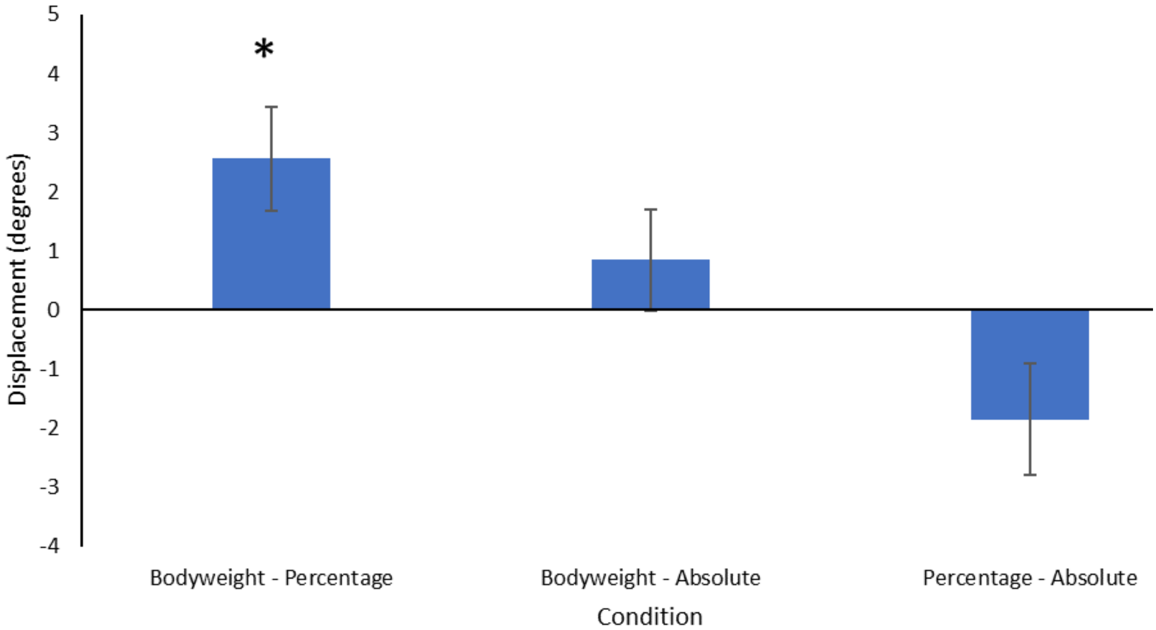


Figure 6-9: Post-hoc analysis of pelvic tilt kinematics. The difference between the load conditions. * represents significant difference.

6.4.4 Comparison between males and females during loaded movement.

Although three variables presented with significant interactions effects, no individual variable showed significant differences between male and female values.

6.5 Discussion

The current study assessed if movement screen, and kinematic differences could be observed between males and females while introducing external load carrying tasks. It was hypothesised that the varying load conditions would result in kinematic changes and that these would be great enough to be observed and recorded by a movement quality screen. The study initially established the presence of interaction effects between load and sex. Two movement screen variables (SKB total left and SKB total right) (Table 6-7) and one kinematic variable (cm past toes left) (Table 6-8) demonstrated significant interaction effects. Both movement screen variables presented with similar interaction. Both presented with females in the bodyweight condition having the lowest score, but would change to the highest score while under loaded conditions (Figure 6-2). Males in the cohort would present with contradicting movement screen scores and although these scores were not as polarising as the female score, males lowest score were seen under loaded conditions (Figure 6-3). Kinematic data for "cm past the toes" demonstrated that males and females respond similarly to the loaded condition. However, under the bodyweight condition, females were capable of a greater knee protrusion than any other combination of condition or sex (Figure 6-4). It was hypothesised that load and sex would both present with a main effect. Load presented with a main effect with six kinematic variables but no H&LLMS movement score (Table 6-12). However, Sex did not show any main effect for any of the screen or kinematic variables.

The H&LLMS total score was used initially to assess the difference between males and females. While females demonstrated lower scores in nearly all movements within the screen (Table 6-6), the total score was not significantly different between the sexes (Table 6-6). This finding is similar to that seen in Gibbs *et al.* (2014), where there was no difference found in the total movement screen score between males (14.6±2.3) and females (14.4±2.4). Despite this, the same study Gibbs *et al* (2014) found that females were still 1.7 times more likely to sustain injury than males in the same cohort during training. That study concluded that there is likely something influencing injury risk that is not recorded by the movement screen used (the FMS). The current study used a different movement screen (the H&LLMS) and found similar results. Therefore, it may be that male to female movement differences that may indicate injury risk, are not observable through movement screens. Therefore, the current study also assessed the underlying mechanism of movement to further understand the differences in movement that may lead to an increased risk of injury.

Kinematic data were reviewed purely on the small knee bend and demonstrated that females in the bodyweight load condition moved their knee a greater distance "cm passed the toe" than their male counterparts in any condition. However, there was no main effect for sex shown within the data, whereas load showed a significant main effect for "cm passed the toe". Previous studies have identified that females present with a greater ankle and knee angle during the same tasks (Majumdar *et al.*, 2010). However, the present study does not concur with this statement. Additionally, a relationship between load and maximum knee angle is established within research (Loverro *et al.*, 2019). These new data suggest that load is likely a factor in the difference in knee kinematics seen in the current cohort. Although a greater knee protrusion is likely linked to a corresponding change in the participant's maximum knee angle, this study did not confirm this. However, as the small knee bend is a closed chain movement, in order to achieve a greater angle at a single joint, requires the surrounding joints to also move further. Therefore, if a participant wanted to produce a greater knee protrusion, they would be able to achieve this by squatting lower. Therefore, the current study assessed vertical displacement of the estimated centre of hip from pre-movement standing to minimum distance from the floor. Pairwise comparison data showed significant differences in the vertical displacement between all conditions except bodyweight and absolute conditions (Table 6-13). This then suggests that the conditions used were different enough to present with significantly different squat movements, with percentage load condition representing the smallest squat depth (149.6mm) and the bodyweight condition demonstrating the greatest squat depth (164.02mm). This suggests that not carrying an external load creates a condition in which the participant is more capable of, or feels more comfortable of, generating greater angles and adopting more extreme positions. However, as the comparisons that show significant difference for "knee passed the toe" and centre of hip joint vertical displacement do not directly match, this cannot be claimed as the causal variable.

The other kinematics data area that presented with load as a main effect was the pelvic, with "Pelvic tilt", "Pelvic level max" and "Pelvic level diff" all differing by load. Mean data (Figure 6-9) show that the lowest pelvic tilt was recorded in the percentage condition which were all below 10°. This variable was generated by assessing how much the pelvis tilted from static values at the start of the trial. Therefore, this is a change from a static value. Consequently, this does not necessarily mean that there was a lesser degree of pelvic tilt during the small knee bend in the percentage load condition. It may mean that those in the percentage condition adopted a greater amount of pelvic tilt during the static portion of the test and therefore were closer to their pelvic tilt limit before moving. Thus reducing the amount of movement they could produce in pelvic tilt. As the percentage load condition represented the greatest load for all participants, it is more likely that the participants were under greater load induced stress and exaggerated their adaptive movements rather than the opposite. However, as the current study did not analyse this variable it is unable to state if this was true.

There were no significant differences between males and females in terms of their height and weight. Moreover, broad analysis of cardiovascular fitness and movement quality was assessed and the only variable to show significant differences was higher pre-enrolment fitness assessment (PFA) run time in females. The lack of significant difference in height and weight will limit the difference in the percentage load used in the study. Consequently, the likelihood of there being a difference in movement screen scores (H&LLMS) or the kinematic data between the percentage and absolute load conditions may also have been reduced. Previous research has demonstrated that the disparity of cardiovascular fitness interacts with injury risk (Lisman *et al.*, 2013) while This study and others have shown that males have a higher level of cardiovascular fitness than females (Table 6-6) (Beck *et al.*, 2000). Therefore, cardiovascular fitness may prove to interact with movement quality. Although running is clearly a cardiovascular activity, movement quality and efficiency play a key role in running speed and therefore time. Consequently, this difference between the sexes may possibly be influenced by movement quality as well as cardiovascular fitness. However, the total movement screen score showed no significant difference, and the participants' running technique was not assessed. Therefore, although the study suggests a sex based differences in running speed and cardiovascular fitness of Phase-2 military recruits, the relevance of sex to movement quality or injury likelihood remains unclear.

The premise for the load variations influencing movement quality between sexes was based on research from Majumdar *et al.* (2010) and the assertion that carrying load over 33% of bodyweight will affect movement patterns. As previous studies that have shown increased injury likelihood in females was also associated with a significantly lower body weight of females (Gibbs *et al.*, 2014), it was suggested that body weight, rather than sex was the main factor in movement quality differences and injury rates. The current cohort of females (66.64±12.37kg) were, on average, 9kg lighter than their male counterparts (75.67±12.86kg). However, this was not significantly different between sexes. This may be pertinent, as it may have resulted in a smaller, and therefore practically irrelevant, difference between the percentage loads used in the study. Percentage load was set at 33% of body weight due to the association of this percentage and movement quality changes in previous research (Majumdar et al., 2010). Based on the average male and female body weight, this would generate critical load values of 24.97kg and 21.78kg respectively. Thus, males have an additional 3.19kg that they can carry before they reach the critical load threshold. Moreover, the absolute load used in the study was 16kg, and therefore the difference between this and the percentage load would have been 8.97kg and 5.78kg for males and females respectively.

Gibbs *et al.* (2014) found that males (75±10.9kg) and females (64±8.7kg) in their study differed in weight by approximately 11kg, which is 2kg greater than the current study. This difference in body weight [males (24.75kg), females (21.21kg)] resulted in a practical difference in the 33% of body weight critical carry limit of 3.63kg between males and females. Moreover, there was also a difference between typical military training carry (16kg) and their 33% critical carry limit (males=8.75kg, females=5.12kg). There was little difference in carrying load between the current study and that of Gibbs *et al.* (2014). Therefore, it is unlikely that these small differences would generate practical differences in movement quality modification between the two studies and suggests that the cohorts of both studies are similar in body mass, as well as sex based critical carry limits. Consequently, the nonsignificant difference in body mass is unlikely to have had a practical difference in the movement quality results.

6.6 **Limitations**

Although assessing a person's movement should typically be conducted while barefoot, the participants in the current study had to support additional external load, which would have increased the force and pressure on their feet. Discomfort from the greater load could have resulted in changes to their movement. Consequently, the study allowed the use of shoes during loaded conditions, which may have resulted in a new variable affecting the person's movement quality. For example, the footwear was not consistent between participants. Therefore, the specific properties of each shoe may have influenced results. Sato et al. (2012) stated that while wearing shoes with an artificial heel raise, participants demonstrated a more upright torso during rear-held barbell squats than those wearing flat shoes. Therefore, if a participant in the current study were to have shoes with a greater heel to toe angle, they would be more likely to be able to attain an upright position during the deep squat movement. This would give them a lower and therefore better score. However, the present study is limited in its interpretation of the impact of the footwear, as the number of participants wearing shoes with a heel raise was not recorded. Therefore, the study is unable to identify who could have benefited from such an advantage or what practical advantage this could have had.

Although this highlights an experimental oversight, the study can justify the use of a participant's actual footwear in two ways. Firstly, having the participants perform each loaded movement without shoes would have likely resulted in movement quality changes across the full range of movement tests due to discomfort. This discomfort based movement modification may have affected the participants' movement in ways which would not represent typical movement. Secondly, the study also conducted non-loaded movement while barefoot and shod to examine the effect of wearing shoes on movement kinematics score. However, this was not conducted on the H&LLMS score. Although the study did assess this effect, the study is unable to determine the effect of the shoes during load bearing movement tasks. Moreover, the current evidence suggests that only the small knee bend kinematics and movement quality would have been affected by the participants' footwear (Sato *et al.*, 2012), leaving the movement of the standing hip flexion unaffected.

Loverro *et al.* (2019) suggested that military service and deployed personnel are more likely to wear and perform operational duties in symmetrically loading vests, and that assessing backpack, or rear loaded carrying is less relevant to military personnel in modern military cohorts. However, this simply shows the lack of relevance to the cohort used within this study. Participants were recruits in the US military, which are likely to have many training and technique differences to the UK Phase-1 military training. During Phase-1 and 2 UK military training, recruits are commonly carrying load in rear loaded backpacks for exercises and physical training. As the current study is attempting to better understand injuries sustained during training, it would be relevant to assess recruits under the conditions in which they are most likely to be exposed to. Moreover, as every member of military personnel is required to pass through both Phase-1 and 2 training facilities, until the practices of these facilities changes and adopts symmetrical loaded carrying, it would be pertinent to assess the effects of such loading on recruits. Therefore, any study attempting to assess the non-combat injury mechanisms within military cohorts should replicate the conditions that personnel would be exposed to while in non-combat situations. As pre-deployment training is perfectly non-combat, replication of training facilities and training would likely give the most controlled situation in which to assess such injury mechanisms. Therefore, the use of rear loaded backpacks is not only still relevant, it may be the most appropriate way in which to assess non-combat injuries sustained by military personnel.

The data from the current study suggest that there is an interaction between a person's sex, external load and the H&LLMS score for the small knee bend. Moreover, "knee passed the toe" kinematics showed a significant difference on the left side only. However, the current study did not record the participant's dominant hand, side or leg. Therefore, it is unclear why such a relationship exists.

Vertical displacement of the centre of hip estimation differed between nearly all the groups. As previously mentioned, the small knee bend is a closed movement. Consequently, the change of one kinematic variable would result in another. Therefore, if a person were to demonstrate a greater vertical displacement of the hip, they would likely show a greater joint angle in the joints distal to the hip. In order to better understand this relationship, an evaluation of these two variables should be undertaken. One potential way of demonstrating such a relationship would be to express these data on an X-Y graph with vertical displacement on the X axis, and joint angle on the Y axis. This way the shape of the movement generated by the load variable could be assessed against one another regardless of the total displacement.

6.7 Conclusions

The present study introduced loaded condition to male and female Phase-2 military recruits to assess if load and sex would influence movement quality. Additionally, the study hypothesised that if movement quality changes were found, that these would be large enough to be observed by both 3D kinematic video capture and movement screen visual observation. The study revealed that load and sex interacted with single kinematic variable ("knee passed the toe"- left leg) one H&LLMS movement (small knee bend total score - left and right leg). Load presented with an interaction for "knee passed the toe" and "Pelvic tilt" kinematic variables, but no movement screen movement total. No interactions were found for sex independently. Therefore, a person's sex itself is unlikely to influence movement enough to present with a sex-based explanation for the 1.7-times higher injury rates in female military recruits.

Assessment of the interaction revealed that females were capable of greater knee protrusion than males and produced their highest score in the bodyweight condition. All other conditions presented with similar data to that of males in the same condition. This may suggest that males and females are similarly susceptible to load induced movement modifications but may start with different abilities while unloaded. Although this difference was considered small and only observed in a single fault. Therefore, this difference may prove to not be clinically relevant if further examination of the subsequent effect on injury likelihood were undertaken.

A person's movement is subject to modification based on the application of external load. However, it is not yet clear that these changes are indicative of, or causal for, any injury. Future research assessing movement and or injury would benefit from investigating and understanding the interaction between load and movement and movement and injury.

6.8 Impact of study

At the point of this thesis being submitted, there has been no practical impact of the current study but it is anticipated that when these findings are distributed through the military report system, there may well be the possibility to generate an Randomised control trial (RCT) on the interaction between load and movement quality over a Phase-1 training period. Total load exposure, average actual load, and how the load is introduced over the Phase-1 training can be assessed during the RCT. Previously in this thesis, it has been mentioned that at the end of Phase-1 training, all recruits must be able to carry the same load. However, there is no requirement to be able to do this in week-1. Therefore, this thesis suggests a staged based introduction of load in either percentage of body weight or absolute load increments. More research into this area would likely yield practically relevant and implementable protocols that would benefit military recruits without interfering with military training.

Chapter 7: A neuromuscular exercise intervention to improve movement control of male and female Phase-1 military recruits: proof of concept study and pilot RCT

7.1 Introduction

With the opening of Ground Close Combat (GCC) roles to women, there has been an urgent need to increase understanding of the causes and mechanisms of musculoskeletal injury (MSKI) within the UK Armed Forces population, and specifically with respect to female military personnel, to enable the development of effective countermeasures. The "Mitigating Injury Risk in Dismounted Close Combat Personnel: Improving Movement Quality of Military Personnel to Protect Hips and Lower Limbs from Injury" research programme aimed to further understand the variables contributing to an increased injury risk in GCC personnel undertaking military training. The present chapter represents the third study within this research programme which entailed a field study that examined the differences in movement quality between male and female personnel using the H&LLMS, the effect of military training on movement quality, and the feasibility and effect of implementing an exercise intervention to improve movement quality in a military training establishment.

Although a great deal of attention has been given to injuries in male cohorts and interventions to reduce them, females are 1.7 times more likely to sustain lower limb injuries in general and are said to be 3.5 times more likely to sustain an ACL injury (Voskanian, 2013). Soligard et al. (2008) demonstrated that 1,892 female football players between 13-17 years, participating in the FIFA 11+ as part of a warm-up, significantly reduced total injury, overuse injury and severe injury likelihood over a competitive season. Between the control (n=837) and intervention (n=1055) groups there was a significant reduction in: total injuries (32%), overuse injuries (53%), and severe injuries (45%). Moreover, Thompson et al. (2016) used biomechanical filming to assess knee movement during double leg landing before and after the FIFA 11+ injury prevention warm up in 51 adolescent female football players. The study showed that the intervention significantly reduced knee valgus moment during double leg jump landing compared to the control group and pre scores. The study concluded that the observed decrease in valgus knee movement would likely result in fewer injuries, as knee valgus movement is highly linked to ACL and knee injuries. However, until injury likelihood is established in a longitudinal study post-intervention, this research is unable to state categorically that this intervention and the resultant reduction in knee valgus movement, would have an effect on injury risk.

Due to the way in which Phase-1 training facilities manage time and troops, any intervention aimed at reducing injury risk in females would also have to be included for male troops. As such, the present study will represent the first study that will examine the movement quality differences before and after an intervention within a mixed sex cohort. In the context of this research programme, movement control was defined, after Comerford and Mottram (2001), as a person being able to cognitively control movement at a specific joint (e.g. in the context of the present protocol, the hip) and maintaining this control during movement at an adjacent joint. The purpose of having good movement control is to ensure the joints are well aligned during movement to prevent abnormal loading and damage to the joint, which could lead to stress fractures (Jones *et al.*, 2002), cartilage damage (Bennell *et al.*, 2011) and joint surface damage that may lead to osteoarthritis (Bennell and Hinman, 2011). Movement quality will be dependent upon the ability to control movement effectively.

Previous chapters within this research programme have shown that no significant difference exists between male and female Phase-2 military recruits. However, this chapter will be focusing on Phase-1 military recruits. As suggested in previous chapters, these cohorts might be more accurately defined as a subsection of the general population due to their non-exposure to military training at the point of enrolment. Additionally, this research study outlined in the current chapter will start and collect movement quality data on the second day of enrolment. Consequently, there is a potential for a sex-based movement quality different to exist at such a point where no military training has been conducted. Therefore, this study will continue to assess the movement quality between the sexes regardless of the conclusion of the previous chapter.

7.2 Aims and Hypotheses

7.2.1 Aims

1. To examine the movement control of those who enrol in Phase-1 military training.
2. To assess if there are differences between males and females in their movement quality prior to Phase-1 military training.
3. To examine the effect of military training on movement quality on Phase-1 recruits.
4. To assess if a pre-exercise neuromuscular warm-up intervention can improve the movement quality of Phase-1 military recruits.
5. To assess the differences between male and female Phase-1 recruits' movement quality after a pre-exercise neuromuscular warm-up intervention.
6. To examine the feasibility of implementing a pre-exercise neuromuscular intervention in Phase-1 training establishments

7.2.2 Hypotheses

H_1 There will not be a significant difference between control and intervention group prior to the neuromuscular intervention.

H_2 There will be a significant difference in movement control ability between male and female recruits prior to initiating phase-1 military training between the intervention and control groups

H_3 There will be a significant difference in movement quality between the intervention and control groups post-intervention.

H_4 There will be a significant difference in movement control ability between males and females following a neuromuscular warm-up programme undertaken during phase-1 military training

7.3 Method

7.3.1 Study design

The current study was comprised of four study design types and used a mixed method approach, which is further explained in the following sub-headings and subsequent chapter.

7.3.1.1 Prospective cross sectional observational study design

Initially, the study assessed the level of movement control in Phase-1 military recruits before training had begun, using a prospective cross-sectional observational study design. During Phase-1 training, a single intake represented three troops segregated by sex. As males remain the larger population in military cohorts, two of the three troops contain males while the remaining troop were all female. In order to obtain an equal amount of both sexes, only a single male troop was used for the study. The male troop whose physical training regime most closely resembled that of the females was used. Although the observation study did not separate the recruits into intervention based groups, only those selected for the observation study would be recruited for the subsequent intervention study. Therefore, at this point, all recruits were provisionally allocated to either intervention or control, in preparation for the intervention study.

7.3.1.2 Feasibility study design

The study assessed the ability of military Physical Training Instructors (PTI's) to undertake and oversee the implementation of a novel exercise intervention, and therefore represented a feasibility study design. The study also served to better understand the intervention integration strategy for military training establishments. Assessment compliance and adherence data would assist in creating a more efficient design for a future RCT with similar cohorts.

7.3.1.3 Feasibility study of the effect of a neuromuscular warm-up programme

The study examined differences in movement quality between male and female military recruits. More specifically, the study was interested in the differences between pre and post-intervention movement quality changes between sexes. Moreover, the study also examined whether or not movement control can be altered by using a pre-workout muscle activation intervention specifically targeting hip and groin region muscles when assessed against a control condition cohort. Consequently, this aim required a pilot RCT study design. As stated earlier, two troops per intake were selected for testing, and these were then reselected for the intervention study. In order to randomise which intake would receive the intervention and which would be a control group, cluster randomisation was employed. This manifested in the first and third intake being enrolled on the intervention group, while the second would be in the control. This resulted in two control troops and four intervention troops. These groups were maintained throughout the study and into the intervention group.

7.3.2 Ethics

The protocol for this study was approved by the Ministry of Defence Research Ethics Committee (Reference: 781/MODREC/2017) and was conducted in accordance with the ethical standards of the Declaration of Helsinki. Specifically, various measures were established to maintain these ethical standards. This research programme was conducted in accordance with the Medical Research Council (MCR) Good Clinical Practice (GCP) guidelines. As such, the study team could have been subject to an independent GCP audit if required, under the direction of the RNSAC/MODREC, to ensure that the scientific approach, as well as the safety and ethical conduct of the study, was appropriate. PTI's were fully trained in implementing the training schedule, recruits were fully informed of the intervention and the impact this would have on them and their time, and recruits were given the opportunity to withdraw at any point during the study without compromising their position in the services. However, as the intervention was administered as part of the standard warm up, all recruits, even those not participating in testing, completed this intervention. The intervention warm-up is similar to the 11+, formerly the FIFA 11+ (Barengo *et al.*, 2014) and therefore, although the recruits had no choice in which warm-up they undertook, neither the military-specific nor the neuromuscular intervention was likely to increase injury risk.

To maintain anonymity, recruits' names, military numbers, and study numbers were kept separate and were never on the same documentation. Documentation transportation was minimal, and done so only when completely necessary. Each document was moved only once, directly from the military institute to the University of Southampton, at which point, the documents were then stored in a restricted room, in a locked filing cabinet. Data were digitised for safety and ease of use. When completed, all documents were stored on a password protected hard drive.

Recruits who participated in the study were refunded for their time. This is common practice in military populations as they are employees, and therefore their time is given a monetary value. The intervention itself had never been used in military populations previously, but similar interventions have shown an ability to significantly change movement quality as well as injury rates in sports populations (Soligard *et al.*, 2008).

7.3.3 Participants

7.3.3.1 Selection

The study required male and female recruits. Therefore, specific Army bases that typically recruit a higher than average number of females were specifically targeted for recruitment. Therefore, heads of bases that showed female intake above 12% were asked directly if they wished to be considered for participant recruitment. After agreeing to participate in the study, the army training facility was sent information packs to distribute to the selected recruits, based on the date that the study would start and finish. The end date was dictated by the breaks in training that would cease continued exposure to the intervention. For example, over Christmas, all recruits are given 2-weeks leave. This would have affected the intervention and potentially the results of the study. Consequently, the study had to ensure that it ran between two of these breaks. The study ran for 4 months and recruited all six troops scheduled for intake during this time. Although this reduced the randomness of participant selection, the study still employed cluster randomisation for the troops themselves, which were randomly allocated intervention or control group.

Twenty four hours prior to testing, members of the study team explained the testing procedure to the recruits and answered any questions that they might have. The explanation included: how long the testing would take, clothing required and what to expect from the testing team. Participants were military employees, and as such anything above their military training requires financial reimbursement. Therefore, we also explained that they would be paid for the testing. As mentioned previously, this testing represents the pre-test for an intervention study as well as a standalone study. It was also explained to the recruits that, depending on their study allocation of intervention or control, their warm up routine was going to be part of their typical training regardless of their participation in the pre-testing. Therefore, regardless of whether a recruit was formally taking part in the pre and post intervention testing or not, they would still be exposed to the intervention itself. Only those in the control group would not be exposed to the intervention.

All GCC recruits were required to pass a medical and physical evaluation before being accepted into Phase-1 training; if they failed, they were not considered for testing. This functioned as the study's exclusion criteria. Inclusion criteria were: currently a recruit in GCC Phase-1 training, between 16 – 34 years, had been free from injury for at least 30 consecutive days and already resided at the testing facilities. All participants were from the same base but not matched for age, height, body mass or physical fitness. Participants initially received a study brief detailing the measures to be taken, the implications of the intervention, and any possible risks and discomforts associated with participation, after which those wishing to participate in the study were provided with a participant information sheet (Appendix F) and asked for volitional consent (Appendix G). Participants were told that at any point they were free to leave the study without giving a reason, with no ramifications.

7.3.4 Sample size

The initial sample size was generated based on the Copenhagen Hip and Groin Outcome Score (HAGOS) questionnaire and resulted in a suggested cohort size of 224 male and 224 female Phase-1 recruits; however, the primary outcome measure for the study was the H&LLMS. The movement screen was not used to generate a cohort size as no study existed to provide effect sizes with which to generate expected cohort sizes. Therefore, this study would represent the first study to use the H&LLMS as the primary outcome measure and will be used to inform subsequent studies using the H&LLMS. An average troop intake would typically consist of 20 male and 10 female recruits and in order to recruit the required 448 participants, would have been completed in 23 weeks if there were an intake each week. It was expected that some participants would remove themselves from training due to a variety of reasons resulting in a smaller final cohort. Therefore, an additional 20%, or 5 weeks was added to recruitment time.

7.3.5 Protocol

An intervention of pre-activation neuromuscular warm-up exercises was implemented with the aid of the Physical Training Instructors (PTI). The intervention involved a prescribed set of movements that were scheduled for the first 15 minutes of each physical training (PT) session (Appendix C). The session replaced the warm-up exercises typically conducted within the physical activity sessions and due to logistical concerns, would be conducted regardless of study consent as an integral part of military training. The movements are designed to activate specific muscles in the hip region and promote efficient muscle activation and movement control during physical training. This targeted intervention aims to promote better management of movement control patterns and hip range of motion (ROM) restrictions. This intervention was developed from a combination of current exercise batteries such as the 11+ (Steffen *et al.*, 2013b) and the Functional Movement Screening Intervention [FMSI] (Bodden *et al.*, 2015), to focus on the hip and pelvic region. The intervention was stage based and included 3 levels lasting 12-weeks in total. Each level lasted 4-weeks and participants progressed onto the next stage without assessment. Participants in the control group undertook a standardised RAMP warm-up (Raise, Activate and mobilise, and Potentiate) (Figure 7-1). The warm-up consisted of jogging, shoulder and hip circles, and specific movements such as wall sits prior to obstacle course training (Racinais *et al.*, 2017).

Event Duration	SHORT			INTERMEDIATE & INTERMITTENT			LONG		
		Environment			Environment			Environment	
STAGE	GOAL	COOL	HOT	GOAL	COOL	HOT	GOAL	COOL	HOT
RAISE	Elevate T_m & T_{core}	5-10 min	=	Elevate T_m & T_{core} – raise baseline VO_2	10-15 min	↓	Stimulate energy systems – raise baseline VO_2	10-20 min	↓
ACTIVATE & MOBILIZE	Prehabilitation injury prevention & rehearsal of movement patterns	5-10 min	=	Prehabilitation injury prevention & simulate sport-specific movement patterns	10-15 min	↓	Prehabilitation injury prevention & light exercise complimenting required movement patterns	5 min	=
POTENTIATE	Activate/Improve Neural drive	2-4 min	=	Activate/improve neural drive	4-6 min	↓	Prime appropriate energy system - raise baseline VO_2	1-2 min	=
POST WARM-UP HEATING	YES	5-10 min	N/A	YES	5-15 min	N/A	NO	N/A	N/A

Figure 7-1: RAMP warm-up protocol as depicted in Racinais et al. (2017), which briefly outlines the requirement of the warm-up and the stages that should be completed. Additionally, the protocol dictates what should be conducted based on the proposed activity and the temperature of the environment the warm-up and activity are to be conducted in.

The intervention sessions were designed to be conducted by PTIs for several reasons, but the most prominent being that this intervention, if shown to improve movement control, would be introduced across a wide range of military training institutes and delivered by the PTIs, when researchers would not be available to run the intervention. Therefore, the study would also serve as a feasibility study to understand if PTI's could be trained effectively to deliver an intervention intended to improve movement control. The PTIs were trained over two sessions in the weeks preceding week one of the study. Training of PTIs involved practical sessions specifically based on being able to identify preferred technique and methods to help the recruits to achieve the preferred technique. Throughout the practical sessions, the PTIs would work in pairs and perform the movements to better understand the practical difficulties in performing the movements and would be able to give suggestions that would benefit the intervention in time and quality. Additionally, a member of the study team undertook observations of the delivery of the intervention and made themselves available for questions and practical input during the intervention.

Prior to the intervention, movement screen data were collected as a baseline for both groups of the intervention study and to better understand the differences between male and female military recruits prior to training. Only those within the initial pre-intervention testing were considered for the post-intervention movement screen testing.

7.3.6 Quality assurance and compliance

To maintain the quality and quantity of the intervention sessions, observations by researchers were scheduled. During these observations, details of which of the movements were conducted and the quality of these movements were recorded. Two members of the research team were allocated to observe at least one intervention session from each of the four intervention troops, per week, resulting in at least 2 sessions of each intervention troop per week being observed. The observed sessions schedule was not available to PTI's, so that they would not alter their behaviour based on investigator presence. Additionally, the investigator conducting the observations was not allocated to specific troops or PTIs and were randomised to ensure that all PT session types were observed. This was because it was suggested that the PTIs could show a variance in their intervention compliance depending on whether they were observed. Therefore, details of compliance and completion rates were maintained. For sessions that were not observed, information about the session was communicated to the principal researcher by email or phone on the same day by the participating PTI.

7.3.7 Outcome measures

The study was primarily focused on evaluating the interaction between the intervention groups, sex and H&LLMS scores. Additionally, the study also collected and analysed data on recruit perception of hip pain in the form of the iHOT and HAGOS questionnaires. The study would also attempt to establish the feasibility of the use of an intervention in military recruit cohorts, and therefore the study would also collect data on intervention compliance by counting the number of exercises that were completed each week as a percentage of the original target of 27 exercises.

7.3.7.1 The Hip and Lower Limb Movement Screen (H&LLMS)

The Hip and Lower Limb Movement Screen (H&LLMS) was the primary outcome measure for the current study. The screen is a prescribed set of seven movements and is explained in detail in Chapter 5. Each movement has a set of parameters that a person's movement is assessed against. These movement criteria are specific to each movement as are the number of criteria for each movement. As each criterion is based on the observation of a dysfunctional movement, these are labelled as faults. The number of faults vary between tests, and the faults are not weighted equally. Although all faults are scores on a dichotomous "pass / fail" system, the first fault for each movement dictates if the entire movement is passed or failed. This is because the faults are ordered in such a way as to have the most fundamental fault first. If the initial fault is not attained, it means that the participant is unable to perform a successful version of the movement. For example, during the standing hip flexion the participant is asked to raise their knee above 90°. Failing to do so will mean that the movement has not been achieved and the whole movement has failed. However, the other faults are also scored at this point to see if post-interventional changes have resulted in a movement achievability change, but also what alterations have been used to generate this newly achieved movement. All other faults after this first movement fault are used to judge how well the movement was conducted. The set movements and faults are used to allocate a numerical value on a person's movement quality. This can either be represented as the total test score, or the score given to each individual test. However, as stated in Chapter 3; section 1, the use of a total score is often inappropriate for specific dysfunction identification and treatment prescription. Therefore, within the current study, total H&LLMS score was only used as a means of identifying the level of feasibility. For more details on reliability and validity, please see chapter 5 section 1.

7.3.7.2 Copenhagen Hip and Groin Outcome Score (HAGOS)

The HAGOS is a Patient-reported outcome measure (PROM) questionnaire consisting of 37 questions separated into six subscales, revolving around the person's perception of pain in the hip and groin area. The HAGOS is scored out of 100, with the higher score representing less or no pain while lower scores represents pain. Thorborg *et al.* (2011) had demonstrated that the HAGOS is adequate for the assessment of symptoms, activity limitations, participation restrictions and quality of life (QOL) in physically active patients with long-standing hip and/or groin pain. The screen was designed, alongside the COSMIN (Consensus-Based Standards for the Selection of Health Status Measurement Instruments) checklist, as a patient report outcome evaluative tool that measures health-related quality of life in young, active populations with long standing hip and groin pain. The final version of the test was shown to have high levels of internal consistency and homogeneity, as all six subscales demonstrated Cronbach's α levels all above 0.78. The test has demonstrated high levels of test-retest reliability, with ICC levels above 0.82 for all six subscales and smallest detectable change (SDC) were between 17.7-33.8. Finally, the final version of the HAGOS revealed construct validity levels above the 0.4 threshold in five of the six subscales. Therefore, the HAGOS can be said to be a valid tool for measure of perceived hip and lower-limb pain and discomfort (Thorborg *et al.*, 2011).

7.3.7.3 International hip outcome tool (iHOT-33)

The iHOT-33 is a quality-of-life patient-reported outcome measure questionnaire, designed for computer self-administration by young, active patients with hip pathologies (Mohtadi *et al.*, 2012). The questionnaire consists of 33 questions and is based on a visual analogue scale. Similarly to the HAGOS, a higher score represents greater quality of life, with lower scores representing greater pain or dysfunction. Mohtadi et al. (2012) have demonstrated that the iHOT-33 has good levels of face, content, and construct validity when scored against the Non-arthritic Hip Score (NAHS) (CC; 0.81) and is highly responsive to clinical change. The questionnaire also shows good reliability (ICC; 0.78). The screen was designed as a self-administered evaluative tool that measures health-related quality of life in young, active populations that demonstrate high rates of hip disorders

7.3.7.4 Reason for using both hip assessment tools:

Both the HAGOS and iHOT have demonstrated their utility in accurately recording the self-reported pain and discomfort of those experiencing hip and groin pain or discomfort. The two tools are very similar in what they attempt to record. However, the HAGOS is aimed at those who are already experiencing pain, while the iHOT was designed for use within high-risk populations, with no requirement for experiencing pain or discomfort at the time of recording. Military recruits can be as young as 18, and therefore would have a low likelihood of currently experiencing hip and groin pain at enrolment. However, Gibbs *et al.* (2014) have previously found that military personnel show high levels of hip and lower-limb injury, including hip and neck of femur fracture. Therefore, it would have been limiting to the study to use either the screen that relies on the recruits having or not having existing pain. Therefore, using both would increase the chances of recording hip and groin dysfunction accurately.

Typically, studies in the area of hip and lower-limb bone health use one or the other. Therefore, if the current study were to choose one questionnaire over the other, it would be limiting the possible comparisons that could be made with the existing literature. Therefore, to increase the present study's ability to compare between the findings of the current studies and previous studies, the current study used both tools. Additionally, using both questionnaires in conjunction may allow for analysis of accuracy and validity in military cohorts which may lead to the current study being able to prescribe the use of a single questionnaire in future studies.

7.3.7.5 Demographic Details

Height is unlikely to change over the 13-week intervention period, and therefore was not used as a variable to establish validity of the intervention. Rather, a person's height, at the age of a Phase-1 recruit is very stable. Therefore, height can be used as a secondary check, alongside participant number, to ensure that each recruit's data were recorded correctly. As height was recorded to 1 decimal place, it was simple to check for change in height over the period. Therefore, any participant who had seemingly changed height, would automatically have their data checked in order to maintain data integrity and accuracy.

In Chapter 4, weight was shown to vary between sexes. In chapter 6, this was used to highlight movement quality differences between those of varying weights and that it was likely that body mass was linked to injury likelihood, in so much, that those who were lighter would be at greater risk. Due to the carrying element of military training, those who carry a greater proportion of body mass during carrying tasks may be at greater risk of injury. Therefore, the current study measured this variable in both pre and post-intervention cohorts.

7.3.8 Data collection

Movement control testing was scheduled for the recruits' second day following initial enrolment to Phase 1 training to allow for a full 24 hours between study information and informed consent, and to align the testing with the recruits' typical initial medical assessment (IMA). The IMA is conducted in the medical centre and included, but is not limited to, eye exams, hearing exams and dental exam. As there are a large number of recruits requiring medical examinations, many of the recruits have time where they are simply waiting for an examination slot. Therefore, the study attempted to reduce any additional time commitment from the recruits and tested them during the waiting time between appointments. As questionnaires could be completed at any point during the session, the Health History Questionnaire, Smoking and Alcohol Histories Questionnaire, Hip Outcome Tool (iHOT) questionnaire and Copenhagen Hip and Groin Outcome Score (HAGOS) were handed out at the start of the day, along with information sheets (Appendix E) and consent forms (Appendix F) while the H&LLMS was completed when recruits were free.

Prior to the physical testing, anthropomorphic and fitness data were collected. The Personal Fitness Assessment is completed as part of the recruit syllabus at the start of Phase-1 training; these data are collected by the physical training instructor (PTI) at each training Unit as standard operation and requires no additional input from the recruits or study team. This information is available for, and compiled by, the study team. Height and body mass was collected to establish BMI, and waist circumference was also measured. All measures were undertaken in appropriate venues, and were accommodated in the recruits' programme where there would be minimum impact upon other training/personal administration activities. Once anthropomorphic data were collected, the participants were encouraged to ask any questions about the testing.

Movement screen data were then collected by a pool of raters, all trained in movement observation and the H&LLMS process (see chapter 5). Multiple raters were used to increase efficiency of time during IMA assessments. However, there was a single lead rater who prioritised rating where possible. The assessment comprised of 7 movements, 6 of which were completed on both left and right legs separately. Participants were given instructions, demonstrations and chances to practice prior to formal scoring. The movements were observed to give a best effort movements, and participants were given multiple attempts at each movement. The full data collection session lasted approximately 30 minutes.

7.3.9 Injury data recording

During phase-1 training, injury occurrence, type, onset and severity were monitored prospectively by the Army training camp medical centre staff. Injuries were defined as a musculoskeletal condition causing the recruit to lose two or more days of physical training, including acute and overuse injuries. Consent to access this medical information prospectively was obtained from recruits at the start of training, and their consent was re-confirmed by the study team at the end of training in the event of any circumstances having changed. Recruits participating in the study who reported injuries to the medical centre, had details of their complaint coded on the Defence Medical Information Capability Programme (DMICP) system by the doctor, nurse or medical assistant. The week of training was also coded on DMICP. The present study was specifically concerned with understanding occurrence of soft tissue hip injuries, stress fractures of the hip and pelvis, and all overuse lower limb injuries.

7.3.10 Data analysis

Initially, the study examined the movement quality of Phase-1 recruits prior to military training and assessed the influence sex had on movement quality. This was achieved using the previously mentioned outcome measures, such as the HAGOS, iHOT and H&LLMS score, as the dependent variable using a between groups T-test, while sex was used as the independent variable.

The study then assessed the effect of a pre-training neuromuscular warm-up intervention on the movement quality of Phase-1 military recruits between intervention and control groups (INT Vs CON). A one-way repeated measures ANOVA was conducted to examine if there were any effects of Platoon on H&LLMS score. Further analysis of the iHOT and HAGOS also utilised this approach and supplemented the H&LLMS score for the relevant outcome score. Post hoc analysis was conducted using a Bonferroni test. The study explored the interaction effects between sex, time and intervention. Again, the previously mentioned outcome measures were used as dependent variables during a repeated measures ANOVA while sex and intervention group were used as the independent variable. Data were collected and stored using Microsoft Excel and analysed using IBM SPSS (22) where alpha was set at 0.05.

The study also assessed the adherence to the intervention by recording individual intervention movements completed prior to training sessions. These data were then assessed against the potential number of interventions and against other troops. Although this was not subject to statistical analysis, it did allow for a dose effect to be assessed informally. This was completed by ranking troops in order of completion, with worst completion rate representing the control group, to examine if a specific dose would elicit a cut-off point for future interventions to attempt to attain. This was completed by using a One-way ANOVA where alpha was set at 0.05.

7.4 **Results**

7.4.1 Interaction effect

The study examined the effect two different interventions would have on H&LLMS data after a 12-week period with male and female military recruits. There was therefore a possibility of an interaction between any independent variable (time, condition, sex) on the dependent variable (H&LLMS score). Consequently, these interactions were assessed for significance (Table 7-1). Results show no interaction with all three independent variables but eight H&LLMS movements that present with interactions with time and condition, whereas only one (left hip abduction with medial rotation) that interacts with time and sex. The movements that present with interactions with time and condition, present with both left and right legs (small knee bend with rotation, sitting hip flexion and hip abduction with medial rotation) as well as including both scores that are combined scores (deep squat and screen total score). Post hoc analyses of the “simple effects” encompassed by the interaction were established using pairwise comparison and can be found in Table 7-2 (Condition × Time) and Table 7-3 (Sex × Time).

Table 7-1: Hip and lower-limb movement screen data assess for an interaction and/or main effect.

		RAMP				H&LLMQI				P-Values					
		Pre		Post		Pre		Post							
Side	**H&LLMS movement**	**Male**	**Female**	**Male**	**Female**	**Male**	**Female**	**Male**	**Female**	**Time * Condition * Sex**	**Time * Condition**	**Time * Sex**	**Time**	**Condition**	**Sex**
Left	**SKB total**	2.61±0.98	2.64±1.01	2.83±0.86	2.79±0.97	2.76±0.82	2.51±0.98	2.73±1.03	2.69±0.72	0.522	0.610	0.779	0.255	0.760	0.629
	SKBR total	2.11±0.68	2.07±1.14	2.72±0.46	2.43±0.85	2.37±0.79	2.09±0.92	2.23±0.89	1.86±0.77	0.674	**0.001***	0.406	0.145	0.159	0.081
	SHF total	1.78±0.88	1.86±1.17	2.00±0.91	1.79±0.70	2.29±0.71	2.00±0.64	1.85±0.76	2.00±0.84	0.086	0.167	0.737	0.501	0.150	0.576
	SitHF total	2.61±1.09	2.71±0.73	3.00±1.24	3.14±0.95	2.97±0.83	2.80±0.87	2.47±0.94	2.51±0.89	0.733	**0.002***	0.620	0.951	0.208	0.826
	Hip L rotation	2.00±0.91	2.36±0.84	2.06±1.06	2.14±1.29	2.77±0.78	2.51±0.61	2.56±1.13	2.31±0.96	0.578	0.618	0.605	0.259	**0.008***	0.913
	Hip M rotation	2.11±1.13	1.36±0.93	2.28±1.02	2.64±0.63	2.73±0.75	2.34±0.76	2.61±0.69	2.66±0.91	1.000	**0.003***	**<0.0005***	**<0.0005***	**<0.0005***	0.174
Right	**SKB total**	2.72±0.89	2.86±0.95	2.56±0.92	2.86±0.95	2.65±0.91	2.51±0.95	2.79±1.01	2.63±0.97	0.701	0.408	0.792	0.857	0.492	0.811
	SKBR total	2.22±0.81	1.64±1.22	2.72±0.46	2.36±0.84	2.29±0.84	2.00±0.80	2.18±0.86	1.86±0.81	0.515	**<0.0005***	0.623	**0.012***	0.219	**0.009***
	SHF total	1.72±0.67	2.07±1.27	1.94±0.73	2.00±0.68	2.19±0.74	2.03±0.66	1.77±0.84	2.06±0.80	0.08	0.199	0.714	0.568	0.533	0.303
	SitHF total	2.39±0.85	2.64±0.93	3.17±1.04	3.00±0.78	2.84±0.81	2.89±0.83	2.56±0.88	2.40±0.91	0.634	**<0.0005***	0.151	0.393	0.376	0.958
	Hip L rotation	2.11±0.90	2.36±0.84	2.17±1.10	2.29±1.27	2.77±0.73	2.51±0.70	2.45±1.22	2.54±0.82	0.344	0.581	0.657	0.539	**0.027***	0.748
	Hip M rotation	2.06±1.26	1.50±1.22	2.39±0.85	2.43±0.94	2.69±0.78	2.43±0.65	2.60±0.80	2.46±0.95	0.295	**0.003***	0.109	**0.009***	**0.002***	0.110
Total	**DS**	1.44±1.04	1.64±1.01	1.89±0.96	1.71±0.91	1.58±0.88	1.94±0.76	1.24±1.08	1.46±1.01	0.579	**0.001***	0.203	0.449	0.496	0.383
	Screen	27.89±5.56	27.71±7.25	31.72±8.24	31.57±6.44	32.90±5.49	30.57±4.64	30.05±7.32	29.43±6.98	0.573	**<0.0005***	0.562	0.218	0.362	0.461

Data displayed in Mean ± SD

* = Indicates significant P-value <0.05.

Table 7-2: post-hoc analysis of Time × Condition.

Side	H&LLMS movement	Condition	Time		M Diff	SE	Sig	95% CI	
								LB	LB
Left	SKBR total	Control	Pre	Post	-0.5	0.180	0.009*	-0.866	-0.134
		Intervention	Pre	Post	0.175	0.097	0.075	-0.018	0.368
	SitHF total	Control	Pre	Post	-0.406	0.215	0.068	-0.844	0.032
		Intervention	Pre	Post	0.423	0.125	0.001*	0.174	0.671
	Hip M rotation	Control	Pre	Post	-0.656	0.209	0.004*	-1.082	-0.231
		Intervention	Pre	Post	-0.041	0.103	0.688	-0.245	0.162
Right	SKBR total	Control	Pre	Post	-0.594	0.134	0.000*	-0.866	-0.321
		Intervention	Pre	Post	0.124	0.095	0.197	-0.065	0.313
	SitHF total	Control	Pre	Post	-0.594	0.167	0.001*	-0.935	-0.253
		Intervention	Pre	Post	0.351	0.111	0.002*	0.131	0.570
	Hip M rotation	Control	Pre	Post	-0.594	0.224	0.012*	-1.050	-0.137
		Intervention	Pre	Post	0.052	0.103	0.618	-0.153	0.256
Total	DS	Control	Pre	Post	-0.281	0.186	0.141	-0.661	0.099
		Intervention	Pre	Post	0.392	0.097	0.000*	0.200	0.584
	Screen	Control	Pre	Post	-3.844	1.068	0.001*	-6.023	-1.665
		Intervention	Pre	Post	2.237	0.763	0.004*	0.722	3.752

Data displayed in Mean Diff ± SE

* = Indicates significant P-value <0.05.

Table 7-3: Post hoc analysis of Time × Sex.

Side	H&LLMS movement	Sex	Time		M Diff	SE	Sig	95% CI	
								LB	LB
Left	Hip M rotation	Male	Pre	Post	0.050	0.105	0.636	-0.159	0.259
		Female	Pre	Post	-0.592	0.170	0.001*	-0.933	-0.250

Data displayed in Mean Diff ± SE

* = Indicates significant P-value <0.05.

7.4.2 Participant Recruitment and retention rates

The study recruited 178 Phase-1 military recruits for the initial pre-intervention observation study, however this was reduced to 129 by the end of the intervention study. This was lower than the pre-intervention estimation, however, as this study represented the first to use the H&LLMS as the primary outcome, this estimation was likely to require amendments before deploying an RCT.

A cohort of 129 Phase-1 recruits (80 males; 49 females) volunteered to participate in this study. This cohort was divided into two study groups: the control (CON) troops comprised n=32 volunteers (18 males; 14 females); the intervention (INT) troops comprised n=97 volunteers (62 males; 35 females). All volunteer recruits had been passed medically and physically fit to undertake military recruit training (Table 7-4).

Table 7-4: Week-1 Age and Anthropometric Measurements of Study Participants; Mean (SD), Minimum, Maximum (n 129).

Group	Sex	Variable	Mean (SD)	Minimum	Maximum
CONTROL (n 32)	**Male (n 18)**	**Age (years)**	21.1 (3.7)	17.0	31.0
		Height (m)	176.6 (0.07)	1.57	1.87
		Body mass (kg)	76.3 (8.7)	58.6	94.8
		Waist Circumference (cm)	82.3 (7.0)	71.5	98.2
		BMI (kg.m-2)	24.5 (3.0)	17.3	29.8
	Female (n 14)	**Age (years)**	21.5 (3.7)	17.0	31.0
		Height (m)	164.7 (0.05)	1.54	1.74
		Body mass (kg)	64.2 (7.6)	48.0	78.6
		Waist Circumference (cm)	74.4 (5.2)	65.2	86.1
		BMI (kg.m-2)	23.6 (2.6)	19.7	29.2
INTERVENTION (n 97)	**Male (n 62)**	**Age (years)**	21.1 (3.6)	17.0	31.0
		Height (m)	175.3 (6.6)	1.60	2.00
		Body mass (kg)	78.0 (9.3)	61.2	101.0
		Waist Circumference (cm)	83.5 (6.0)	69.5	98.2
		BMI (kg.m-2)	25.2 (2.7)	19.8	30.7
	Female (n 35)	**Age (years)**	23.3 (6.5)	17.0	47.0
		Height (m)	164.7 (0.1)	1.50	1.78
		Body mass (kg)	62.1 (8.7)	40.4	80.4
		Waist Circumference (cm)	74.5 (5.4)	61.2	90.2
		BMI (kg.m-2)	23.0 (2.2)	18.1	28.7

7.4.3 Pre intervention H&LLMS between groups

Prior to undertaking the exercise intervention, recruits in the intervention group scored significantly higher H&LLMS total scores than those within the control group (p=0.001) (27.8±6 CON, 32±5.3 INT). Further analysis highlighted that individual movements also presented with significantly different H&LLMS scores prior to intervention (Table 7-5). However, as subsequent analysis will utilise a repeated measures ANOVA, the pre-intervention differences will not affect the ability to demonstrate a significant change in movement quality within the intervention groups.

Table 7-5: Individual H&LLMS score differences between intervention groups prior to intervention. Only movements that showed significant differences are presented in the table.

	CON	**INT**	
Movement	**Mean (SD)**	**Mean (SD)**	**P value**
Standing hip flexion (Left)	1.81 (1.00)	2.19 (0.70)	0.021
Sitting hip flexion (Right)	2.50 (0.88)	2.86 (0.82)	0.038
Hip abduction with lateral rotation (Right)	2.22 (0.87)	2.68 (0.73)	0.004
Hip abduction with lateral abduction (Left)	2.16 (0.88)	2.68 (0.73)	0.001
Hip abduction with medial rotation (Right)	1.81 (1.26)	2.60 (0.75)	0.000
Hip abduction with medial rotation (Left)	1.78 (1.10)	2.59 (0.77)	0.000

7.4.4 Pre intervention H&LLMS between sexes

Prior to undertaking the exercise intervention, females had significantly (p=0.005) lower, and therefore better H&LLMS score than males (Mean ± SD: 28.2±5.6 Female; 31.8±5.9 Male).

7.4.5 Compliance

Due to the way in which the intervention was conducted, the study will refer to the number of movements completed, rather than total intervention sessions. Initial data on observed intervention compliance showed that an average of only 19% (M±SD = 5±3) of the movements were being conducted per week. A meeting with the PTIs was conducted to understand the main barriers to integrating the intervention and to create solutions to these barriers. The PTIs explained that the intervention was taking more that the allotted 15 minutes and that their schedules did not allow for this increase in time. Therefore, the intervention was either not conducted or some movements, deemed by the PTIs to be less important, were removed. Therefore, an intervention could have been completed, but would have included fewer than the total number of exercises or movements. Additionally, in some cases, the troop command had instructed the PTIs to reduce the time of PT so that the troop could prepare for a later activity more thoroughly. This resulted in even less time allowed for PT and again impacted on the exposure the intervention participants had to the intervention. For more details on the reasons behind the change to the implementation strategy that were gathered during the focus groups, please see chapter 8.

It was suggested that conducting the intervention outside of PT time would best resolve this issue. Therefore, the study team spoke to the troop command to inquire about time slots that would be suitable for a physical intervention. The intervention had been suggested originally to run at least 3 times per week and we wanted to maintain this level of exposure. The number of sessions per week that were deemed viable varied between troops, but in all cases represented an improvement on the current engagement. Therefore, a new timetable was created and PTIs were assigned additional times to conduct the intervention outside of their typical work schedule.

This solution was seen as advantageous by the study team as this resolved two issues. As the intervention was previously scheduled to run alongside PT, this meant that the tapering of training towards the final few weeks of phase-1 would have resulted in fewer intervention sessions being run towards the end of training. The new solution resulted in three intervention sessions per week regardless of the number of PT sessions. Additionally, previous interventions could have been conducted wherever the PT session was and made it very difficult for the study team to make observations. The new solution meant that all intervention sessions were to be conducted outside of the troop's residential block. This was not only in the middle of camp and easily accessible to the research team, but the troops were typically close to one another. Therefore, if two sessions were being conducted at one time, an observation of both could be conducted by a single person.

7.4.5.1 Changes to compliance after changes to intervention delivery

After the changes to the implementation of the intervention were adopted, the average weekly compliance increased from 19% to 35% (*Figure 7-2*), which represents an additional four movements. However, this increase was not spread evenly across the four troops, resulting in different intervention doses experienced by the recruits in varying troops (*Figure 7-3*).

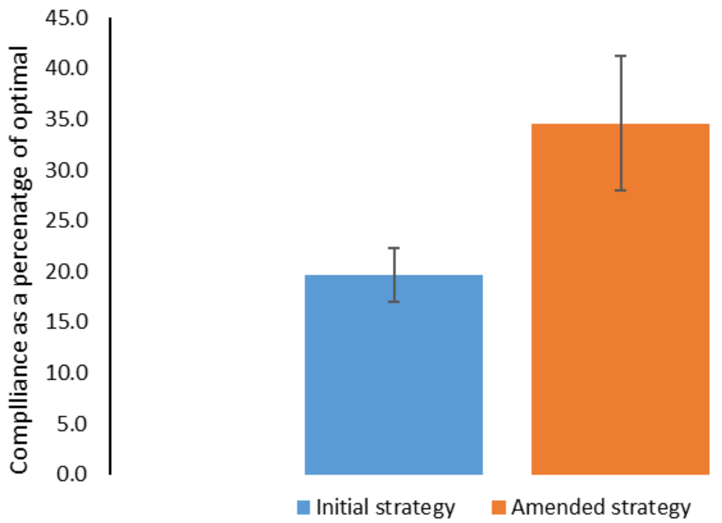


Figure 7-2: Intervention adherence before and after implementation changes

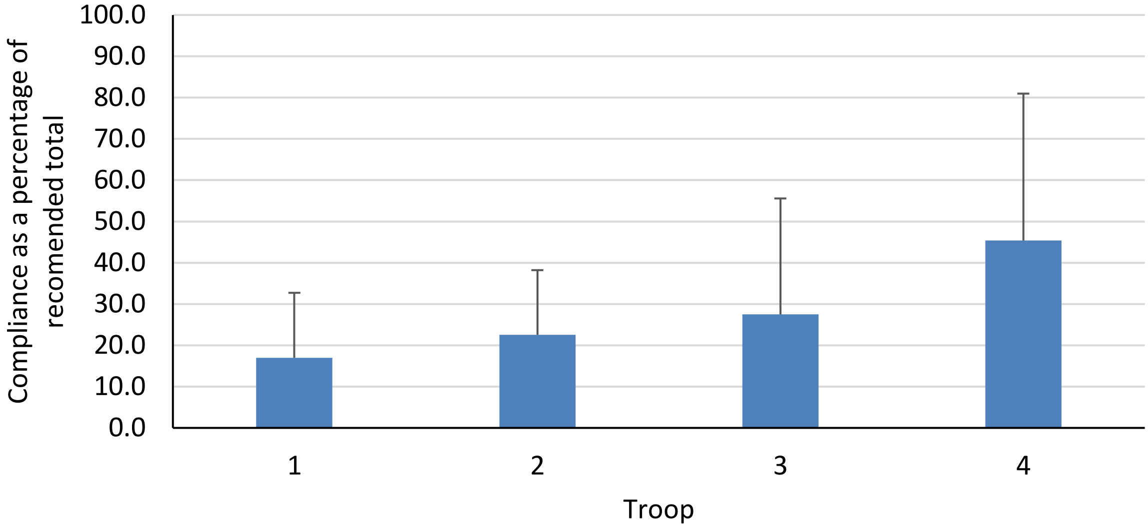


Figure 7-3: Intervention compliance as a percentage of recommended total.

7.4.6 Post-intervention H&LLMS score between conditions

The CON group's post-intervention movement screen total scores were higher than the intervention group (31.7±7.4 CON, 29.8±7.2 INT). This is also reflected in the individual movements within the H&LLMS shown in Table 7-6.

Table 7-6: Individual H&LLMS score differences between intervention groups post intervention.

	CON	INT	
Movement	**Mean (SD)**	**Mean (SD)**	**P value**
Small knee bend with rotation (Right)	2.56 (0.67)	2.06 (0.85)	0.003
Small knee bend with rotation (Left)	2.59 (0.67)	2.09 (0.87)	0.003
Deep squat	1.81 (0.93)	1.32 (1.06)	0.020
Sitting hip flexion (Right)	3.09 (0.93)	2.51 (0.89)	0.002
Sitting hip flexion (Left)	3.06 (1.11)	2.48 (0.91)	0.004

7.4.7 Post-intervention H&LLMS score between sexes

Post-intervention H&LLMS scores, showed that females exhibited a significantly lower, and therefore better H&LLMS score (p=0.001) compared to males (30.5±6.7 females, 30.9±7.8 males). Moreover, females in both intervention and control groups exhibited a significantly lower, and therefore better H&LLMS score (p=0.001) compared to males (INT: 29.4±7 females, 30.0±7.3 males; CON: 31.6±6.4 females, 31.7±8.2 males).

7.4.8 Pre to post-intervention H&LLMS scores between condition.

After the 12-week intervention period during which recruits undertook military training, movement quality of the CON group was impaired by 14 % and movement quality of the INT group had improved by 7 % (ΔH&LLMS: CON +3.8±6; INT -2.2±7; P≤0.001). This then demonstrates that those in the CON group significantly increased their score, while those in the INT group significantly reduced their scores and thus improved their movement quality. Therefore, there was a significant interaction effect (P = 0.001) between the groups over time (*Figure 7-4*).

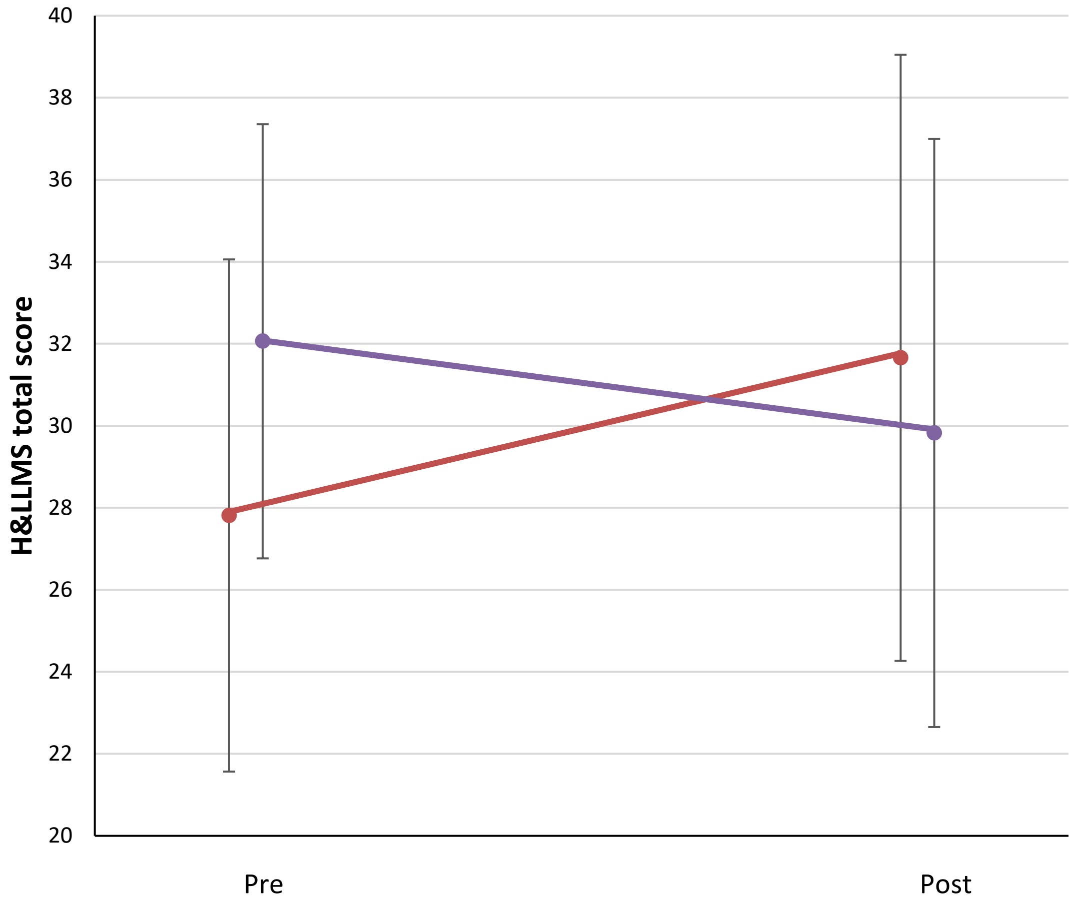


Figure 7-4: Mean (SD) H&LLMS scores (week-1 and week-13) for the Control (CON; n 32, Red) and Intervention (INT; n 97, Purple) Groups, Pre vs. Post 12-weeks; Significant Interaction Effect (n 129).

7.4.9 Pre to post-intervention H&LLMS scores between sexes.

Comparison of the influence of sex on movement quality modification showed there were no significant differences in the H&LLMS total score of male and female post-intervention (*Figure 7-5*).

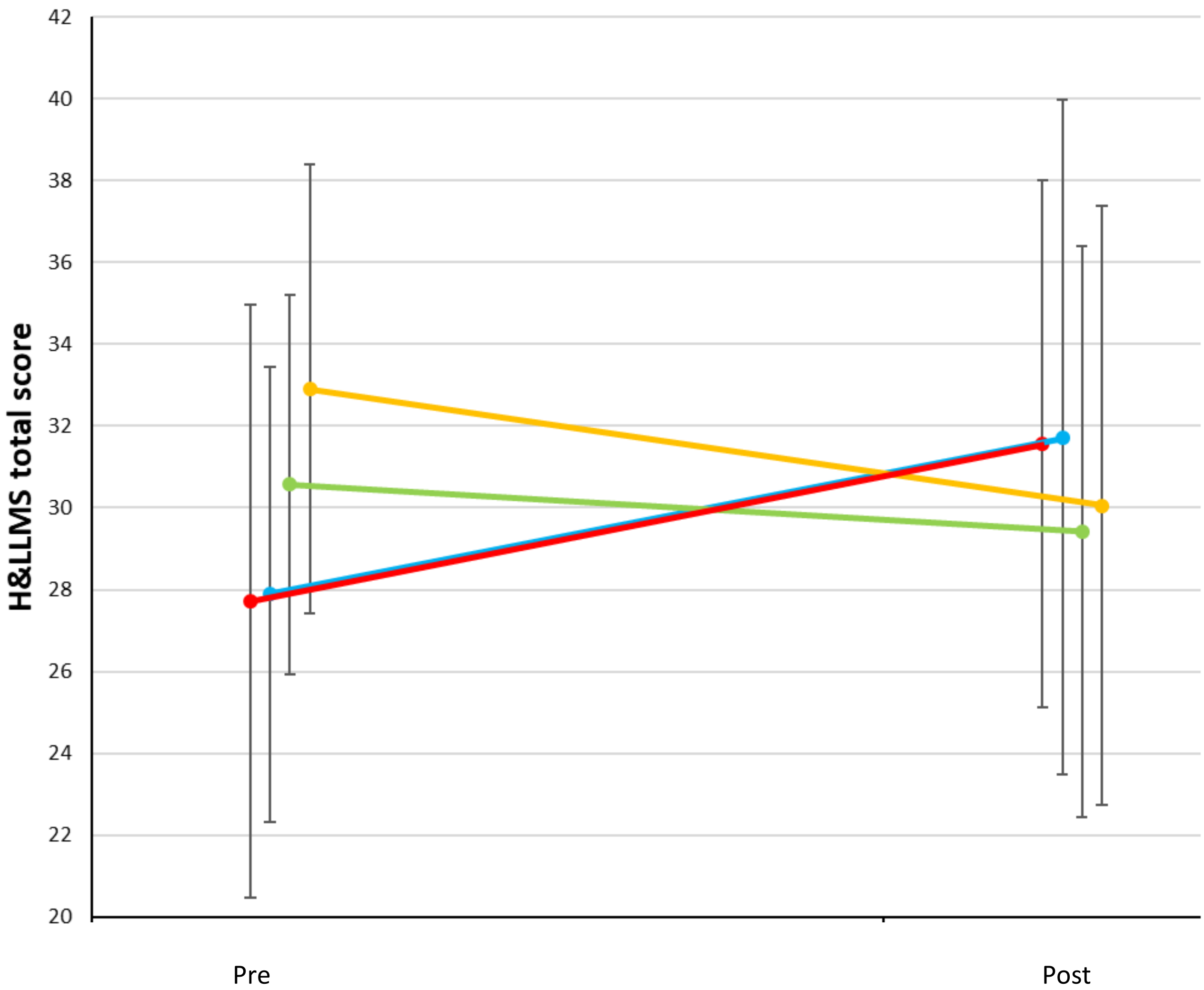


Figure 7-5: Mean (SD) H&LLMS scores (week-1 and week-13) for Male and Female Recruits in the CON (male, n 18 [Blue]; female, n 14 [Red]) and INT (male, n 62 [Yellow]; female, n 35 [Green]) Groups.

The change to each individual movements within the screen [small knee bend left (p=0.001), small knee bend with rotation left (p=0.001) and right (p<0.0001), deep squat (p<0.0001), hip abduction with medial rotation left (p=0.012) and right (p=0.016) and hip abduction with lateral rotation left (p=0.024) and right (p=0.037)] all demonstrated significant differences between CON and INT groups (*Figure 7-6*).

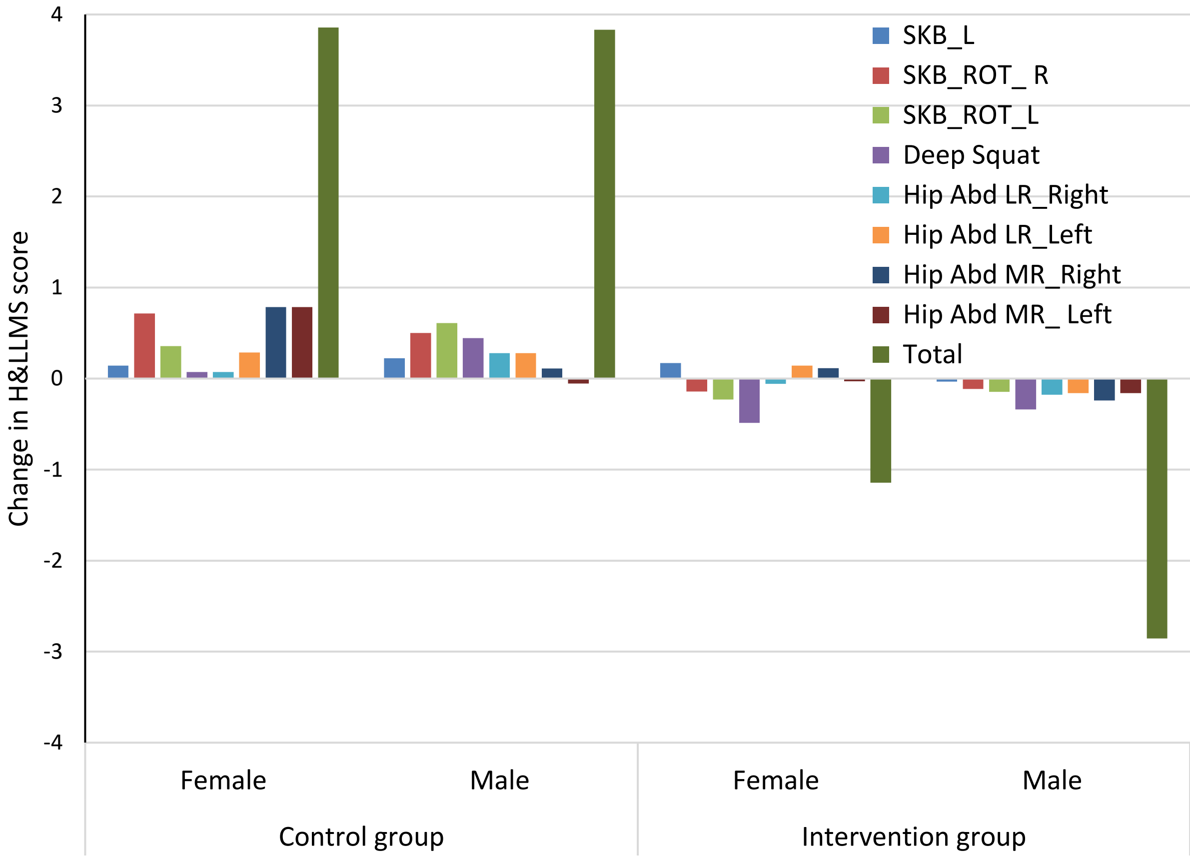


Figure 7-6: Mean H&LLMS scores change (week-1 to week-13) for screen total and individual movements that were significantly different over the same period between the control and intervention groups.

7.4.10 Pre to post-intervention H&LLMS score between sex and condition

During the study, although on average all those in the intervention group improved their H&LLMS scores (*Figure 7-6*), males improved by a greater amount (-1.1±5.3 females, (-1.5±8.7 male). Conversely, in the control group, males worsened to a greater extent than females (1.9±7.4 females, 3.4±8.7 males). Although females retained a lower, and therefore better, H&LLMS score.

7.4.11 Dose response

Although variation in compliance to the intervention between the four troops was not intentional, this gave the study the ability to examine the possibility of a dose effect. *Figure* 7-7 illustrates the significant difference between the control group and intervention group whose dose was 13.4 movements per week (p=0.014). Although *Figure 7-7* appears to show a reducing trend in the other lower dose intervention groups, no significant difference in movement quality was shown between the four intervention troops. Therefore a trend can be seen between the movements that were significantly different between INT and CON groups, (Dose 0 = 33.4±1.2, Dose 3.9 = 30.5±1.2, Dose 5.9 = 29.6±1.9, Dose 7.5 = 29.7±1.4, Dose 13.4 = 27.4±1.3).

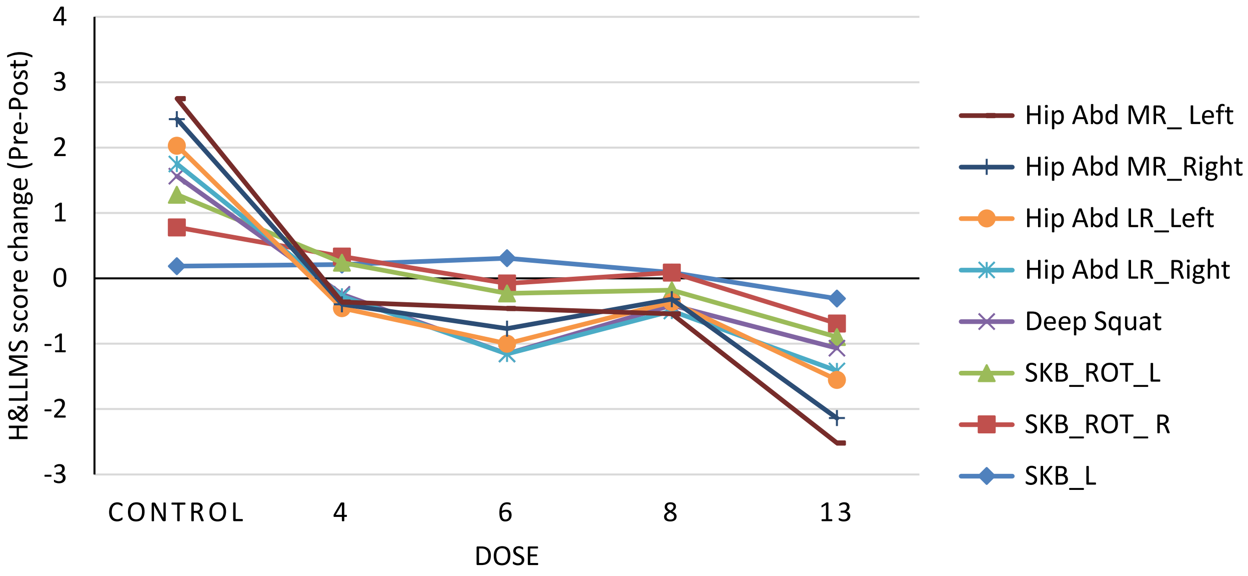


Figure 7-7: Dose response of the mean individual significant H&LLMS movements score. The different lines represent the 8 significantly different H&LLMS tests (Hip Abd MR, Hip Abd LR and SKB were significant on both left and right sides), while the X axis indicates the average number of intervention exercises completed each week.

In order to better assess the potential of a dose response, change in H&LLMS total score was also analysed. Although total score is not seen as a specific outcome measure, the change of such a large number may give large enough change to assess in a relatively small cohort. *Table 7-7* demonstrates the mean H&LLMS total score change for each dose group, including the CON group which represent a zero dose group. Mean data show that the higher the dose, the lower the mean, with CON showing the highest, and therefore worse score. This reiterates the depiction of the individual movement scores in *Figure 7-7*. An assessment of the significance of the difference of total H&LLMS score was also completed and shows that the only paired groups that show a significant difference is that of CON and 13.4 movements per week. Therefore, the highest and lowest dose demonstrate a significant difference (p= <0.005)(*Table 7-8*).

Table 7-7: Post-intervention H&LLMS total scores separated by dose of individual troop

Dose	**N**	**Mean (SD)**	**Minimum**	**Maximum**
CON	32	3.84 (6.04)	-8.00	24.00
3.90	33	-0.21 (5.57)	-16.00	11.00
5.90	13	-1.30 (7.02)	-11.00	12.00
7.50	22	-1.04 (7.58)	-18.00	17.00
13.40	29	-4.00 (9.63)	-26.00	18.00

Dose = movements per week

Table 7-8: Bonferroni post-hoc test results of the change between pre and post intervention (represents significance)*

Dose	**CON**	**3.90**	**5.90**	**7.50**	**13.40**
CON	1.00	0.26	0.33	0.16	0.00 *
3.90	0.26	1.00	1.00	1.00	0.42
5.90	0.33	1.00	1.00	1.00	1.00
7.50	0.16	1.00	1.00	1.00	1.00
13.40	0.00 *	0.42	1.00	1.00	1.00

7.4.12 HAGOS (week-1)

Table 7-9 illustrates that pre-intervention HAGOS scores were higher, and therefore better for those in the INT group for all but, “Participation in physical activity” and “Pain” sub-sections. *Table 7-10* demonstrates that the only sub-section that shows any significant difference was that of Quality of Life. Therefore, the only significant differences showed that those in the INT group demonstrated higher, and therefore better scores.

Table 7-9: HAGOS section scores at week-1 and week-13 for CON and INT.

		Week-1				Week-13			
	Sub heading	**N**	**Minimum**	**Maximum**	**Mean (SD)**	**N**	**Minimum**	**Maximum**	**Mean (SD)**
CON	**Symptoms**	39	64	100	92.72 (8.94)	39	32	100	83.44 (16.03)
	Pain	39	82	100	97.95 (4.75)	39	43	100	89.49 (15.89)
	Physical function and daily living	39	82	100	97.95 (4.30)	39	1	100	91.38 (18.31)
	Function, sport and recreational activities	39	54	100	95.38 (10.21)	39	11	100	83.67 (21.36)
	Participation in physical activity	39	93	100	98.87 (2.35)	39	79	100	96.95 (5.68)
	Quality of life	39	68	100	95.67 (9.08)	39	50	100	90.77 (13.87)
INT	**Symptoms**	95	61	100	95.15 (7.84)	95	54	100	89.99 (10.44)
	Pain	95	71	100	98.40 (4.46)	95	57	100	96.72 (7.00)
	Physical function and daily living	95	79	100	98.05 (4.48)	95	75	100	97.73 (5.04)
	Function, sport and recreational activities	95	57	100	96.58 (7.21)	95	46	100	94.18 (10.54)
	Participation in physical activity	95	71	100	98.37 (4.25	95	82	100	98.40 (3.88)
	Quality of life	95	75	100	98.32 (4.70)	95	71	100	96.23 (7.13)

Further analysis demonstrates that the "quality of life" section of the HAGOS was the only section to show significant differences between conditions prior to the intervention. This indicates that there was little difference in self-reported hip, groin and lower-limb dysfunction prior to the intervention (*Table 7-10*), thus showing no initial bias in self-reported hip, groin and lower-limb dysfunction prior to military Phase-1 training and the intervention. Subsequently, any differences seen post-intervention will likely be the result of the intervention itself.

Table 7-10: Differences in HAGOS section score between CON and INT at week-1.

Subscale	Diff	P value
Symptoms	-2	0.120
Pain	0	0.602
Physical function and daily living	0	0.902
Function, sport and recreational activities	-2	0.444
Participation in physical activity	1	0.487
Quality of life	-2	0.028 *

- Refers to a higher score for the INT condition

+ Refers to a higher score for the CON condition

7.4.13 HAGOS (week-13)

Table 7-9 demonstrates that the post intervention HAGOS scores for those in the CON group gave lower scores on all 6 sub-sections of the HAGOS reporting on hip, groin and lower-limb dysfunction. When both the control and intervention group data are analysed for significant differences between post-intervention HAGOS scores, the results, shown in *Table 7-11*, demonstrate that there were significant differences in five of the post intervention HAGOS category scores between the two intervention groups; with “Participation in physical activities” being the only section not demonstrating a significant difference post intervention. *Figure 7-8* demonstrates that the HAGOS total score was lower, and therefor worse for the CON group, while Table 7-9 shows that the individual sub-sections were all lower and, again, therefore worse for the CON group. Moreover, a repeated measures ANOVA demonstrated a significant interaction between time and intervention group (p=0.008) (*Figure 7-8*).

Table 7-11: Differences in HAGOS section score between CON and INT at week-13.

Subscale	**Diff**	**P value**
Symptoms	-6	0.006 *
Pain	-7	0.000 *
Physical function and daily living	-7	0.002 *
Function, sport and recreational activities	-10	0.000 *
Participation in physical activity	-1	0.090
Quality of life	-5	0.003 *

- Refers to a higher score for the INT condition

+ Refers to a higher score for the CON condition

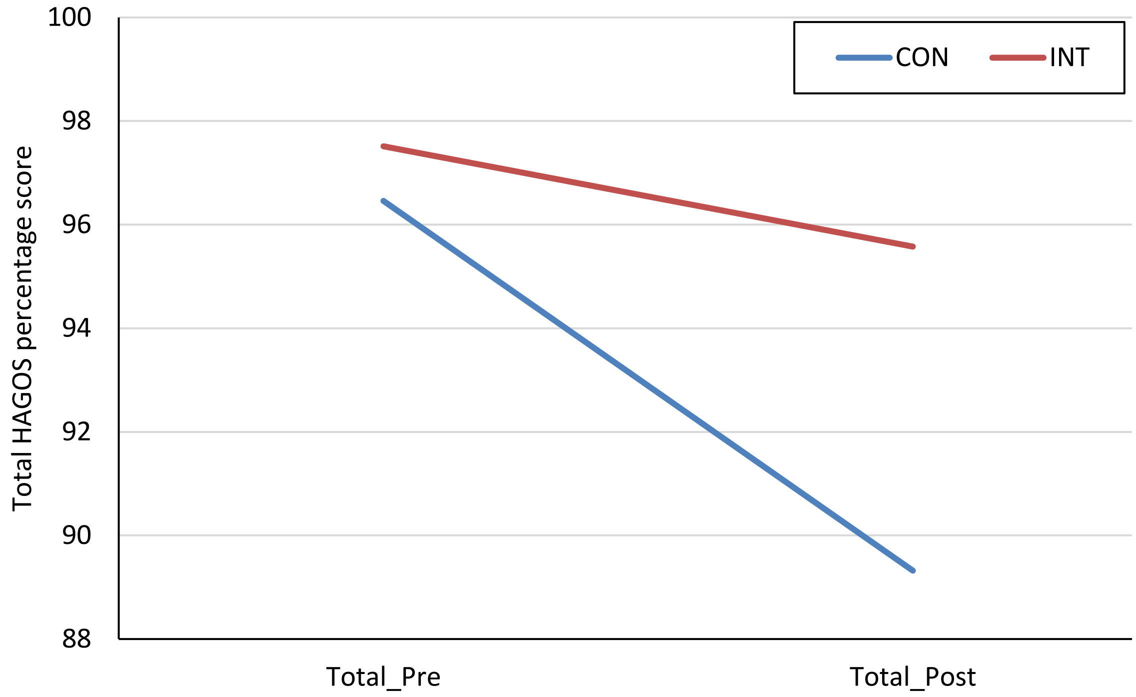


Figure 7-8: Mean of the HAGOS total score. Interaction between time and group. Higher score represent less or no pain.

7.4.14 iHOT (week-1)

Pre-intervention data show that those in the intervention group gave answers indicating less hip, groin and lower-limb dysfunction (*Table 7-12*). This difference was shown to be significant and therefore indicates a bias prior to the intervention.

Table 7-12: Differences in iHOT section score between CON and INT at week-1.

		N	Mean (SD)	P value
PRE iHOT Total Percentage	Control	35	81.40 (20.73)	<0.0005*
	Intervention	95	94.29 (11.82)	

7.4.15 iHOT (week-13)

Post-intervention data show that there was no significant difference in self-reported hip, groin and lower-limb dysfunction between the intervention groups (Table 7-13). Examining the mean data shows that those in the control group demonstrated a change in iHOT score of 9 (from 81.4 to 90.7) while those in the intervention group did not change (94.3 to 94.5). This then suggests that the control group improved their experience of hip, groin and lower-limb dysfunction whereas the intervention group saw no changes over the same period. A repeated measures ANOVA (Figure 7-9) shows a significant interaction between time and intervention group (p=0.04).

Table 7-13: Differences in iHOT section score between CON and INT at week-13.

		N	Mean (SD)	P value
Post iHOT Total Percentage	Control	35	90.71 (21.92)	0.264
	Intervention	95	94.45 (14.51	

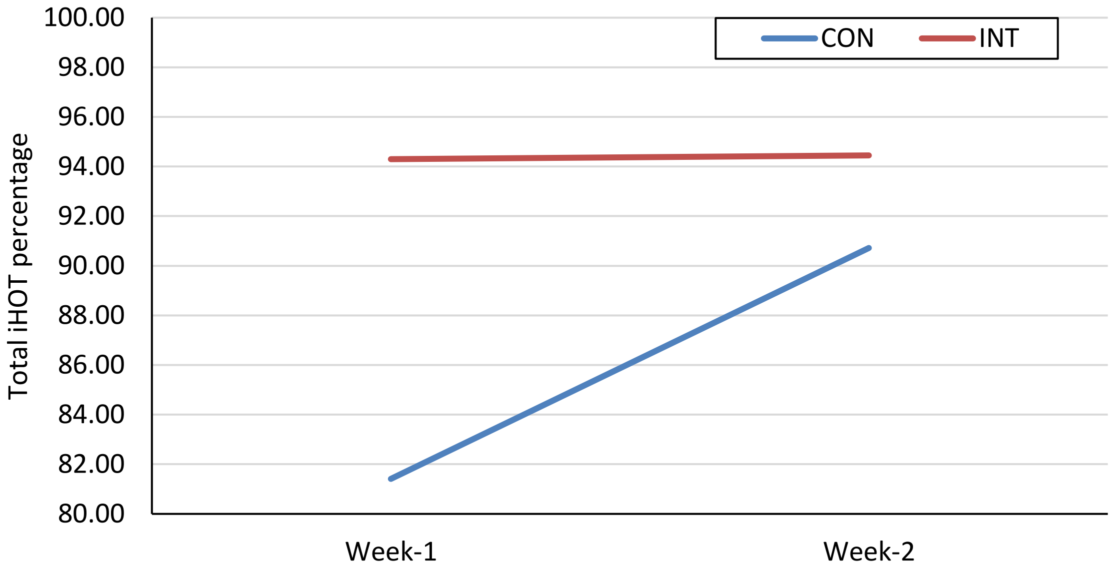


Figure 7-9: iHOT score comparison between pre and post and intervention.

7.4.16 Smoking habits and alcohol consumption questionnaire

The Smoking habits and alcohol consumption questionnaire revealed no difference in any variable between control and intervention. However, when differences were assessed between male and female recruits, males showed higher levels of alcohol consumption at week 1 compared to females (p=0.04) (*Table 7-14*). The variation in the number of females that answered questions on alcohol consumption and medication was because one participant failed to register an answer for their alcohol consumption.

7.4.17 Health history questionnaire

The health history questionnaire showed no difference in any variable between control and intervention (Table 7-15). However, females demonstrated a higher intake of prescription medication (p=0.015). The questionnaire used a dichotomous rating of yes / no, and therefore there is no measure of the amount of prescription medication that either males or females took. However, some of the female recruits gave explanations on their questionnaires. The females stated that the medication they were taking was prescription birth control. As such, this is specific to female recruits and may suggest why females presented with higher prescription medication scores.

Table 7-14: Alcohol consumption questionnaire results.

Sex	Variable	N	Minimum	Maximum	Mean (SD)

Female	Alcohol consumption	65	0	2.00	0.78 (0.59)
	Medication	66	0	1.00	0.12 (0.33)
Male	Alcohol consumption	106	0	5.00	1.09 (1.10)
	Medication	106	0	1.00	0.03 (0.17)

Table 7-15: Health history questionnaire data and statistics.

Condition	Sex	Mean (SD)	P Value
Chest pain	Female	0.02 (0.12)	0.86
	Male	0.02 (0.14)	
Breathlessness	Female	0.00 (0.00)	0.43
	Male	0.01 (0.10)	
Asthma	Female	0.06 (0.24)	0.70
	Male	0.05 (0.21)	
Anaemia	Female	0.02 (0.12)	0.21
	Male	0.00 (0.00)	
Circulation	Female	0.00 (0.00)	0.43
	Male	0.01 (0.10)	
Hospitalisation	Female	0.35 (0.48)	0.27
	Male	0.43 (0.50)	
Broken bones	Female	0.30 (0.46)	0.07
	Male	0.44 (0.50)	

7.5 Discussion

Poor movement quality has previously been associated with increased injury risk (Whittaker *et al.*, 2017), and has been shown to improve through the implementation of a neuromuscular warm-up intervention (Soligard et al., 2010). The study presented in the current chapter examined movement quality in Phase-1 Army recruits at the start of training, while also assessing the differences between sexes. The study showed that females had a significantly lower H&LLMS score, which indicated better movement quality. Moreover, the study examined the feasibility of implementing a neuromuscular warm-up intervention over a 12-weeks training programme. The study highlighted that initial adherence was low, but after modification to the implementation strategy, adherence improved. Finally, the study assessed if this neuromuscular warm-up intervention improved recruit movement quality against a control group. The study demonstrated that the intervention used within the study was able to significantly improve the H&LLMS scores of Phase-1 military recruits and showed a significant difference between the INT and CON conditions. This was also assessed for a sex based difference, which highlighted a similarity between the direction and magnitude of movement quality modification post-intervention for males and females.

7.5.1 Time and condition (H&LLMS).

The present findings demonstrate that the neuromuscular warm-up intervention significantly improved movement quality scores. Also, the control group demonstrated a worsening of movement quality. Therefore, not only does this show the potential efficacy of a warm-up specifically designed to improve movement quality but that the physical training currently employed by the military diminishes movement quality. The neuromuscular warm-up intervention used within this cohort sought to improve the way in which a person moves through repetition of base movements that would engage and activate the larger, stronger proximal muscles at the hip rather than the more distal muscle groups, thus improving biomechanical and neuromuscular characteristics of the limb/s (Padua *et al.*, 2012). This evidence is supported by Nemati *et al.* (2017) and Baeza *et al.* (2017) who have showed than the FIFA 11+ improved FMS scores between pre and post intervention scores in male football players. Both studies used male football players under 15yo, who completed three sessions per week for four or six weeks. Both papers demonstrate that FMS scores increased for those in the intervention group. However, Nemati *et al.* (2017) also showed that those in the control group reduced their FMS score between pre and post-intervention testing. Although this was not significant in the football study, this does suggest, like the present study does, that some interventions are counterproductive for movement quality. In the case of Nemati *et al.* (2017), the predominantly cardiovascular based warm-up used, resulted in a reduction in their FMS score. The intervention used in Nemati *et al.* (2017) was only four-weeks and therefore may have had a more exaggerated effect had it continued for longer. However, this is not clear, and the longer study conducted by Baeza *et al.* (2017) shows that the additional two-weeks did not reduce the FMS score of the control group any further.

The present study now adds to this evidence, while highlighting that not all physical training interventions will improve movement quality. The Army warm-up used with the CON group presented with a worsening of movement quality. Therefore questioning the appropriateness of the warm-up in Army Phase-1 training populations.

Previous research using similar warm-up interventions in sporting groups have demonstrated a reduction of lower-limb injuries (Soligard *et al.*, 2008), but some others, such as Thompson *et al.* (2016), have sought to understand how such a change in injury rates occur. They found that peak ankle eversion reduced while knee moments increased significantly during double leg jump landing tasks. The findings from Thompson *et al.* (2016) suggest that the intervention can generate biomechanical alterations within a cohort but it is not yet clear what effect this would have on performance or injury likelihood. Therefore, this mirrors the results from the current thesis, in that there is evidence that the intervention can alter injury likelihood but it is not clear what clinical relevance these changes may have in a cohort over a period of time. Moreover, the cohort in the Thompson *et al.* (2016) study, completed 15 intervention sessions which again mirrors the current thesis in overall exposure. This in itself is not a problem, but it may restrict the understanding of the underlying causality of change. Padua *et al.* (2012) states that in order for a skill to be fully learnt and internalised, the length of the intervention is central. As both the current study and the Thompson *et al.* (2016) study gave relatively low exposure levels, it is unlikely that the change would have remained for long after the intervention. As such, the underlying causality of the change of movement quality is still not fully understood.

If movement quality is a risk factor for injury, as suggested by Whittaker *et al.* (2017), then this study gives clear evidence that such a variable can be modified with specific interventions. Therefore, if movement quality contributes to injury risk, rather than being correlated with injury, a change in movement quality would result in a reduction in injuries. Moreover, those in the CON group showed that during the Phase-1 training, their injury risk may have increased due to a worsening of their movement quality. This not only demonstrates the difference between the conditions, it highlights that the methods of training within Phase-1 training seems to increase the injury risk for recruits. This is in direct contradiction of the intended outcome of Phase-1 physical training program which is intended to improve the physical fitness of every recruit, to the point that 100% of recruits will pass the Army fitness standards. However, the results of the present study suggest that the recruits are at a greater risk of injury than when they started. But more importantly, they are at a greater risk, potentially due to the specific training they are undertaking. This evidence stresses the need for changes.

7.5.2 Time and Sex interaction (H&LLMS)

Assessing the interaction between time and sex revealed a single movement that was significantly influenced. Hip abduction with medial rotation (left leg) not only presented with significance for this interaction, but also for "time × condition", but also separate assessments of "time" and "condition" independently. This suggests that the movement score was significantly influenced by at least three variables. The data show that prior to the RAMP intervention, females presented with a lower, and therefore better, score than their male counterparts (Table 7-1). However, post RAMP intervention, females present with a higher, and therefore worse, score. A similar trend can be seen for the right legged version of the same movement, but no interaction was identified. As only a single movement on a single leg was identified as interaction with "time × sex" it is difficult to interpret the importance or ascertain why. Especially as this anecdotal difference is not observed for the larger H&LLMQ intervention cohort. The movement in question requires the individual to demonstrate hip abduction with as few compensatory movements as possible. Consequently, having a large active range of motion available at the hip would be advantageous. Simoneau et al (1998) demonstrated that females have a greater active range of motion all on tests conducted within their methods, including seated and prone internal, external rotation and abduction. Therefore, this may suggest that females have a greater range of motion that they are capable of using before compensatory methods are introduced. Although, this does not account for the reduction in ability from pre to post intervention or the lack of interaction with the H&LLMQI cohort.

7.5.3 Sex and condition interaction (H&LLMS)

Previous studies have demonstrated that males (Kiesel *et al.*, 2011) and females (Soligard *et al.*, 2008) respond to specific interventions for movement quality and injury reductions. However, no studies have compared the responses between the sexes to the same intervention. The current study highlights that the direction of change is similar for both sexes in either the INT or CON group. Specifically, males and females in the CON group both demonstrated increases in score, while males and females in the INT group demonstrated reductions in score. Although there were significant differences in pre and post-intervention scores between the sex groups, the interaction between sexes suggests that if both sexes are administered the same intervention, they will likely respond similarly. This is particularly relevant for populations that are difficult to separate during everyday activities, such as military, emergency services and school populations, as these groups are not separated based on sex, but on time of intake. In such cohorts, having an intervention that can be administered to the entire group without the risk of negatively effecting some fraction of the cohort is vital. This study demonstrated that both males and females improve or reduce their movement quality based on the intervention condition rather than their sex. The neuromuscular warm-up intervention has shown itself to be an appropriate intervention tool for movement quality modification in mixed sex cohorts. This gives greater weight to the continued use of the neuromuscular warm-up intervention in such cohorts for further research into movement quality modification.

7.5.4 Interaction of sex, Condition and time (H&LLMS).

The literature has demonstrated that when a single cohort contains male and females, there is a difference in injury rates, and that females are between 2 and 10 times more likely to sustain an injury (Soligard *et al.*, 2008). There is also a strong indication that injury rates are linked with movement quality (Soligard *et al.*, 2008). Therefore, the current study hypothesised that males' and females' movement quality would differ, and that this difference would give greater insight into the greater injury risk for women. Prior to undertaking the exercise intervention, females had significantly ($p=0.005$) lower, and therefore better H&LLMS score than males (Mean ± SD: 28.2±5.6 Female; 31.8±5.9 Male,). However, there was no significant interaction between sex and movement quality change over time, with both sexes responding to their separate intervention conditions similarly.

These pre-intervention results demonstrate a clear separation between previous research and the recorded data. Gibbs *et al.* (2014) demonstrated that there was no significant different in movement quality between sexes using the FMS. The FMS is fundamentally different from the H&LLMS (for more details on this please see chapter 3.1), which may account for some of the discrepancy between the two results. However, this still does not give greater insight into the increased injury likelihood for females.

From the different movement quality scores seen pre-intervention, the change in mean H&LLMS scores over the course of the intervention indicated that male and female recruits demonstrated similar levels of improvement. As such, the proposed exercise intervention could likely realise similar improvements in movement quality in both male and female recruits. Indeed, the present study demonstrated that movement quality is a modifiable injury risk factor, which can be affected by an exercise intervention programme, even with relatively modest exposure. Previous studies using other movement screening tools have found similar improvements in movement quality as reported in the present study (Steffen *et al.*, 2013a; Bodden *et al.*, 2015). However, this is the first study to examine the influence of a movement quality intervention on both males and females simultaneously. This is an important point, as both the male and female recruits in the present study were exposed to the same military training programme.

7.5.5 The effect of a neuromuscular warm-up on self-reported hip pain

Average HAGOS scores indicate that those in the CON group reported lower scores and therefore higher hip, groin and lower-limb dysfunction at both pre and post intervention time points. Moreover, interaction effect between the INT condition and time demonstrated that while those in the INT group demonstrated significantly higher HAGOS scores than those in the CON group post- intervention, the CON group scores decreased and demonstrated a worsening of their self-reported lower hip, groin and lower-limb dysfunction. The initial validation study of the HAGOS (Thorborg *et al.*, 2011) stated that in order for a total score change to be considered clinically relevant for individuals, the change would have to be between 17.7 – 33.8 points. However, for use within groups, this number reduced to between 2.7 – 5.2. Both groups showed a deterioration in their score over the 12-week intervention. However, based on these clinically relevant estimations, only the CON group showed clinically relevant changes (CON=-7.14; INT=-1.94). These results suggest that while those in the INT group maintained low levels of self- reported lower hip, groin and lower-limb dysfunction, the CON group were exposed to something that increased their self-reported hip, groin and lower-limb dysfunction. As the only aspect of their training to differ consistently was the neuromuscular warm-up, it is likely that this is at least an influencing factor. This study is based on the principle that prolonged and repetitive movement affects bodily structures based on the quality of this movement. As those in the CON group reduced their H&LLMS score, it seems plausible that this has also impacted their perception of hip groin and lower-limb dysfunction and pain. However, this study does not have the required evidence to assign causality. Therefore, the study can purely state that there seems to be a link between H&LLMS score and questionnaire responses to hip, groin and lower-limb dysfunction and pain.

Future studies could record and present findings on similar outcome measures in order to more fully understand the link between military training and perception of hip pain. Additionally, using such an outcome measure may prove useful as a grouping or stratification factor alongside the commonly used age, sex and mass, to give greater understanding of the links between perceived and actual hip dysfunction. However, as perceived hip pain, as used in the current study, is not dichotomous, the most appropriate way to split this factor is yet unclear. Therefore, future studies are encouraged to identify whether a cut-off point or sub-groups would suffice in generating significantly separate groups.

In a similar fashion to the HAGOS, the average iHOT scores showed that those in the INT group demonstrated lower self-reported hip, groin and lower-limb dysfunction before and post-intervention. Additionally, interaction effect between the intervention condition and time demonstrated that while those in the INT group demonstrated significantly higher iHOT scores than those in the CON group post-intervention, those in the CON group improved their self- reported hip, groin and lower-limb dysfunction over the intervention period. However, in contrast to the HAGOS, both the CON and INT group demonstrated an improvement between their pre and post-intervention scores. Moreover, while the HAGOS showed a larger reduction score for those in the CON group, the iHOT has demonstrated a larger improvement for those in the CON group. Although this suggests that the standard military training has a more positive impact on self-reported hip and lower-limb pain than the intervention, it may have been a result of the lower levels of self-reported pain prior to the intervention from those in the intervention group. While the CON group scored 81.4, the INT group scored 94.29. This leaves very little room in which to demonstrate an improvement. Additionally, even though those in the CON group exhibited an improved iHOT score, they still did not attain the same level as those in the INT group. Moreover, Nwachukwu *et al.* (2017) conducted research into the minimal clinical important difference, and found that the iHOT was shown to have a clinical difference if the score had improved by 24.5. The current study has shown a change in score of 9.31 (CON) and 0.16 (INT), which suggest a non-clinically relevant change in iHOT score. However, as pre-intervention scores were above 75 for both intervention groups, there was no way in which their scores could have improved by more than 18.6 (CON) and 5.71 (INT) respectively. Therefore, it may be that the closer a person is to the peak score of 100, the less chance there is of achieving a clinically significant improvement, or that the closer one is to 100, the change required to indicate a clinically significant difference reduces. As this is not clear at this point, the current study can purely state that the difference seen between pre and post intervention iHOT scores in not likely to be clinically relevant. The discrepancy in findings between the HAGOS and iHOT is discussed below.

When working with cohorts that sustain a high number of injuries, there is often value in gathering information on the effect these injuries have on individuals. In recent years, many tools have become available that record patient response to lower-limb pain and quality of life (Ramisetty *et al.*, 2015), however, the data gathered would be considered of greater value if a single tool could prove more accurate or reliable in a specific cohort of injury type. Systematic reviews of the most valid and reliable PROM tools available have reported that the iHOT and HAGOS are the most prominent PROM screens and suggested that the iHOT is better able to identify risk factors for hip degeneration than the HAGOS (Ramisetty *et al.*, 2015). However, this was purely assessing studies addressing those who had recently undergone hip surgery, rather than in cohorts of those likely to sustain hip and lower-limb injury. Thorborg *et al.* (2011) claimed that the HAGOS is an appropriate assessment tool for symptoms, activity limitations, participation restrictions and quality of life in cohorts of physically active people with long-standing hip and groin pain. This current research programme, and the present intervention study has attempted to find another prospective study that used both patient-reported outcome tool questionnaire, however, has been unable to do so. Therefore, this may represent the only study that does so. The lack of research showing a combined use of the iHOT and HAGOS may be due to them targeting different cohorts. However, they both assess the same limb and pain response. As neither questionnaire requires any significant time or physical exertion, administering both to a single cohort would not disturb testing any more than the administration of a single one. Therefore, the current study used both in an attempt to identify one of these two as the most appropriate within a military Phase-1 training cohort.

Results from the present study show that there is a disagreement between the two hip, groin and lower-limb dysfunction questionnaires, i.e. the HAGOS and iHOT. This poses the question of which tool can be considered the most appropriate tool to use within this population. As stated previously, military recruit cohorts are comprised of those with and without hip and lower-limb pain. By using both questionnaires, it is more likely that the study would record accurate data. Moreover, assessing against one another with the same cohort, may highlight the specific differences between the questionnaires and hopefully one would emerge as the most appropriate.

Pre-intervention scores for the HAGOS and iHOT showed disagreement, so they seem to be collecting different data prior to any changes brought on by the 13-week intervention period. This may be due to there being a difference in the focus of each tool. Specifically, the iHOT was developed for use with populations at high risk of hip, groin and lower-limb dysfunction; whereas, the HAGOS was developed for those experiencing hip, groin and lower-limb dysfunction already. Neither screens represent the population used within the present study. However, Ramisetty *et al.*(2015) concluded that of all Patient reported outcomes (PRO) tools availabe for measuring hip pain, these two were the most appropriate and scored higher in their measurment properties. The current sudy is therefore not suggesting that one is better than the other. Merely that one may be more appropriate for this spesific cohort and/or what may be the reason for the difference in the results fomr the two PRO tools. The likelihood of recruiting personnel who are currently suffering from hip pain is substantially higher than those who have recently undergone hip surgery, as these people would be restricted from enrolling. Therefore, it is more likely that the HAGOS is more appropriate within the current cohort. If this were the case, this would mean that both groups reduced their score and therefore the overall perceived hip pain increased. This was greater for those in the CON group, but still present in the INT group to a lesser degree. The different scores recorded by the two screens is evidence of the disparity between what the tools are collecting and perhaps evidence that the individual tools are specific to certain populations and/or that the tools should be used in conjunction more often.

7.5.6 Adherence to intervention

The current study hypothesised that the more the intervention was completed, the more likely it would be that the intervention would have an observable effect on movement quality and H&LLMS scores. Although this hypothesis was purely used to assign a number of interventions undertaken per week, and based on previous intervention studies (Soligard *et al.*, 2008), the study was not designed in a way that would generate different exposure levels other than the two main INT or CON groups. The study aimed to have participants complete the intervention 3-times a week, with 9 movements per session. Resulting in a total of 27 movements being completed each week. However, this was not achieved.

Initially, low adherence was observed (19%); and therefore, amendments were made to change this. A meeting was arranged where the researchers would present the evidence for the intervention and after, would take questions and practical issues from the PTI's. This was thought to better inform the PTI's and give them important information as to the importance and relevance of the intervention. Once completed, adaptations were made to better fit the intervention around military training. Unfortunately, this increase to 35% of potential intervention opportunities was still lower than anticipated. McKay *et al.* (2014) showed that that injury knowledge and beliefs does not significantly affect injury mitigation intervention adherence for youth female football coaches or players. Therefore, it is not surprising that the steps taken within the current study did not increase adherence by a greater amount. What may have been more appropriate is the use of coaching workshops. McKay *et al.* (2014) and Frank *et al.* (2015) have shown that this approach results in greater engagement from coaches and can result in the intervention being ran independent of the research team. This is advantageous in cohorts that already have a rapport with the coach and would have their motivations to undertake training artificially affected by the introduction of an external entity. The current study was designed to run in this way, and therefore, would likely have benefited from the use of workshops.

The study demonstrated that just over a single session was completed each week. Although this was originally disappointing, it aligns with previous warm-up based lower-limb MSK interventions. Soligard *et al.* (2008) showed that an intervention completed 1.3 times per week and saw a 35% reduction in injury when compared to a control group; however, they did not assess movement quality. As the current study did not allocate a mid-intervention movement screen test, the study is unable to assess the effect of the change to the implementation of a recruit's movement quality. However, this information will aid in the development of future interventions and studies conducted within military training facilities.

Previously in this chapter (section 7.3.2), it was suggested that there may have been an increase in adherence from the recruits because of the financial compensation awarded to those who participated in testing. However, as the recruits were paid based on their participation in the pre and post-intervention testing rather than their individual adherence to the exercises, this was unlikely to have a substantial effect on intervention adherence. Moreover, every recruit would have been categorised into intervention or control group regardless of whether they had given consent to be tested or not. This is due to them being in troops that would complete the exact same training as each other. Therefore, if a single person within a troop were to have been in the intervention group, the rest of the troop would have been. This was explained to the troops before any testing took place. Therefore, if they were already having to complete the intervention, and they would also have to submit for medical testing prior to Phase-1 training, it was very little additional effort to submit for observational testing lasting 15-mins. Therefore, the recruits, in large, saw this compensation as money for something that they were already doing, and had little influence on their recruitment for the study, and no influence on their adherence to the intervention.

A factor that may have influenced adherence rates were the observations completed by the study team. However, after conversation with the PTIs, this is unlikely. It was originally thought that having a member of the study team around during most of the intervention sessions would give the lead PTI the opportunity to check and reassure them during the intervention. Additionally, this was thought to have the potential to coerce the PTIs into completing a greater number of interventions due to them being observed. What seemed to actually happen, is that the PTIs saw this as a constant checking that they were completing the intervention and they felt a small amount of resentment. Moreover, there were a number of occasions where the study team member arrived to observe the intervention, but was informed that the intervention would not be completed. Therefore, the presence of a study team member had no positive influence, while potentially creating a negative experience for the PTI. This seems to mirror that stated by Steffen *et al.* (2013b), and that the presence of a qualitied practitioner did not affect the adherence of the FIFA11+ intervention. However, Steffen *et al.* (2013a) stated that when coaches were supervised by a qualified practitioner, their athletes showed significant improvements in performance based tasks over less invasive, or hands-on approaches to coach training. Steffen *et al.* (2013a) stated that those in the supervised coach group, significantly improved their single leg balance, their Star Excursion Balance Test score and risk of injury when compared to the unsupervised group. Moreover, the study found that those with lower exposure to the intervention were 3.5-times more likely to sustain an injury of any kind, and therefore suggesting a potential dose response.

7.5.7 Dose response

The study recruited two troops of recruits for the control condition and four troops for the intervention condition. The intention was to ensure that all troops in the intervention condition received the same amount of exposure to the intervention. However, as detailed in section 7.4.4 of the result, intervention exposure varied between the individual intervention troops. Although this was not ideal, it did give the study team the potential to observe a possible dose response to the intervention. Being able to better understand the effect of adherence and intervention dose increases the understanding of the mechanisms of change and allows for detail and depth of data analysis. With an overall increase in intervention exposure there was a trend in reduction in movement screen score (*Figure 7-7*), therefore indicating improved movement quality. However, the difference between the intervention exposures received by each troop was not statistically different, and ultimately resulted in non-significant differences between the movement quality of the four troops. However, even this small variation was enough to show a significant difference in total H&LLMS score between the CON and the troop with the highest dose (13.4 movements per week). Although a screen total score is seen as simple and unspecific, the change to such score may well prove viable for analysis. If this is the case, the current study has demonstrated that there was a significant difference between the CON group and the highest dose group. However, there was no significant difference between CON and three of the intervention troops with lower doses. There was also no significant difference between the four intervention troops. This seems to suggest that 13.4 may be the smallest dose required to elicit and change in movement quality. The likelihood of the current study happening to unintentionally use the perfect lowest dose is highly unlikely. However, as the next highest dose was 8, and did not generate significant difference between this does and those lower, it would suggest that the minimum dose required for movement quality changes is between 8.1 and 13.4 movement per week. However, as these doses were not informed by previous research, and occurred by happenstance, a more rigorous and evidence based study based on dose is required before such a conclusion can be made.

Soligard *et al.* (2010) showed that increasing the exposure of a movement quality intervention from 20% to 45% of the potential interventions opportunities per week decreased injury risk by 35% in female football players. Therefore, if the intervention adherence of the current study could replicate this percentage, and if improved movement quality is a mechanism for injury risk reduction, it is likely that the mechanism of injury rate change would also present within the current study data. As such, the current study was able to indicate that movement quality interventions exhibit a dose response within a military cohort with male and female recruits.

7.5.8 Links between the H&LLMS and injury

Although injury data was prospectively collected by military medical officers, these data were not made available to the lead investigator under circumstances that allowed for this data to be practically used within this study. Therefore, this study was unable to analyse injury data in conjunction with movement quality or any other outcome score. This obviously limits the interpretation and impact of the study. However, the study still addresses key and novel areas which add to the knowledge base in the area of movement quality and factors affecting movement quality in military cohorts.

7.6 Limitations of the study

Movement quality has been linked to injury risk (Whittaker et al., 2017), and other neuromuscular interventions have shown an ability to modify injury rates (Soligard et al., 2010). Therefore, it is reasonable to suggest that the interventions used in the present study may have similar effects for both males and females. Consequently, this suggests that those who were exposed to the military training, without the neuromuscular warm-up within this study, were more likely to sustain injury than those in the intervention group. However, the present study cannot confirm this due to not collecting injury data. Not only does this mean the present study cannot evaluate the relationship between total movement quality score and total injuries, but also the specific relationship between a single point improvement in movement quality score and injury is unknown. The current findings only indicate the discrepancy in movement quality between the two protocols, rather than indicate to what degree those in each group are at risk of injury.

Initially, the study aimed to recruit n=448 volunteers, which would have been equally divided between males and females and the CON and INT groups. This sample size was generated using HAGOS scores and effect sizes from previous studies. However, Mohtadi *et al.* (2012) stated that if the HAGOS were used for sample size estimation, it would likely result in an over-estimation, and that this questionnaire should not be used as a primary outcome tool. However, the present study was the first to use the H&LLMS as a primary outcome tool and therefore was limited in its ability to generate an approximate sample size. Although the study aimed to recruit the 448 recruits, the recruiting tempo dictated the numbers and resulted in a large difference between intended and actual recruits. The final cohort was smaller than anticipated and unequal in terms of the distribution between male and female recruits and between the CON and INT groups. This change in the planned study sample size would have reduced the statistical power. Therefore, the study sample size was a limitation to the interpretation the study can make. However, the data and insights from this work have provided preliminary evidence on efficacy, as well as important understandings to the implementation of a neuromuscular warm-up exercise intervention. As such, this has provided a robust interrogation on the feasibility of such an intervention in Phase-1 Army training.

The planned protocol was to undertake the intervention prior to all PT sessions, as would be the case in a sporting context. However, this planned delivery reduced the time available for scheduled PT elements that needed to be completed during each lesson. Reported reductions in PT time within the recruit syllabus (PTI Focus Group), and the requirements for recruits to meet the same pass-out standards on completion of Phase-1, made time within PT sessions very compressed. Future adoption of exercises from the intervention as part of a MSKI risk mitigation programme will need to consider effective programming to maintain the required integrity of all elements of Phase-1 recruit training.

The current study used an information and presentation style to affect adherence levels with the PTI's. However, an assessment of the relevant literature revealed that this would have been inadequate in sporting cohorts. A more appropriate method would have been to use coaching workshops. McKay *et al,* (2014) and Frank *et al.* (2015) state that this approach would have yielded an increased likelihood of higher adherence from the PTIs which would have likely increased the adherence from the recruits also. Therefore, future studies should adopt such an approach during the initial engagement with cohorts undertaking such interventions.

7.7 Timescale

Phase-1 training lasts 14 weeks, although the intervention was only completed for 12 of these weeks with post-intervention data collected in week 13. The initial troop was recruited in mid-August (later than anticipated), which meant that post-intervention testing would start in early November. As recruits were given two weeks leave over Christmas, this would result in the intervention not being conducted by the PTIs, if at all, and not being observed by the study team. As such, it was suggested that the study would only recruit 3 intakes, and therefore 6 troops, that would end prior to the Christmas break. This greatly restricted the number of participants available for recruitment. Additionally, only participants from the pre-intervention observation study were recruited into the intervention study giving a total of 178.

The full pilot RCT was completed in 18 weeks with a total of 6 troops (2 CON, 4 INT) and 128 recruits. Although this may result in fewer female participants than predicted necessary for a fully powered study (based on the HAGOS), this is based on theoretically required numbers.

7.8 Conclusions

The neuromuscular warm-up intervention used within the present study improved movement quality in Phase-1 military recruits. This then demonstrates that movement quality is modifiable and liable to improvement and decrements through physical training. However, although the intervention improved movement quality, Army Phase-1 military training was associated with a decrease in movement quality in both male and female recruits. If, as previous papers and research have suggested, movement quality is a risk factor in musculoskeletal injury, then the current study can imply, indirectly, that movement quality is a modifiable risk factor for lower limb musculoskeletal injuries. Therefore, this would suggest that Army Phase-1 military training may increase the risk of injury through the mechanisms of reduced movement quality. However, the present study did not assess lower limb musculoskeletal injuries and therefore cannot confirm if this modification in movement control would result in a reduced injury rate, which requires investigation.

Male and female recruits in both the INT group and CON group demonstrated similar levels of movement quality change (ΔH&LLMS: CON +3.8±6; INT -2.2±7; P=0.00). Therefore, although previous studies into movement quality have demonstrated movement quality changes in males or females in response to different interventions, the current study shows that the movement quality response to the same intervention is similar between males and females. As such, this study shows that, for populations where it is impractical to conduct separate physical training for males and females, neuromuscular interventions can be delivered to both, whist expecting similar results.

The significant changes to movement quality were achieved in spite of the adherence to the programme being lower than optimum. It was found that removing the intervention from military physical training and conducting it at another time improved adherence, therefore indicating how feasibility could be improved. Additionally, the study suggests the presence of a dose response. However, as these does groups manifested independent of evidence, the study was unable to definitively prove such an interaction.

7.9 **Impact of study**

Since the completion of the study, the results have been distributed to military services in the form of a military report. From this, the Navy have initiated an RCT study at a Phase-1 training establishment that will also include injury data based on the results and effect sizes from the current study.

The present study demonstrated that movement quality is modifiable, however, perhaps the greatest impact of the study is the knowledge that movement quality modification is similar between males and females. More specifically, movement quality can improve or worsen through intervention in similar magnitudes from both sexes. In the current study, those in the control group demonstrated a reduction in movement quality while those in the intervention group improved regardless of sex. This information allows those developing and delivering routine physical training in the military, and other mixed sex cohorts, to adapt currently employed programmes so that they are based on understanding and evidence.

As previously stated, current research suggests that movement quality may be linked to injury rates. The present findings may prove important to military economics and retention of recruits if further research provides definitive evidence. Firstly, if fewer recruits sustain injury during training, more will pass through training. This will increase the number of Phase-2 recruits and service personnel. Moreover, this is likely to increase the quality of recruits passing Phase-1 training as fewer of them would require rehabilitation and therefore be able to train more often, at a higher level. Furthermore, the greatest indicator of future injury, is past injury. Therefore, by removing the initial injury, the likelihood of future injury reduces. All of the aforementioned improvements due to improved movement quality would likely result in improved quality of life for the recruit. The military would also receive an improved financial return. If the number of injuries reduces during training, the military could expect to reduce their expenditure on rehabilitation. Moreover, the loss of recruits is expensive, and reduces the amount of recruits passing per money spent. Furthermore, reducing the initial injury would likely reduce future injuries and therefore see fewer service personnel removed from service due to musculoskeletal injury and dysfunction. Therefore, although the current study did not investigate or confirm a relationship between movement quality and injury rates, if such a relationship did exist, it would not need to be a large relationship for an organisation as large as the military to see a substantial reduction in injuries and their subsequent cost.

Chapter 8: Qualitative assessment of the intervention implementation strategy

8.1 Introduction

This study sought to evaluate the implementation strategy for the movement quality intervention outlines in chapter 7. This was achieved by systematically observing how the intervention was deployed during Phase-1 training while also observing the adherence levels throughout the 12-week schedule. Moreover, motivations and experiences of the intervention were also obtained through two focus groups. The first focus group was completed with the Physical Training Instructors (PTIs) to gain understanding of the experience of conducting the intervention. The second was completed with the recipient recruits, to gain an understanding of how the intervention was to complete. Previous studies have shown that movement quality can be modified through physical activity interventions (Kiesel et al,. 2011). However, some studies have reported low levels of adherence during these interventions (Soligard et al., 2008). Nevertheless, there appears to be a dose response relationship between intervention adherence and movement quality and/or injury occurrence (Steffen et al., (2013). If confirmed, any intervention aiming to modify movement quality would benefit from increasing adherence rates. Understanding the barriers to higher adherence would allow for evidence changes to the implementation strategy that would increase adherence.

During the current study, changes were made to the intervention during the programme to increase adherence. However, even with modifications to the implementation approach, at best, peak adherence was 35% of the planned delivery. Better understanding of the barriers to, and motivations for, undertaking a novel neuromuscular intervention would support more appropriate and effective implementation strategies. This would support greater adherence and, if the intervention was effective, a dose response in movement quality outcomes proportionate to the level of adherence. The previous chapter (Chapter 7) demonstrated an ability to modify movement quality as well as highlighting evidence of a potential dose response. This intervention may prove a viable option as an injury reduction strategy. However, a greater level of adherence would be required to achieve the most effective outcome.

8.2 Aims and Hypotheses

8.2.1 Aims

1. To increase the understanding of the barriers to, and motivations of physical training instructors for delivering a movement quality intervention in Phase-1 military cohorts.
2. To increase the understanding of the barriers to, and motivations of Phase-1 military recruits for undertaking a movement quality intervention.

8.2.2 Hypotheses

H_1 There will be barriers to intervention delivery.

H_2 The intervention implementation strategy is able to be improved through conversation and feedback from recruits.

H_2 The intervention implementation strategy is able to be improved through conversation and feedback from physical training instructors.

8.3 Methods

8.3.1 Qualitative study design

This study is linked to the study described in chapter 7 which assessed the feasibility of implementing a neuromuscular exercise intervention to Phase-1 military recruits. The PTIs were introduced to the intervention during a class based session and two practical training sessions. Training of the PTIs involved practical sessions specifically based on being able to identify preferred technique and methods to help the recruits to achieve the preferred technique. Throughout the practical sessions, the PTIs experienced the practical difficulties in performing the intervention and were able to give suggestions that would benefit the intervention. Additionally, a member of the study team undertook observations of the delivery of the intervention and made themselves available for questions and practical input during the intervention. The initial implementation strategy was deployed in unison with the military PTIs, which suggested that the intervention be completed in conjunction with, and just preceding the recruits typical physical activity sessions. However, this strategy resulted in a low adherence level and was changed. In doing so, the study sought to attain advice and opinion from those who delivered and experienced the intervention. The study sought to understand the barriers to, and motivations for undertaking movement quality interventions from both the perspectives of the deliverer PTIs and the participating recruits. This information was used to inform modifications of the current intervention implementation approach, as well as improve future implementation of such an intervention aimed to improve movement quality. The study employed a qualitative study design, in the form of focus groups.

8.3.2 Ethics

The protocol for this study was included within the same application submitted for the intervention study (Chapter 7); which was approved by the Ministry of Defence Research Ethics Committee (Reference: 781/MODREC/2017) and was conducted in accordance with the ethical standards of the

Declaration of Helsinki. All ethical considerations were therefore identical to that explained in chapter 7, section 3.2.

8.3.3 Participants

Only those who undertook or delivered the intervention were approached for participation in the focus groups. A study briefing was conducted where participants were provided with a full description of the focus group component of the study, were provided with a participant information sheet (Appendix L & M) and had opportunity to ask questions of the study team. It was also explained that the focus group was voluntary, and that non-participation would not negatively impact the PTIs' Service career or the recruits' training outcome. Potential focus group participants. Of those invited, 30 recruits and 18 PTIs volunteered.

8.3.4 Focus groups quality assurance

The study involved Phase-1 military recruits and Army PTIs. These two groups were likely to have different motivations towards the intervention based on their respective roles and experiences with the intervention. The PTIs were taught the intervention, and were responsible for conducting the intervention delivery sessions with the recruits. The PTIs were familiar with other types of warm-up sessions, and were familiar with the typical barriers to physical exercise programs. Whereas, the recruits had volunteered to undertake Phase-1 Army training, and therefore had no influence over the training programme nor were likely to know the difference between the study intervention and the standard military warm-up. Better understanding of the experiences of both cohorts would improve any subsequent intervention within similar cohorts for both the PTIs and recruits.

Two separate focus groups were undertaken, involving either recruits or PTI volunteers. These were conducted at the end of Phase-1 training and were completely voluntary. Prior to starting the recording, all those present were told that they were not obligated to attend the focus group, at which point, some did leave. A count of each focus group was collected at this point, and the recording started shortly after. The semi-structured interview guides were based on previous work on barriers and facilitators to programme adoption and implementation among youth sports performers and coaches (Orr et al., 2013 and Mckay et al., 2016) (Appendix N & O), and reviewed by Dr Booysen based on her experiences of undertaking similar work in the sporting environment (Booysen., 2016). Those answering questions were asked to give as much detail as they wanted. Focus groups were conducted in informal settings in order to increase the comfort of the participants. Each focus group was scheduled for circa one hour. Digital recordings were taken at each focus group and as such, at points, the researchers would narrate nonverbal events for the purpose of accuracy. Field notes were also taken as a secondary data source.

8.3.5 Data analysis

Focus Group data were evaluated through thematic analysis. Braun and Clarke (2012) state that many data analysis tools used in psychology have origins elsewhere, and most do not transition into psychology without modification. Thematic analysis is an example of one such tool that has undergone modification to better meet the requirements of the research paradigm. Braun and Clarke (2012) stated that this method is a way of systematically identifying and sorting common patterns presented by a narrative data set. Within the current study, the data set was the transcript of the PTI and recruit focus groups, and the patterns were the categories of topics raised by study volunteers as talking points. Data were prepared by transcribing the PTI and recruit focus group interviews, which were then coded according to the six phases of thematic analysis, as detailed by Braun and Clarke (2006). Coding was informed, but not limited to the themes of questions asked.

8.4 **Results of the focus groups**

Results from the focus groups highlighted four consistent themes and one that was only expressed by the PTIs, but done so to such a degree that it was also considered a major theme (**Error! Reference source not found.**).The only difference between the PTIs and recruits was that the recruits gave no mention of time required to undertake the intervention (**Error! Reference source not found.**). This likely represents the responsibilities of the PTIs to maintain strict schedule for training delivery sessions during Phase-1 training.

8.4.1 Focus groups (Physical Training Instructors)

All vocal PTIs expressed concern over the discrepancy between the entry physical fitness level of the recruits and the level of fitness they deemed necessary to perform the role of military personnel. The PTIs explained that they had seen a marked decrease in the physical fitness and physical ability of more recent Phase-1 recruit intakes. This had since led to a modification in the way in which the military training was conducted.

PTIs also stated that recruits were not scheduled to attend physical training serials adequately during the 14-week Phase-1 training to achieve the required fitness improvements. During the final few weeks of Phase-1 training, it was explained that recently, less time was given to physical training and more time devoted to other activities. However, recruit pass out standards remained the same as previous years. To ensure that the recruits were as physically fit as they could be, the PTIs claimed that they were required to complete the same training volume as before, but in fewer sessions. The PTIs expressed that they thought these changes had resulted in less than optimal conditioning and physical training procedures.

The physical fitness standards at the end of Phase-1 were seen by many of the PTIs as attainable by most who were recruited. But when the recruits move to Phase-2, the fitness standards would vary depending on the trade into which recruits were enrolled. Some of these trades would require a much higher level of physical fitness and therefore, the PTIs expressed concern that those who go on to more physically demanding Phase-2 training might not be fully physically prepared. This would likely result in the recruits failing week-1 physical assessment in Phase-2 and being given additional physical training. It was their opinion that the greater the discrepancy between physical fitness of the recruit and the physical fitness required, the higher the risk of injury would be during Phase-2.

All PTIs involved with the intervention stated that it took up too much time. Additionally, there were certain sessions where the intervention was seen as less appropriate than the (Army standard) RAMP warm up; such as prior to Tactical Advancement to Battle (TABs) and Obstacle courses.

As reported in section 7.4.4.1, the intervention was initially conducted before physical training, but this proved inconvenient, resulting in less than 20% of planned interventions taking place. However, after moving the intervention location and times to fit around 'down time' in trop lines, the exposure levels increased to 35% of planned (Figure 7-2). Additionally, they stated that the intervention ran better in troop lines, but that this only lasted a few weeks.

The PTIs reported that most of the movements covered within the intervention were already undertaken during typical training sessions and the RAMP warm up. However, when questioned specifically about the movements, they gave incorrect definitions of the movements, thus showing a discrepancy in their theoretical knowledge. For example, they misidentified muscle activation movements, such as the plank, for stretches. Additionally, they also claimed that some of the movements in the intervention were too difficult for the recruits.

When asked about barriers they faced while completing the intervention, the PTIs mentioned that recruit motivation was probably not a factor in the success / failure of the intervention, as the intervention and any PT task were completed regardless of motivation. However, the PTIs suggested that gaining a greater buy-in from the PTIs would likely increase the likelihood of a successful intervention. This was also noticed by the study team as credentials of the study team and worth of the intervention was questioned throughout Phase-1 training by the PTIs in front of recruits.

Although all previously stated barriers and issues were raised by the PTIs, the main barrier was found to be time. All PTIs identified this as perhaps the main barrier and suggested that the intervention be made shorter. It was explained to the PTIs that this is a goal of the research team, but that at this point, there was no evidence to justify the removal of one or more exercises, and that this would be part of future research and testing.

8.4.2 4.2.2 Focus groups (Recruits)

The recruits varied in their opinions and attitudes towards the intervention. Some showed interest in the study while others thought that this intervention would be an extra punishment and arduous task to be completed that they thought was not required. Many of those who thought this had no present or past hip and lower-limb injuries.

The motivation of the platoons (training cohorts) also varied, but this time due to their daily routine and the schedule. They stated that when the intervention was run before PT, they were more motivated for the intervention and physical tasks. However, when the intervention moved and was no longer associated with PT, they felt surprised by the intervention as it was not on the daily schedule. As such, their motivation was affected negatively. The recruits countered this though, by explaining that they still all completed the intervention each time it was presented.

Most recruits stated that the intervention was easy and scored it as <5 on a 1-10 scale. However, some recruits claimed that the intervention was painful and that they were unable to complete certain tasks during the intervention.

The recruits referred to the movements within the intervention as ‘stretches’ which was similar to the PTIs. Therefore, the researcher asked them to state which movements were stretches. The recruits from one troop stated that they thought that all the movements were stretches, whereas the remaining recruits from a different troop all stated that the movements were strength and activation movements. This reaffirms the link between PTI buy-in and filtering down of information from the PTI to recruits. This may have also affected the recruits' feelings about the importance of the intervention.

When asked if the recruits thought that the intervention should be continued after the study, they stated that it should, but with specific changes. The intervention should be shorter while including other body areas. Additionally, this should be added to the daily schedule to reduce their surprise and the recruits should be given more autonomy over when this is completed.

8.5 **Discussion**

8.5.1 PTI experience of executing the intervention

The main findings from the focus group showed that the main barrier to completing the intervention was time. The PTIs explained that there were now fewer physical training sessions than they had conducted in previous years and that this was a strain on the quality of session. By adding a new element of training, this time was again stressed. Removing the intervention from planned training reduced this stress on time and improved the quality and completion rate of the intervention. This was reflected in the data presented in chapter 7. Therefore, any further study using Phase-1 recruits may benefit by exploring similar implementation strategies. Moreover, reducing the time of the intervention would also improve adherence, according to the PTIs. One way to achieve this reduction in time required would be to remove less relevant movements within the intervention. However, it was not possible to remove specific movements during this intervention study as there was no evidence to suggest that the movements gave varying degrees of movement quality changes. Consequently, future investigation into the intervention, randomised removal of specific movements may yield a shorter, more efficient intervention.

The PTIs also suggested that they had reservations about the intervention and had not fully engaged with it. This was apparent when talking to them about the importance of each movement, where they regularly stated that muscle activation movements were stretches. The PTIs suggested that their lack of buy-in may have been due to not believing that the study would have an effect. It was originally thought that showing the evidence from previous studies would have been enough to gain buy-in. However, McKay *et al.* (2014) showed that the knowledge and beliefs one has does not significantly affect injury mitigation intervention adherence. This study has given further evidence that this approach is less than optimal for increasing intervention adherence. However, the current study has demonstrated that movement quality is not only modifiable, but that the currently employed intervention improved movement quality. Moreover, the current study showed a potential dose response. Therefore, it may prove important to gain a greater intervention adherence.

McKay *et al.* (2014) and Frank *et al.* (2015) stated that using coaching sessions and workshops increased the buy-in from the delivering cohort which in turn increases the adherence rates. The current study did not use this method, and employed a presentation with follow up taught sessions on how to complete specific movements lasting 30-mins each. The PTIs explained that they felt dictated to by people outside the military. At the time, they were not very receptive to the information and verbalised their issues with the intervention. Reflecting on how the current study approached teaching military PTIs new content, the current study highlighted a gap between what was done, and what is optimal.

8.5.2 Recruit experience of undertaking the intervention

Recruits also suggested that the intervention was too long, and that the relocation away from physical activity session improved the intervention. However, the recruits stated that they were often surprised by the intervention as it was now not in the schedule. This was a particularly important issue when the intervention was completed prior to the recruits needing to be in dress clothes. Many of them would be dressed early, and would then have to either complete the intervention in their dress clothes and attempt to keep them clean and un-creased. Or they would need to quickly change into other clothes and then redress afterwards. If they were not given enough notice beforehand, this decision would often be taken from them and they would have to complete the intervention in dress clothes. Although this is fully achievable, and would not have hampered their ability to perform the movements, they may have received warnings and perhaps harsher punishments if they arrived at inspection in less than satisfactory appearance. Therefore, future interventions with such cohorts should ensure that the intervention is outside of training, but specifically within the schedule.

Recruits stated that they did have varying levels of motivation to complete the intervention. However, as they expressed, they would have to complete anything that their training team selected for them. Therefore, they would always complete the intervention, when it was ran. However, they may not have done so with as much enthusiasm as possible at each opportunity. The lack of autonomy that military recruits have creates a potential issue with intervention studies. In so much as they are heavily coerced into the intervention with little say over their involvement. As phase-1 and 2 military training facilities emphasise the recruits ability to take orders, work as a team and maintain a strict routine, this lack of autonomy at the start is by design and unlikely to change. What this means is that the PTIs and senior troop leaders are key to the adoption and adherence of any intervention. But this may not guarantee full commitment of the recruits at all time. As this was not measured in the study, it is unclear how much of an effect this change in motivation had on the change of movement quality. However, it may be something that future studies can observe and record to better understand the influence this would have on movement quality change.

8.5.3 Summary

The focus groups demonstrated that there were five themes consistent across the PTI and recruit cohort. Insufficient time, fitness standards of the recruits, buy-in to the intervention, understanding of the intervention and motivation to undertake the intervention. Of these, fitness standards of the recruits was not modifiable prior to recruitment. Therefore, four potentially modifiable themes were presented. Insufficient time was somewhat resolved by removing the intervention from the PT programme. The intervention was more efficient and easier to complete when separated from physical training. This was reinforced by the data showing improved adherence post change (Chapter 7). However, ensuring that this was actually added to the recruits' timetable would have allowed them to prepare more fully.

Moreover, reducing the number of exercises in the intervention would also reduce the time required for completion. Therefore, a better understanding of which exercises within the neuromuscular intervention give the most pronounced movement quality changes would reduce the amount of time required to complete the intervention and likely produce a more efficient intervention that would better suit military training institutes. However, this analysis has yet to be completed. As such, it would have been inappropriate to reduce the number of exercises based on superficial or anecdotal evidence.

8.6 **Conclusion**

The study presented in the current chapter examined the feasibility of implementing a neuromuscular warm-up intervention over a 12-week training programme. Within this, the opinions of recruits and military training team was recorded to improve further interventions proposed for use within similar cohorts. The study identified; insufficient time, fitness standards of the recruits, buy-in to the intervention, understanding of the intervention and motivation to be themes important for the recruits and PTIs. The study recommends that future interventions conducted with military cohorts need to use coaching work-shops to introduce the intervention and screening methods to better explain and incorporate the intervention into military training. Moreover, the intervention may not work best when combined with physical training and, as the current study found, completing this outside of this framework, and into free-time may present with a more consistent schedule. However, if this approach is taken, consideration to add this to the daily schedule would improve the motivation of the recruits.

Chapter 9: General discussion

9.1 Overview

This thesis has addressed movement quality in military trainee cohorts through three specific studies. In this chapter, the recurring and major themes from each study will be stated, interpreted and explored. To remind the reader, this thesis is based on the epistemological approach that movement quality has an impact on the hard and soft tissues surrounding the moving joint and limb. Thus, the interpretation of the study findings will be viewed through such a lens. From this, it was hypothesised that movement quality would impact injury and disease likelihood, such as ligament or skeletal damage.

If poor movement quality resulted in an increased injury, disease or pain risk, it might be possible that good movement could reduce these same parameters. A systematic review (Fransen *et al.*, 2015) and a meta-analysis (Uthman *et al.*, 2013) concluded that there was sufficient evidence to show that exercise prescription, specifically aimed at improving muscle strength, neuromotor control and joint range of motion, improved osteoarthritis pain and symptoms better than control conditions. Although these findings do not demonstrate objective evidence that good movement can prevent injury, it does indicate that good movement quality could reduce previously painful symptoms and improve quality of life in study volunteers. Additionally, Soligard *et al.* (2008) showed that an intervention specifically designed to focus on movement quality improvement in lower-limbs, prior to a competitive season, reduced injury rates in female football players during the season. Therefore, movement quality appears to be linked with injury, self-reported pain and symptoms of skeletal disease. The current research programme engaged in a comprehensive assessment of the link between movement quality and injury within military Phase-1 and Phase 2 recruits.

9.2 Summary of experimental evidence

The initial study explored previously reported data from Gibbs *et al.* (2014) to assess the ability of a single movement quality screen (FMS) to predict injuries in military Phase-1 recruits. Moreover, the data were subject to more stringent interrogation to understand the contribution of the prediction provided by each element of the total screen. In this case, these elements were single movements scored on a 3-point scale; for more detail of the study, please see (Chapter 4). Evidence from the study provided greater insight into movement quality and movement quality screening in Royal Navy Phase-1 recruits, which is detailed below.

The mean FMS score achieved was 14.5 (2.3) which is consistent with other studies (Kiesel et al, 2007 and O'Connor et al, 2011). There was no significant difference between the FMS scores achieved for the two sexes [$\overline{x}$ (SD) male; 14.6 (2.3) and females; 14.4 (2.4)]. However, females were 1.7 times more likely to sustain an injury. This suggests that the FMS is not suitable to distinguish between male and female injury likelihood when used for mixed sex cohorts. This is evidence that the FMS is not an appropriate tool for assessing movement quality and injury likelihood in mixed sex Royal Navy cohorts. However, further analysis was required to assess the full data, which is detailed below.

The initial retrospective study in the present thesis showed that the FMS did significantly contribute to the injury prediction model. However, this contribution was so small (8.5%) as to question its relevancy to the model and injury prediction. Moreover, when the individual movements within the FMS were assessed for their respective contributions to the injury prediction model, this again showed a similarly small contribution from only two of the movements. Shoulder RoM and press-up contributed 10.2% towards the injury prediction model respectively. Ultimately, the FMS total score demonstrated a low level of contribution to the injury prediction model and a lack of ability to distinguish between the different injury risk levels of males and females in the same military training cohort.

The initial study had identified that males and females presented with different body mass, while being expected to carry the same external loads during training. This was suggested as a potential variable that would influence movement quality and may contribute to the differences in injury likelihood between males and females. Therefore, study 2 investigated kinematic measurement differences between male and female trainees, and the effect of different load conditions (Chapter 6). This study would aid in informing the subsequent intervention study which would require the use of the Hip and Lower-Limb Movement Screen (H&LLMS). Therefore, the laboratory study provided an opportunity to assess the level of kinematic movement that can be distinguished by the H&LMS.

The study identified that a person's sex had no influence on their H&LLMS score, while only highlighting a single significantly different kinematic variable. Females were capable of projecting their knee further forward than males during a small knee bend. This might demonstrate that females have a greater ankle RoM, or gastrocnemius / soleus flexibility. Although not strictly the same variable, knee projection must correlate with ankle RoM Although there are anthropomorphic variations that will also influence this. Greater ankle RoM has been associated with lower likelihood of dynamic valgus knee movement (Lima et al., 2018). Moreover, this association was observed during loaded and unloaded tasks. Therefore, females in this thesis's laboratory study may be at a lower injury likelihood due to the association between their greater ankle RoM and dynamic knee valgus. Leardini et al (2001) explain that the subtalar joint (STJ) may also be responsible for this discrepancy in movement. Their study showed that the STJ presented with movement that added to that of the ankle joint. However, further observation suggest that this may only have been present under loaded conditions. Therefore, this may suggest that females in the current study may have shown greater STJ movement during the loaded conditions. However, there is little evidence to suggest that this was also present during the unloaded conditions.

Analysis of the interaction between movement quality and load showed that there was no influence on H&LLMS score and only two kinematics variables presented with significant differences. In the shod-no load condition, participants were able to protrude their knee further forward. While in the percentage load condition, participants presented with a lower pelvic tilt. The greater knee projection shown in the shod-no load condition may again suggest a greater ankle RoM or lower-limb muscle flexibility. However, this may be a result of the footwear rather than tissue structure. Most sports and running shoes have a heel to toe wedge that may contribute to the difference seen in this condition. As the heel increases, the static ankle angle becomes more plantarflexed. Thus allowing a greater amount of degrees a person can move their shin through before they reach their structural limit. This artificially increased knee protrusion would manifest in such an example. However, this does not account for the difference between the shod-no load and shod-absolute / percentage load. This may have been due to the participants not feeling confident or comfortable achieving a greater knee projection while under these external loads.

Participants also demonstrated a lesser degree of pelvic tilt in the loaded conditions. However, this is more difficult to interpret. The data show a change in degree rather than a start and end point. Thus, the smaller change may indicate a starting pelvic tilt position that was closer to the structural restriction or end range of motion. This may then suggest that while the load is applied, the static position of the pelvis changes.

The final thesis study was a prospective analysis of the influence of a neuromuscular activation programme on movement quality (Chapter 7). This was a feasibility study to explore the implementation of a neuromuscular exercise intervention in an Army Phase-1 training establishment. The study also examined the effect of a neuromuscular control exercise intervention on movement quality in a mixed sex cohort of Army Phase-1 military recruits. Initial adherence levels were low (19%), however, this increased once a more appropriate implementation strategy was agreed upon. The intervention attained a mild adherence level of 35%, however, the neuromuscular intervention was successfully integrated into the Phase-1 military recruit training. There were no institutional barriers, nor were there sex based barriers that would render the intervention impractical for ether males or females.

The study demonstrated that the neuromuscular intervention improved movement quality of those in the intervention group, while the control group showed a decline in their movement quality. Moreover, when assessed for a sex-based difference, males and females presented with very similar direction and magnitude of movement quality modification. More specifically, males and females in the intervention group improved to similar degrees, and those in the control group worsened by a similar amount.

Results from the experimental studies raised major themes in movement quality which will be discussed in this chapter.

9.3 Themes

9.3.1 The association between the FMS total score and injury

The initial and major theme of the current thesis was that movement quality screen total scores show an ability to predict injury. The analyses of the association between the FMS total score and injury occurrence (Chapter 4), indicated that the FMS total score was a significant contribution factor in the injury prediction model shown in chapter 4 (Equation 1), thus showing an ability to predict injury likelihood regardless of type or severity. This concurred with previous studies from Kiesel et al. (2007) and O'Connor et al. (2011). Further analysis of the data revealed that a cut-off of ≤13 would result in significantly different injury rates. Although this cut-off was lower than reported by Kiesel et al. (2007) and O'Connor et al. (2011), who reported that ≤14 was the preferred cut-off; it adds evidence to suggest that a singular value can distinguish between those more and less likely to sustain an injury. Moreover, FMS total score was linked to injury severity, with those recruits whose lower FMS scores presented with higher rates of chronic injuries. Initially it was thought that this relationship might be due to the increased numbers of injuries sustained by those achieving an FMS score of ≤13. However, when expressed as a percentage of total injures, the interaction was still apparent.

Stress fractures are more likely to be chronic injuries. And chronic injuries, are more likely to have been sustained through overuse or long duration of intense exercise that are repeated (Pope, 1999).The current research programme shows that recruits who demonstrated lower levels of movement quality, measured by the FMS, were more likely to sustain chronic injuries (Figure 4-4). This suggests a link between repetitive movement, lower movement quality and chronic injury. This thesis is founded on the theory of kinesiopathology, which suggests that movements generate stress on the surrounding hard and soft tissue structures. This stress acts as an external stimulus which the body reacts to by changing the hard and soft tissue to better deal with similar movements potentially required in future. When a movement is repeated with high regularity, this stimulus is generated and reacted to more regularly and greater adaptation may occur as a result (Sahrmann, 2002). This initial finding seems to suggest that the repetitive actions undertaken during Phase-1 training in study 1, combined with lower levels of movement quality, measure by the FMS, resulted in a higher risk of chronic injury. Through the epistemological view of kinesiopathology, this seems to show that movements that deviate from that which is most appropriate for the hard and soft tissue structures involved in the movement, and therefore classified as poorer movement, would stimulate the body to generate adaptations which better accommodate the stresses involved in this movement (Sahrmann, 2002). As the movement is inappropriate for the structures, a change to better suit a poor movement would result in deterioration of the structures to perform appropriate actions at such a joint and may increase the chances of injury over an extended time. This seems to support the kinesiopathological theory, while also highlighting that there may be a link between morphological changes and injury rates. Conversely, there were no significant differences in the percentage of acute injuries sustained by the recruits, regardless of total FMS score. This then suggests that acute injuries may be due to variables not recorded by the FMS and that the link between movement quality and acute injuries is not strong. During physical activity and training there is a greater likelihood of slips, trips and falls which may contribute to acute injury recording. Therefore this may suggest that these types of injuries are not aligned with movement quality. This may also suggest that slips, trips and falls contribute to a potential irreducible minimum injury likelihood associated with physical activity.

The initial study (Chapter 4), identified the extent to which each variable contributed to the prediction model (Equation 1). FMS total score contributes very little to the predictive model (8.5%) and accounted for a very small amount of variance within the data. The study identified the FMS as having good specificity (96%) and therefore was able to identify a large proportion of those that did not sustain an injury. However, the FMS demonstrated poor sensitivity (23%) which shows an inability to accurately identify those most likely to sustain injury. This confirms findings from Dorrel et al. (2015), as well as three systematic reviews (Bonazza *et al.*, 2017; Moran *et al.*, 2017; Whittaker *et al.*, 2017). The FMS was originally suggested to be used alongside other quality and performance assessments in order to give information about the best training for individual athletes (Cook *et al.,* 2006). However, more recently, the FMS has been assessed for its ability to be used independently as an injury predictive (Kiesel et al., 2007), or performance identifying (Kiesel *et al.,* 2011) tool. The results from the current study give evidence to suggest that the FMS, in its current form, and used independently, is not an appropriate tool for identifying injury likelihood in military cohorts. Consequently, the previous findings of the links between total score and chronic injury may be less significant, and less clinically relevant than originally thought.

Although the FMS total score gave a weak prediction ability (8.5%), Rusling *et al.* (2015) suggested that the individual movements within the FMS may be more specific to the injuries sustained by the specific cohort. In the case of Royal Navy recruits within the current study, 78% of all injuries were sustained by the lower-limb. Therefore, the current research programme hypothesised that lower-limb specific movements within the FMS would give a more precise injury prediction score relative to the upper-limb and torso movements. Of the seven movements within the FMS, two showed significant contribution to the prediction model. However, these movements were not lower-limb as previously assumed by the current author. Shoulder mobility and press-up movements gave a combined contribution of 10.5% of the variance in the data, and therefore represented a better contribution than the FMS total score. The underlying mechanism that link these two upper-limb movements to lower-limb injury likelihood in Royal Navy recruits is still unclear, and may prove to be clinically irrelevant due to the overall contribution percentage. However, as these two movements contributed a greater amount to the prediction model than the entire FMS (2-movements = 10.5% Vs FMS total score = 8.5%), it does suggest that the movements used to predict injury, will influence the prediction quality. In this case, the other five movements used in the FMS may have diluted the contributions of the two significantly contributing movements, which resulted in a lower level of injury prediction in the total score. This reinforces the point made by Rusling *et al.* (2015), and suggests that specific screens and movements should be developed and used in specific cohorts. In the case of military recruits, who sustain high numbers of lower-limb injuries, a more lower-limb specific screen may prove more efficient and valuable. As such, exploration into the direct mechanisms of injuries in these cohorts is paramount and should be addressed in future research.

9.3.2 Male Vs Females

Previous research in military cohorts has demonstrated that females are more likely to sustain an injury in both Phase-1 and 2 training (Bell *et al.*, 2000; Strowbridge, 2002; Finestone *et al.*, 2008) and active service (Rhon *et al.*, 2018). Study 1 of the current thesis also sought to understand the injury rate differences between males and females and demonstrated that 38.3% of females were injured compared to 27.3% of males. This represents females being 1.4 times more likely to sustain injury than their male counterparts; However, as males represent around 90% of the generic military population, they are still more likely to be injured. Although this is a lower difference than that reported by previous studies, that showed injury rates for females as high as 5-times greater than that of males

(Soligard *et al.*, 2008), it does concur with previous research demonstrating a sex based difference in injury rates. Examination of the mechanism of injury rate differences between males and females has led to multiple variables being highlighted as contributing factors. For example, Kodesh *et al.*, (2015) stated that physical fitness demonstrates a similar discrepancy, while Lisman *et al* (2013), claim that movement quality has also demonstrated a relationship with injury likelihood.

Bell *et al.* (1994) stated that females entered training with a lower cardiovascular fitness than males in the same cohort, and subsequently claimed that this was the main risk factor in injuries sustained during Phase-1 and 2 training. Study 2 (Chapter 6) demonstrated that cardiovascular fitness, in the form of the recruits' pre-enrolment Personal Fitness Assessment (PFA) (Table 6-6), was lower in females. However, Study 2, did not assess prospective injury rates, and therefore cannot suggest that this was indicative of injury risk. Gibbs *et al.* (2014) assessed Royal Navy recruits (n=956) and also concluded that females exhibited significantly lower cardiovascular fitness than their male counterparts. However, the link between, or the mechanism behind, cardiovascular fitness and lower-limb injury is not immediately apparent. A persons lactate threshold or $\dot{V}O_{2max}$ is unlikely to affect the structures of the lower-limb in a direct way. However, movement efficiency or economy may do.

Another variable that has been established as being predictive of injury, is movement quality (Kiesel *et al.*, 2014). As mentioned in chapters 2, a person's movement quality can be measured and assigned a score, using a movement quality screen. The screen most commonly used in research is the FMS. However, the initial study (Chapter 4), demonstrated that there was no movement quality difference between male and female Phase-1 recruits, but that females were still 1.7-times more likely to sustain an injury over the same period. Therefore, movement quality alone, as recorded by the FMS, may not be able to explain the sex based injury risk difference.

9.3.2.1 Response to load

Military cohorts are at an increased risk of injury due to the specific physical requirements of the role. There are many physically demanding aspects to military training that may contribute to injury risk;

however, there is evidence to suggest that load carrying, and specifically percentage of body mass being carried is a modifiable risk factor (Majumdar *et al.,* 2010). As previously stated, Gibbs *et al.* (2014) demonstrated that females sustained a greater number of injuries compared to males, despite there being no significant difference in total FMS score. However, they also demonstrated that females had an 11 kg lower average body mass. Therefore, low body mass relative to absolute loads for military load carriage tasks may help to explain the injury rate discrepancy. However, body mass may interact with other variables which combine to generate a change in injury risk for specific and general injury rates. One such hypothesis is that body mass interacts with load carrying and movement quality. As the external load increases, the person's ability to maintain typical movement patterns reduces and therefore movement quality decreases. Majumdar *et al.*, (2010) states that this interaction reaches a critical limit of 33% of body mass, at which point, injury likelihood significantly increases. If a person's movement quality is low, the addition of an external load may introduce movement modifications to accommodate the increased load which would result in a compromised movement. Moreover, although a general additional external load will likely introduce such modifications, there is likely a relative load relationship. Majumdar *et al.*, (2010) states that this relationship is based on body mass and a person's injury risk significantly increases when they are exposed to loads about 33% of body mass. Therefore, those who are lighter, would reach this threshold before those of a higher body mass. As female military recruits have shown a lower body mass during Phase-1 training, they may be at a greater risk of injury based on their lower levels of body mass. Therefore, although a person's sex may be considered a variable able to predict injury, body mass may be more specific in cohorts that are exposed to load carrying.

Movement quality has been typically investigated with no additional load. Therefore, each participant demonstrated their movement quality with body mass only. Gibbs *et al.* (2014) stated that there was no sex-related difference in movement quality but that injuries were still significantly greater in females. These females were 11 ± 2.2 kg lighter, but still trained with the same absolute load of 16 kg. Although the performance outcomes are therefore the same between males and females in military training, the effort required or the strain generated by the extra percentage load may mean that the tasks are not equivalent. However, when there is variability between groups, it is unlikely that a task will be both absolutely and relatively equal at all times. The current thesis suggests that those of light body mass would carry a greater percentage of their body mass in typical tasks. This increased percentage load may increase the likelihood of producing movement quality faults which may lead to an increased risk of injury.

As the load increases, an ability to appropriately move under the load is compromised due to multiple variables. Factors such as coordination, proprioception and neuromuscular control all contribute to the movement quality of a person. Therefore, it suggests that the results from Bell *et al.* (1994) may have originally been misinterpreted. As the mean strength of recruits was significantly different between males and females, this may have contributed to the injury risk discrepancy between the sexes. Therefore, the following questions are raised; does movement quality deteriorate with increased load for everyone? If so, what kinematic changes are generated from such external load inputs?

Study 2 assessed the response to four different load conditions (body mass barefoot, body mass wearing shoes, 16kg rear backpack, and 33% of body mass rear backpack). The two loaded conditions varied to simulate either real military training conditions and the relative load of 33% percent of body mass, which was proposed as the critical load limit associated with increased risk of injury (Majumdar *et al.,* 2010). The present study demonstrated that the load a person is exposed to affects their kinematics but not their movement screen score. This effect was shown, despite the sex of the person, and therefore suggests that something other than sex was responsible for differences in movement quality. These results suggest a link to Gibbs *et al.* (2014) who demonstrated no difference between movement screen scores, but in this case, used the FMS . Although both the H&LLMS and the FMS are movement screens, there are distinct differences which are detailed in an earlier chapter (Chapter 5). These differences in movement screens are not only based on the movements within them but also on the scoring system employed. For greater detail of the differences, please see chapter 6, Section 5. The point is being made here to illustrate that visual observation of movement may be inherently less able to identify movement quality variations that lead to injuries. As more specific optoelectronic camera recordings established kinematic differences, this supports the suggestion that movement screens are not sensitive enough to identify the subtle movement changes experienced while under load. When assessing the interaction between load carrying and sex during Study 2 (Chapter 6), the only variable that showed significant differences was sagittal plane projection of the knee. Although this has been linked to potential injuries (Lima et al., 2018), again the study did not record injury data. There exists a sex based injury rate difference, with females sustaining a greater number of injuries than males. However, the current study was not able to identify the cause of this difference, nor was it able to identify the likely ramifications of such kinematic changes in terms of injury likelihood.

As previously stated, all Army Phase-1 recruits must successfully complete a fitness test at the end of Phase-1, in which they must carry a set load (16 kg). Therefore, all recruits must be able to achieve this physical target. However, they are not required to have achieved this in week-1 of training. Phase-1 military training exposes recruits to load carrying using a progressive increase from light to heavy throughout the 14-weeks. However, the current research programme suggests that the most specific way in which to achieve this step based increase in load carrying would be to set the starting load and any subsequent changes based on the person's body mass. Moreover, the load can be set so that no recruit would carry more than 33% of body mass before a set date or number of load carrying tasks exposure. Although all recruits will be required to achieve a carrying load of 16kg by the end of the 14-weeks, It is hypothesised that by incrementally increasing the carrying load based on body mass, that the recruits will have time to adapt appropriately, and that this would result in fewer movement quality adaptations that lead to injury. However, this would result in each recruit having a different load at each load carrying training sessions, and may require daily body mass checks. This is not very practical when the sessions are strictly timed and troops typically contain 30 recruits. However, if the starting load and increments are based on the recruits entry body mass, or if recruits are grouped into categories of body mass separated by ~5kg, there can be a more specific load carrying mass to body mass relationship. These suggestions would likely have a similar effect on movement quality change while reducing the amount of time and resources to undertake a more specific load carrying exposure course.

9.3.3 Movement quality is modifiable

This thesis shows that there is an interaction between movement quality, or FMS total score, and injury. However, a mechanism is yet to be made apparent. Better understanding the mechanisms of interaction would aid in developing more efficient interventions and screens for reducing and predicting injuries. However, this is predicated on movement quality being modifiable and subject to change. If movement quality were static, or personally ingrained by a certain age or due to skeletal structures, understanding the mechanism of injury would result in little practical difference for injury rate, thus reducing the need to develop injury reduction interventions. This thesis (chapter 7) sought to investigate if movement quality could be modified by assessing a specific neuromuscular warm-up intervention alongside the military standard RAMP (Raise, Activate, mobilise and potentiate). The study used the H&LLMS to determine movement quality and demonstrated that movement quality in

Phase-1 recruits is modifiable. However, this means that movement quality , as assessed by the H&LLMS, can also deteriorate as well as improve. Therefore, movement quality can be seen as a non-static entity and liable to modification based on internal and external interaction. Consequently, the environment and requirement of the role one is currently adopting, as well as the person's individual goals, will all impact on the direction and magnitude of change of their movement quality.

9.3.3.1 Response to interventions

The neuromuscular intervention used in study 3 (Chapter 7) demonstrated a significant 7% improvement in movement quality in those who undertook the intervention, whereas those in the control group showed a 14% decline in their movement quality. These findings indicated that the currently employed military training significantly reduces movement quality through the a 12-week intervention conducted during the 14-week Phase-1 military training (Figure 7.4). This thesis used an intervention based on improving neuromuscular control and consequently suggests that the improvement in movement quality seen in the intervention group was due to an improvement in the recruits' neuromuscular control. However, Padua *et al.* (2012) state that there would be greater evidence for the improvement mechanism if the movement quality changes are retained after the intervention ends. Padua *et al.* (2012) continue by stating that learning a skill is typically defined by a permanent change to one's movement, while also highlighting that in other injury prevention intervention studies, the participants have shown a return to pre-intervention injury rates 2-years post intervention (Myklebust and Bahr, 2005). This then suggests that the changes experienced from the intervention may be transient, and therefore not the result of neuromuscular adaptations. The previously mentioned research used within the meta-analysis (Yoo *et al.*, 2010) all involved using some form of performance based intervention, such as drop-jumps (Pollard *et al.*, 2006; Padua and DiStefano, 2009) , plyometric and balance training (Myer *et al.*, 2006), while assessing specific ACL injury rates (Lim *et al.*, 2009). These interventions were not aimed at improving neuromuscular control, and gave greater emphasis on the outcome of the task. Therefore, these earlier studies may have seen improvements in injury rates based on aspects other than movement quality and neuromuscular control. The likelihood of maintaining muscular changes, developed by training would be less than that seen by neuromuscular changes. This is due to the effect of rest on performance variables, such as strength and speed, rather than on control and skill. Therefore, although these studies showed a return to pre-intervention injury rates, this does not necessarily mean that similar affect would be seen after movement quality focused intervention.

Studies from Hewett *et al.* (1999); Emery *et al.* (2015) and Hislop *et al.* (2017) have all shown that neuromuscular interventions also influence injury rates. And even though Thompson *et al.* (2016) claim that more work is still required to fully understand the mechanistic bases of the reduction in injury rates, there is evidence that physical activity specifically designed to improve movement quality can reduce injury risk in high injury sports and cohorts. These studies have found that neuromuscular training strategies reduce the risk of injury in a variety of youth sport. The studies previously mentioned vary from meta-analyses, systematic reviews and RCTs, and therefore vary in their methodological approach. One such variation is the definition of injury. Those assessing movement quality use non-contact injury as the basis, as contact injuries would unlikely be affected by movement quality. However, those assessing neuromuscular training and injury have used all injuries to provide a greater external validity. Although this gives greater generalizability, it does not allow for the individual contribution of movement quality to be highlighted and compared against other variables affected by neuromuscular training, such as strength and flexibility.

Padua *et al.* (2012) stated that the time in which a person is exposed to an intervention interacts with the longevity of their movement quality improvement. Therefore, the longer the intervention, the greater the likelihood of these changes being retained as a result of alterations to neuromuscular changes. As the current study lasted a relatively short period (12-weeks), the chances of these changes being the result of neuromuscular changes are reduced. Padua *et al.* (2012) also suggested that injury reduction and movement quality changes are also typically stated based on results recorded immediately post-intervention. Study 3 of the current thesis also recorded post-intervention data immediately after the completion of the intervention, and therefore is limited on its ability to give evidence on how these movement quality changes would present after a period of non-intervention. Padua *et al.* (2012) stated that neuromuscular changes cannot be confirmed from such data and suggest that follow-up tests must be performed to fully understand the mechanism of movement quality change.

The current thesis employed a short intervention that did not utilise a 1-year follow up test. Therefore, the current thesis concedes that it is unclear what the mechanism of movement quality change is. However, this may not be as critical as suggested by Padua *et al.* (2012). If an intervention is to be integrated into the routine training and behaviour of a cohort, the intervention would not have an end point. Therefore, the movement quality and subsequent effects of this would likely persist throughout the duration of the training. Those whose profession or employment demands high levels of physical ability maintain physical training throughout their employment. If they were to reduce or cease this, their physical ability would also reduce. However, no research paper is suggesting the irrelevance of cardiovascular training, due to the detraining effect, nor should they. It may be that in order to maintain a low level of injury likelihood, one must conduct specific training integrated into and alongside their physical training. The manner in which the intervention in Study 3 (chapter 7) was employed does not restrict this to a single intervention, lasting a set time period. Therefore, it is likely that this intervention style would result in an improved movement quality throughout the entire Phase-1 training and potentially throughout their military career.

As this thesis has also strongly suggested that movement quality is linked to injury likelihood (Chapter 2), the reduction in movement quality seen in the control group would suggest that military training, in its current form, would increase the likelihood of the Phase-1 recruits sustaining an injury. However, as the study only recorded data from a small number of recruits (n=124), statistical analysis of the interaction between the intervention, movement quality and injury would likely have been inappropriate. Consequently, the current thesis was unable to establish if this modification in movement quality seen through the 12-weeks influenced injury rates.

Although the lack of injury data limits the interpretation of the current thesis, Soligard *et al.* (2010) claimed that females football players exposed to a similar dose of movement quality intervention sessions demonstrated a reduced incidence of ACL injuries. Soligard *et al.* (2010) used a single group of female football players over a full season and reported that ~20 - 45% of scheduled intervention sessions had been completed. Regardless of this disparity between optimal and achieved, Soligard *et al.* (2010) presented a 35% reduction in ACL injuries when compared to the same team the previous year. Although using a previous year is not directly comparable due to variables such as age of players, training and previous injury changing between the seasons, it does give an indication of the potential impact of the intervention. The current study was unable to achieve the same study design, but instead used three separate groups of military recruits who were undertaking military training simultaneously. This current intervention study used three separate troops that would experience the same training, and the same weekly progression of training. However, they would have different schedules. Therefore, there was the potential for specific and group differences between these set troops. The study aimed to have each troop complete the same number of intervention sessions. However, this was not achieved. Although this is not optimum, it gave the study the ad hoc advantage of assessing the potential of a dose response to the intervention. The data shows that the only significant difference in movement quality was seen between the highest dose (13.4 movements per week) and the CON group (Chapter 7). There were no significant differences between the movement qualities of any of the INT groups. Although not conclusive evidence, these findings appear to suggest that the highest dose seen within Study 3 may be the lowest dose level required to establish statistically relevant movement quality changes.

9.3.3.2 Sex based response to intervention.

The H&LLM screen and intervention employed by the current thesis were initially developed and intended for use in cohorts of either males or females, rather than the combination of the two (Botha *et al.*, 2014). Consequently, little is known about how the movement quality of males and females would respond to an identical intervention. During Phase-1 military training troops are single sex, and therefore it is possible to conduct separate training for either. However, it is impractical to conduct separate training to separate groups when both groups are required to attain the same end point standard. Moreover, if there is little response difference between males and females, it may prove advantageous to deploy the intervention across all troops regardless of sex. Consequently, any intervention to reduce injuries in female cohorts would also be deployed in male cohorts. Therefore, it was prudent to understand how both sexes would respond to interventions initially designed for and examined in single sex cohorts. Previous studies into the movement quality of females have purely assessed females, and this thesis may represent the first movement quality intervention study with both males and females. The study identified that males and females responded similarly to training, in terms of changes in movement quality. Specifically, both sexes in the control group worsened through the 12-weeks of military training, whereas both sexes improved their movement quality in the intervention group. Although there was an observable difference in the magnitude of change in both groups between the sexes, there was no significant difference in the interaction between sex and intervention group. This suggests that both sexes respond similarly to intervention and to a similar degree. Therefore, organisations that deliver physical training to cohorts that cannot be separated easily according to sex, can deliver injury prevention intervention based on movement quality, while expecting similar responses in both sexes.

However, Gibbs *et al.* (2014) states that females were 1.7-time more likely to sustain injury despite showing no significant difference in movement quality scores to their male counterparts. Therefore, a 1-point change in total movement quality score may represent different injury reduction rates based on the sex of a person. However, as the present study was unable to assess injury data, there is no clear measure of the interaction between a 1-point change in movement quality score and injury rate. Therefore, the clinical relevance of the moment quality change is yet to be established. Moreover, the current thesis theorises that if movement quality improves, when recorded during body mass movements, then movement quality while under load would also improve. However, it is not clear if such a relationship between body mass and loaded movement exists, and to what extent a 1-point change in body mass movement quality would have on loaded movement quality. Previous research on the interaction between movement quality interventions and injury have all assessed movement quality during body mass movements (Gibbs *et al.*, 2014). Furthermore, although they have shown that improving movement quality has reduced injuries for females in football (Soligard *et al.*, 2008) and firefighters (Frost *et al.*, 2017), there is no information about the impact this would have on movement quality under load.

9.3.4 Variations of Small knee bend techniques and implications for research interpretation.

The small knee bend is a valuable tool in movement screening due to its relevance to many sports, occupational activities and daily tasks that require single leg support. The movement provides a means of dynamic movement assessment in a controlled setting that can highlight pathological differences in movement quality. Moreover, the environment in which the screen in conducted, the speed of the movements and the simplicity of the movements generate a situation in which the participant is likely to produce a movement deemed of greater quality than that which would be achieved had this movement been conducted as part of a more complex physical activity. In chapter 4.2.11, the current thesis explored the similarities of the small knee bend to a step down movement and a running motion, depending on the position of the non-weight bearing leg. During both of these actions, the speed and ground surface are not standardised, and therefore present a greater challenge than conducting such an action in a laboratory setting. Additionally, this would most likely also decrease the injury risk during the movement. However, research using the small knee bend has failed to clarify potential differences between the actual movements used. This may have led to a large variation in the way the small knee bends are performed between each study. Therefore, there may be little utility in direct comparison between research papers that do not explicitly state the movement parameters.

Variations in terms and definitions lead to discrepancies in practice and ultimately between findings of research attempting to record the same phenomenon. As previously stated in chapter 4.2.11, even the orientation of the unsupported limb affects the muscle activation during a small knee bend or single leg squat. Warner *et al.* (2019) stated that when movements that claim to be the same are in fact different, it becomes difficult to interpret and compare the results of studies that are not explicit in their movement parameters. Movement screens, and the movements within them, are being used to identify people at greater risk of injuries based on the principle that movements that deviate from optimal or typical will generate internal forces that deviate from that which the joint is best suited to absorb (Sahrmann, 2002). As stated previously (Chapter 2), these irregular forces stress the hard and soft tissue structures and may instigate tissue structure modification (Sahrmann, 2002). These modifications may then proliferate over time and result in pathological changes in structure and potentially, injury. If a screen or movements within a screen are not able to identify differences between those exhibiting optimal and pathological movements, this screen or movement is not valid for its intended purpose. Moreover, if it were unable to identify between movements that vary a great deal, it would be increasingly difficult to distinguish between cohorts of individuals that demonstrate slight variations on movements that fit within two standard deviations of what would be considered typical movement within a given cohort. This is not to say that the two movements described as small knee bends or single leg squats are invalid in any particular use individually. This thesis simply states that each movement requires an individual and strict distinction. This way, those designing studies can choose the movement specific to the requirements of their intended population, thus giving a more specific and direct comparison between studies that employed similar movements or that which contained similar cohorts.

9.3.5 Utility of movement quality screens

The current thesis has been consistent in stating that the underlying theme of the study is that movement will influence bodily structures. As such, the study has employed two movement screens (FMS and H&LLMS) to identify various aspects of a person's movement quality, with varying degrees of accuracy. It is the belief of the author that some movement screens, in this case the H&LLMS, can assess and quantitatively identify physical ability and movement quality. Data from the intervention study (Chapter 7) demonstrated that the H&LLMS was able to identify pre- to post-intervention movement quality changes. As movement quality has been shown by previous papers to be a contributing variable in injury likelihood (Kiesel et al., 2007), this may suggest that these movement screens may be able to identify, to some extent, potential injury risk factors. Moreover, this thesis proposes that a better understanding of movement quality characteristics would enable more efficiently designed interventions training. Study 3 used an intervention informed by movement screen data, and demonstrated that movement quality is modifiable. Not only could movement quality improve through a movement quality based intervention, but that it can be made worse through military Phase-1 training.

Currently employed movement quality interventions have been found to improve movement quality. However, as Thompson *et al.* (2016) stated, the mechanistic understanding of the change is yet to be fully understood, which would likely aid in further improvements. Although some interventions have demonstrated significant changes to injury rates, non-specific use of interventions is not necessarily the most effective approach for a given cohort. Using movement screens, more detail can be gained to amend and improve future interventions and further reduce injuries. Soligard *et al.* (2008) has demonstrated that interventions based on improving movement quality can reduce ACL injuries in female football players. However, there are likely individuals within the Soligard *et al.* (2008) study, who present on either extremes of the bell curve. Using the spread of data, one can generate categories of participants' responses. These internal categories can be referred to as super-responders and non-responders. Movement quality screens can use these internal populations to better understand why these certain populations respond differently. If this can be recorded and established, the intervention itself can be improved so that it is more targeted and delivers more efficient changes, more exaggerated changes, or that it works for a greater amount of people.

9.4 **Limitations**

This thesis set out to more fully understand movement quality and how one could modify this. The study used load as well as an intervention to influence acute and long term changes of movement quality. However, the study was limited in the range of movements in which this was assessed. During the laboratory study, in which load was used to influence movement quality, this was only assessed during a small knee bend but the participants also undertook many more movements, such as standing hip flexion, squat, and step-up and down tasks. This limited the interpretation of the results recorded by the study. Analysis was restricted to a single movement for time efficiency and this movement was chosen over the others due to its link towards step-up / down tasks as well as running / walking (Chapter 5). However, further investigation into the influence of movement quality during the additional movement tasks would produce more data that would allow for a greater depth of interpretation of the interaction between load and movement quality.

The study also sought to understand the link between movement quality screen scores and injury likelihood. The prospective study was intended as a feasibility study, so limited assessment of movement quality changes through the use of an intervention, rather than a larger study over time. However, the report from this study, disseminated through military reporting structure has gained attention from the Navy and has yielded a full RCT (detailed in the future research: chapter 11).

The number of females recruited in the current thesis represents a similar percentage to that of the general military population within the initial study (Chapter 4), and intervention study (Chapter 7). Although this increases the external validity of the findings, this potentially reduces the statistical power of the findings. It may have been advantageous for the study to have recruited the same number of males and females in all studies. However, the mean differences still displayed sufficient variance to be classified as significantly different. The laboratory study (Chapter 6) recruited an equal number of males (n = 15) and females (n = 15), which was chosen to specifically increase the likelihood of identifying sex based movement quality differences. However, this was not practical in the initial (Chapter 4) and intervention (Chapter 7) studies due to the study using active military recruit training bases.

The study was unable to recruit all those from pre-intervention testing for post-intervention testing. Some were injured to the point that they did not return to their original troop, or any other troop that was used within the study. Moreover, some were removed on medical grounds from military training. Therefore, the data may have been inaccurate in their injury and movement screen data. This is a form of selection bias which may have influenced the results of the study (Whittaker *et al.* 2017). The intervention study (Chapter 7) showed that, of the 178 recruits originally selected for pre-intervention testing, only 129 were present for post-intervention testing. This highlights that some 49 recruits were not present in both time points. Although it is not certain that any or all of these would have been a result of a medical discharge, the likelihood is that at least some percentage would have been. This then demonstrates that this bias may have been present within the intervention chapter.

The exact presentation of this bias is difficult to definitively state. However, the two most common ways in which a recruit would have been able to attend at the start, but not the post-intervention testing are due to injury. A recruit may be removed through medical discharge or back-trooping, where a person is taken out of training for a period of recovery time and then joins a new troop who are now at the week that the injured recruit was at when they sustained the injury. Therefore, it could have been that those who were at greater risk of injury were injured and removed, thus inflating the final score of those who completed training. However, further examination of the screen scores for those who did not return for post-intervention assessment reveals that they had a higher, and therefore better, than average H&LLMS score (CON=23.3±13; INT=35.3±4.3). If these data would have been lower than average, it would have been appropriate to suggest that these recruits would have been at a potential greater risk of injury and therefore the likelihood of them being medically discharged or back-trooped would have been high. However, these data simply suggest that there was a lower risk of chronic injury. As the study shows that there was an irreducible minimum of injuries that was largely built on acute injuries.

The risk of survivor bias being present within an injury prone cohort through a prolonged period of time is likely. Therefore, the researcher was aware of the possibility this bias would be present. Initially, the study had organised to have access to injury data of all participants so that injuries that lead to medical discharge and back trooping were available for collection. However, as stated in other areas within this chapter, access to injury data was restricted to the point that it was not practical to use. This meant that measures that could have been used to analyse and interpret the data were no longer available to the researcher. Although this impacts the research data, there is no evidence to suggest that this bias would impact the two cohorts (intervention or control) or sexes (male or female) differently. Therefore, comparisons between these groups likely remains valid.

Finally, the initial study that assessed which variables contributed to injury risk in Royal Navy recruits suggested that body mass, and load carrying may be linked to injury (Chapter 4); while the laboratory study demonstrated that load affected movement quality (Chapter 6). However, during the intervention study, parameters of load carriage, such as total load, type of load and time carrying load were not recorded. This was purposeful as load carriage may have been associated with many duties and activities that were not pertinent to the study. For example, the recruits would have to carry their meals, laundry and shopping. Moreover, during physical activity, the recruits may have been asked to practice carrying people. Collecting this information would have been intrusive and impractical. Therefore, this was a limitation but one that was deemed reasonable to adopt.

Chapter 10: Future research

10.1 Movement quality and injury

One aspect that was not assessed within the current thesis was the influence on movement quality changes on injury likelihood. Pre study estimations of cohort size suggested that the intervention study would yield a high enough number of recruits to conduct statistical analysis of the relationship between these two variables. However, the number of recruits was not sufficient of such an analysis. Therefore, the primary study leading from the work within this thesis should examine the relationship between movement quality change and injury likelihood, in order to better understand the interaction between movement quality intervention, movement quality changes and injury likelihood. Without examining the relationship between movement quality change and injury risk, there is no solid evidence of a causal relationship.

Establishing such a relationship is so vital for the progression of the research field of injury risk, that the researchers involved with the original intervention at ATC Pirbright, have instigated such a study at another military establishment. Findings from the original study were compiled and distributed in military reports to all branches of the military. Since then, the researchers involved with the study have been contacted with the intention of replicating the intervention study with a larger Navy cohort, with the inclusion of injury data through and entire 6-month intake at HMS Raleigh. The study will compare data from the previous year, with date matched cohorts, to understand if the neuromuscular intervention used in study 3 (Chapter 7) can improve movement quality and if this effects injury rates of those within the intervention.

Results from a study exploring the interaction between movement quality and injury will allow for a greater understanding of the contribution movement quality has on the injury prediction model. Moreover, the individual movements within the screen can also be assessed to understand the individual contribution to the model. Additionally, the screen need not be the only variable to be assessed for contribution, which would allow for sex based differences to also be examined for their contribution to initial injury risk or the change post-intervention. It may also be possible to identify the movements within the intervention that contributed to a greater or lesser degree. From which, amendments can be made to ensure future studies work with a more efficient version of both the intervention and screen.

10.2 **Post-intervention loaded movement quality changes**

The current thesis explored the relationship between load carrying and movement quality (Chapter 6). This interaction was subject to kinematics analysis as well as H&LLMS scoring. During unloaded trials, the full H&LLMS screen was observed and recorded. However, during loaded trials, some movements were removed. Specifically, the small knee bend with rotation, as this movement is linked to injury itself and any movements that are conducted sat or laying down, as the movement would not be affected by the load. Remaining movements included the small knee bend, deep squat and standing hip flexion. However, in order to fully understand the interaction between load and movement quality, this restrictive movement list may not prove adequate. Therefore, the current study suggests the use of cohort specific movements based on the specific requirements and/or likely injuries of military training and service cohorts. For example, stepping up and down stairs, jumps and jump landings may prove appropriate within such a cohort. Better understanding how movement quality, as assessed by the H&LLMS, will manifest during typical daily activities may prove to be more appropriate for military recruit cohort health and injury mitigation than the H&LLMS alone.

Chapter 7 demonstrated that a neuromuscular intervention could improve the movement quality of those who undertook the training. This modification showed a difference between the control group and intervention while showing no significant differences between males and females. However, the recruits were not testing for their movement quality under load before or after the intervention. The laboratory study provided within the current research programme (chapter 6) demonstrates that movement quality of Phase-2 recruits was altered by externally carried load. Therefore, movement quality interacts with externally carried load. But we do not yet know if the improvements seen in chapter 7 would result in an improvement in movement quality under loaded conditions. As Phase-1 military recruits are exposed to loaded carrying during their training, the interaction between movement quality interventions and movement quality under load may prove relevant in training outcome variables. Future research should consider including loaded movement pre and post-movement quality interventions. Testing could include typical load used in Phase-1 training, such as 16kg, and the participants would perform an additional screen while loaded that would include the sub-set of H&LLMS movements that are deemed appropriate to undertake while carrying load. Adding this to the pre and post-intervention screens would not add a great deal of time and may yield valuable information.

Although Phase-1 military training is standardised across all facilities, there may be some variation that affect load carrying and the subsequent interaction with movement quality and injury. Specific cohorts that vary load carrying factors; such as total load (kg), total time under load, average time in load, and days under load may all interact with recruit movement quality and injury likelihood differently. As such, including information about load carrying during training could allow for a more appropriate intervention and screening to be generated for those specific cohorts. Although this may prove difficult to achieve and complete accuracy, formal training loads can be weighed before training sessions and recorded to better understand the typical loads, times and/or exposures to these loads experienced by Phase-1 military recruits and how these may interact with movement quality and potentially injury rates.

10.3 **Longevity of movement quality / injury rate change**

Padua *et al.* (2012) stated that movement quality changes are directly linked to the amount of neuromuscular elements within an intervention, and the length of exposure to an intervention. Therefore, Future research should aim to better understand the interaction between the exposure one has to an intervention per week, the length of an intervention and potentially, the length of time between each intervention session, and movement quality.

Firstly, exposure may be positively correlated with movement quality modification. The intervention study (Chapter 7) demonstrated a potential dose response between the four dose rates exhibited by the intervention groups. However, there were no significant findings. However, the minimum and maximum doses were below 35%. This is still very low and a dose response may only be detectable with larger gaps between dose groups. understanding the minimum dose will aid cohorts with restrictions on time, while understanding the most efficient dose would aid those with a greater emphasis on movement quality changes.

Secondly, future studies should vary the length of interventions to better understand the interaction between length and movement quality or injury likelihood change. Assessing the minimum time required to change movement quality of injury likelihood would again benefit those with restrictive times, while understanding the time required to elicit the most radical change would benefit those who prioritise movement quality or injury likelihood.

Finally, future studies should include post-intervention follow-up testing to reassess movement quality at set periods beyond intervention exposure. Perhaps a series of 3, 6, 9 and 12-months would allow for movement quality reduction to manifest itself to a large enough degree that statistical analysis would prove appropriate. Moreover, the same method should be used to assess the interaction between injury rates and length of time away from the intervention. Again, such information would be useful in understanding the minimum required chronic exposure to produce the greatest injury reduction over a person's career.

10.4 **Incremental introduction of load**

As load has been shown to interact with movement quality and factor into increased injury risk, the current thesis suggests that the load used within military recruit training should be recorded. However, future studies may wish to assess the impact of an intervention designed to implement load carrying in Phase-1 military cohorts in stages. Phase-1 military training lasts 14-weeks, but may be more practical to suggest that an intervention can be conducted over the middle 12-weeks, as was the case for the intervention study (Chapter 7). Military recruits must pass a physical standard by the end of this time, which includes, but not restricted to, a timed run while loaded. This load is standardised (16kg) regardless of height, weight or sex, and as such, requires all recruits to be able to pass this assessment in a given time. However, prior to this, there is no reason why any individual recruit should use a particular load. Therefore, the load carried by each individual can start low and increase throughout the 12-week training. This may reduce the difference between what the recruits are physically capable of, and what they are expected to do in the initial weeks of training. Which may reduce the likelihood of injury. Therefore, such a change to protocol should be researched to assess the interaction of a stage based load increase and injury rates within a military Phase-1 or 2 cohort.

Chapter 11: Conclusion

The purpose of the current research programme was to assess and identify variables that would explain and contribute to the difference in injury rates recorded between male and female military recruits. Moreover, the current thesis primarily focused on movement quality and the interaction this may have had on injury likelihood. The study demonstrated that there was no interaction between a person's sex and H&LLMS score. However, there was an interaction between a person's sex and movement kinematics. The data show that females produce a greater knee protrusion during a small knee bend, but this difference was very small. Consequently, these kinematic differences may prove to be clinically irrelevant.

Movement quality is liable to modification through carrying an external load. The laboratory study (Chapter 6) demonstrated a potential interaction between load and movement quality. Kinematic data showed that knee protrusion, pelvic tilt and hip vertical displacement all varied during the small knee bend. The study sought to understand the effect percentage body weight would have on movement quality, however, was unable to identify a specific movement response per load condition. What the study did show is that additional load affects movement quality. This then suggests that those less capable of appropriately accommodating additional load will modify their movements to a greater degree. This then suggests that a person's body weight may interact with movement quality. The current thesis suggest that the changes to movement quality would likely be greater and more pronounced during movements and tasks that were more complex or dynamic, or if a greater load were introduced.

Movement quality is liable to modification in both improvements and reductions in ability. The intervention study (Chapter 7) shows that movement quality responded differently to a neuromuscular intervention than it did with a Phase-1 military training standardised warm-up. From this, the current research programme suggests that the standardised military warm-up used within chapter 7, is not only not as effective as the neuromuscular intervention employed, but actually reduced movement quality among those in the control group. Therefore, attention must be taken to ensure improvement, rather than regression of movement quality in physical training. Thus, the current research programme suggests that the intervention used within chapter 7 be assessed more thoroughly in other military establishments to examine the interaction with movement quality and potentially injury likelihood.

Ultimately, the current research programme suggest that the interaction between sex and injury rates may be more accurately described as an interaction between body weight, movement quality and injury rates. With a greater proportion of those at greater risk being represented by those who are lighter in body weight, and therefore, more likely to be female.

Chapter 12: Appendices

Appendix A Hip and Lower-Limb Movement Screening Tests (H&LLMS)

Created by Booysen (2013) version 1 (dated November 2018)

Each participant will be given an introductory and practice trial of the tests by the same investigator (NB), who will observe the movement patterns during these tests and record the findings.

1.1 Movement Control Test (Observe for movement faults)

Figure 1: Ideal alignment during SKB and SKB with trunk rotation test

In both Movement Control tests (1.1.1 and 1.1.2) the participant stands on one leg, which is placed in a position with the 2nd metatarsal aligned along the 10° neutral line of weight transfer to ensure a correct foot position (Figure 1). The pelvis is maintained level and the trunk positioned vertical. The participant is instructed to perform a small knee bend (SKB), by flexing the knee and dorsi-flexing the ankle while keeping the heel on the floor. To standardise the position a piece of tape will be placed on the floor in a T-shape. The participant will stand with the long axis of the foot aligned to the stem of the T; the second toe placed on the stem. The participant will be asked to bend the knee until he no longer can see the line along the toes (corresponding to 2-8cm over the 2nd metatarsal)(Bremander et al., 2007). The researcher will then mark this distance with a panel. The pelvis is maintained level and the trunk positioned vertical. The participant is instructed to perform a small knee bend (SKB), by flexing the knee and dorsi-flexing the ankle while keeping the heel on the floor touching the knee against the panel, and then returning to extension.

Saggital line (line of gait progression)

10° neutral line (line of weight transfer)

Femur line (line of hip rotation)

2nd toe line (line of tibial rotation)

a. SKB test leg backward

During this test the body weight must be kept on the heel rather than the ball of the foot. The line of the femur should be on the 10° neutral line of weight transfer and the knee should be guided over the 2nd metatarsal and move more than 2 cm past the toes (Chmielewski et al., 2007; Ageberg et al., 2010). Figure 2 illustrates the lateral and frontal view of the test.

Figure 2: SKB test (a) lateral view (b) frontal view

The same investigator will give verbal instructions (Table 1) how to perform the test. The investigator will observe for movement faults (Table 2) while the test is performed; answering the appropriate questions (Table 2). A maximum score of five will be given for each weight bearing leg with zero presenting good movement control or a pass.

Table 1. SKB test verbal instructions

Verbal Instructions
• Stand on one leg with your foot pointing forward. • Place the unsupported foot behind you by bending your knee to 90°. • While keeping your body upright, keeping your pelvis and heel in position, bend your knee so that your knee is in line with your 2nd toe and moves past it until you can no longer see the tape line. • Do you understand the instructions?

Table 2. SKB test observed faults

Observed Movement Faults	Questions
• Functional femoral line falls medial • Knees not move past 2nd toe < 2 cm past toes • Trunk leans forward • Hip hitching • Anterior pelvic tilt	• Does the knee move inward from the 2nd toe? • Does the pelvis drop (hitch) on the weight bearing side? • Does the knee fail to move 2 cm past the toes? • Does the trunk lean forwards (flex)? • Does the pelvis tilt forwards (anteriorly)?

1.1.1 b. SKB test with the leg forward (Lewis etal 2015)

The test will be performed as above (Table 1) except the unsupported foot will be placed anterior (forward). The investigator will observe for movement faults (Table 2) while the test is performed; answering the appropriate questions Table 2.

1.1.2 SKB with trunk rotation test

During this test the participant is asked to rotate the shoulders and upper trunk around from side-to-side while keeping the pelvis from moving, facing forwards, as illustrated in Figure 3.

Figure 3: SKB with trunk rotation (a) medial rotation (b) lateral rotation

The same investigator will give verbal instructions (Table 3) how to perform the test and will observe for movement faults (Table 4) while the test is performed; answering the appropriate questions (Table4). A maximum score of five will be given for each weight bearing leg, with zero presenting good movement control or a pass.

Table 3. SKB with trunk rotation test verbal instructions

Verbal Instructions
• Stand on one leg with your foot pointing forward. • Place the unsupported foot behind you by bending your knee 90°. • While keeping your body upright, keeping your pelvis and heel in position, bend your knee so that your knee aligns along your 2nd toe. • While holding this position turn your upper body to the left and right looking over your shoulder 30°. • Do you understand the instructions?

Table 4. SKB with trunk rotation observed faults

Observed Movement Faults	Questions
• Hip and pelvis rotation to follow trunk • Trunk side bending • Hip hitching • Trunk rotation < 30° • Poor balance • Trunk flexion	• Does the pelvis follow the trunk rotation? • Does the trunk side-bend? • Does the pelvis drop (hitch) on the weight bearing side? • Does the trunk fail to rotate less than 30°? • Do the toes claw or any loss of balance? • Does the trunk lean forwards (flex)?

1.1.3 Standing hip flexion test (flex 0-110°)

The participant stands with the pelvis maintained level and the trunk vertical. The participant is instructed to lift the leg so that the hip flexes to 110° with knee flexion (Figure 4).

Figure 4: Standing hip flexion test (flex 0-110°)

The same investigator will give verbal instructions (Table 5) how to perform the test. The investigator will observe for movement faults (Table 6) while the test is performed; answering the appropriate questions (Table 6). A maximum score of five will be given for each weight bearing leg with zero presenting good movement control or a pass.

Table 5. Standing hip flexion test verbal instructions

Verbal Instructions
• Stand with your feet approximately hip width apart and the toes pointing forward. • Place your arms across your chest. • While keeping your body upright, keeping your pelvis steady and knee locked, raise the opposite leg, bending your hip up to 110°. • Do you understand the instructions? • Rating the weight bearing leg

Table 6. Standing hip flexion test observed faults

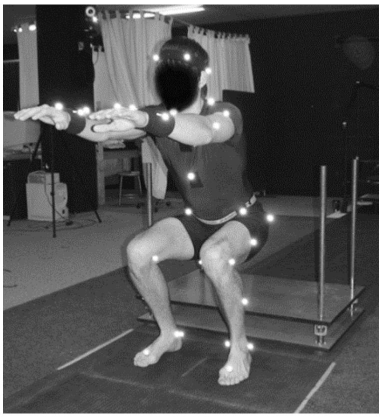
Observed Movement Faults	Questions
• Hip hitching • Posterior pelvic tilt • Spinal flexion • Body leans back • Knee flexed	• Does the pelvis drop (hitch) on the weight bearing side? • Does the pelvis tilt backwards (posterior)? • Does the hip fail to bend (flex) just beyond 90 degrees (approximate 110 degrees)? • Does the trunk lean backwards (extend)? • Does the weight bearing knee bend (flex)?

1.1.4 *Deep squat*

The participant stands in a position with the 2nd metatarsal aligned along the 10° neutral line of weight transfer to ensure a correct foot position. The participant is instructed to perform a squat, by flexing the knees and dorsi-flexing the ankle while keeping the heels on the floor.

During this test the body weight must be kept on the heels rather than the ball of the foot. The line of the femur should be horizontal and align on the 10° neutral line of weight transfer whiles the knees align to the 2nd metatarsal. The trunk must be maintained parallel with the tibia or vertical (Figure 5).

Figure 5: Deep squat



The same investigator will give verbal instructions (Table 7) how to perform the test. The investigator will observe for movement faults (Table 8) while the test is performed; answering the appropriate questions (Table 8). A maximum score of six will be given with zero presenting good movement control or a pass.

Table 7. Deep squat verbal instructions

Verbal Instructions
• Stand with your feet approximately shoulder width apart and the toes pointing forward. • Place your arms forward. • While keeping your body upright, keeping your heels in position and your weight equal, move down as deep as possible aligning your knee to your 2nd toe. Your upper thigh needs to be horizontal with the floor. • Do you understand the instructions?

Table 8. Deep squat observed faults

Observed Movement Faults	**Questions**
• Trunk leans forward • Femur not horizontal • Anterior pelvic tilt • Knees move medial • Knees move lateral • Bodyweight shifts laterally	• Does the trunk fail to stay parallel with the shin (tibia)? • Does the thigh (femur) fail to reachhorizontal with the floor? • Does the pelvis tilt forward (anteriorly)? • Does the bodyweight shift to one side?

1.1.5 Sitting hip flexion test (flex 90°-110°)

The participant sits in a position with hip and knee angles flexed to 90°. The pelvis is maintained level and the trunk positioned vertical while the feet is not touching the floor. The participant is instructed to flex the hip to 110° (Figure 6).

Figure 6: Sitting hip flexion test (flex 90°-110°)

The same investigator will give verbal instructions (Table 9) how to perform the test. The investigator will observe for movement faults (Table 10) while the test is performed; answering the appropriate questions (Table 10). A maximum score of six will be given for each leg flexed with zero presenting good movement control or a pass.

Table 9. Sitting hip flexion test verbal instructions

Verbal Instructions
• Sit with your arms across your chest. • While keeping your body upright, keeping your pelvis steady raise the opposite leg, bending your hip to 110°, making sure to maintain your foot alignment with the ankle, knee and hip. • Do you understand the instructions?

Table 10. Sitting hip flexion test observed faults

Observed Movement Faults	Questions
• Axial rotation pelvis • Hip hitching • Lateral rotation leg • Posterior pelvic tilt • Spinal flexion • Body leans back	• Is there axial rotation of the pelvis? • Does the pelvis hitch? • Does the foot fail to align with the ankle, knee and hip? • Does the pelvis tilt backwards (posterior)? Does the hip fail to bend (flex) just beyond 90 degrees (approximate 110 degrees)? • Does the trunk lean backwards (extend)?

In both tests for hip abductor lateral and medial rotator stabilisers (1.1.6 and 1.1.7), the participant is positioned in side lying with the pelvis and spine in neutral alignment and the bottom leg flexed for support. The uppermost leg is extended and supported horizontally, with the hip extended as far as no lumbar extension or anterior pelvic tilt occurs. The participant is instructed to lift the leg towards the ceiling into hip abduction (Figure 7).

Figure 7: Ideal starting alignment for hip abductor stabiliser tests

Hip abductor lateral rotator test (deep posterior Gluteus Medius and deep intrinsic Lateral Rotators): The uppermost leg, the hip is laterally rotated as illustrated in figure 8.

Figure 8a: Hip abductor lateral rotator test posterior view

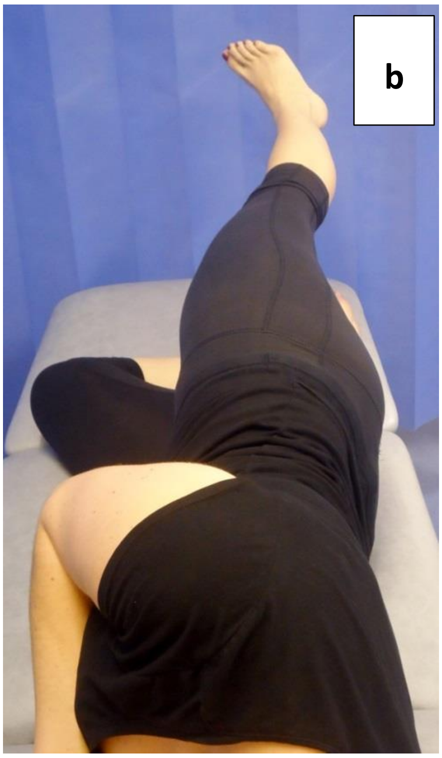


Figure 8b: Hip abductor lateral rotator test top view

The same investigator will give verbal instructions (Table 11) how to perform the test. The investigator will observe for movement faults (Table 12) while the test is performed; answering the appropriate questions (Table 12). A maximum score of four will be given for each leg with zero presenting good movement control or a pass.

Table 11. Hip abductor lateral rotator test verbal instructions

Verbal Instructions

• Lie on your side with your bottom leg bent for support. • While maintaining the leg straight, with the upper body straight and your leg turned outward, lift your leg towards the ceiling 45° while keeping your pelvis steady. • Do you understand the instructions?

Table 12. Hip abductor lateral rotator test observed faults

Observed Movement Faults	**Questions**
• Medial rotation hip • Flexion hip • Rotation pelvis backward • Pelvic hitching	• Does the leg loose outwards (lateral) rotation? • Does the hip/knee (leg) move forwards (flexion)? • Does the pelvis move backward? • Does the pelvis hitch?

1.1.6 ***Hip abductor medial rotator stabilisers test*** *(Gluteus Minimis and deep anterior Gluteus Medius):* The uppermost leg, the hip is medially rotated as illustrated in figure 9.

Figure 9a: Hip abductor medial rotator test posterior view

Figure 9b: Hip abductor medial rotator test top view

The same investigator will give verbal instructions (Table13) how to perform the test. The investigator will observe for movement faults (Table 14) while the test is performed; answering the appropriate questions (Table 14). A maximum score of four will be given for each leg with zero presenting good movement control or a pass.

Table 13. Hip abductor medial rotator test verbal instructions

Verbal Instructions
• Lie on your side with your bottom leg bent for support. • While maintaining the leg straight, with the upper body straight and your leg turned inward, lift your leg towards the ceiling 35° while keeping your pelvis steady. • Do you understand the instructions?

Table 14. Hip abductor medial rotator test observed faults

Observed Movement Faults	**Questions**
• Lateral rotation hip • Flexion hip • Rotation pelvis backward • Pelvic hitching	• Does the leg loose downwards (medial) rotation? • Does the hip/knee (leg) move forwardflexion? • Does the pelvis rotate backwards (not stay vertical)? • Does the pelvis hitch?

Appendix B Hip and Lower Limb Movement Screening Scoring System

Hip and Lower Limb Movement Screening Tests				
	Test	Verbal Instruction	Outcome	
1.1	SKB Test	• Stand on one leg with your foot pointing forward. • Place the unsupported foot behind you by bending your knee 90°. • While keeping your body upright, keeping your pelvis and heel in position, bend your knee so that your knee is in line with your 2nd toe and moves past it until you can no longer see the tape line. • Do you understand the instructions		Ric
			Does the knee move inward from the 2nd toe?	Y=1 N=0
			Does the pelvis drop (hitch) on the weight bearing side?	Y=1 N=0
			Does the knee fail to move 2cm past the toes?	Y=1 N=0
			Does the trunk lean forwards (flex)?	Y=1 N=0
			Does the pelvis tilt forwards (anterior)?	Y=1 N=0
			Total Score	
1.2	SKB Test leg forward	• Stand on one leg with your foot pointing forward. • Place the unsupported foot forward. • While keeping your body upright, keeping your pelvis and heel in position, bend your knee so that your knee is in line with your 2nd toe and moves past it until you can no longer see the tape line. • Do you understand the instructions?		Righ
			Does the knee move inward from the 2nd toe?	Y=1 N=0
			Does the pelvis drop (hitch) on the weight bearing side?	Y=1 N=0
			Does the knee fail to move 2cm past the toes?	Y=1 N=0
			Does the trunk lean forwards (flex)?	Y=1 N=0
			Does the pelvis tilt forwards (anterior)?	Y=1 N=0
			Total Score	

	Test	Verbal Instruction	Outcome	
1.3	SKB with Trunk Rotation Test	•Stand on one leg with your foot pointing forward. • Place the unsupported foot behind you by bending your knee 90°. • While keeping your body upright, keeping your pelvis and heel in position, bend your knee so that your knee aligns along your 2nd toe. • While holding this position turn your upper body to the left and right looking over your shoulder 30° • Do you understand the instructions?		Rig
			Does the hip and pelvis follow the trunk?	Y=1 N=0
			Does the trunk side-bend?	Y=1 N=0
			Does the pelvis drop (hitch) on the weight bearing side?	Y=1 N=0
			Does the trunk rotate less than 30°?	Y=1 N=0
			Do the toes claw or any loss of balance?	Y= N=
			Does the trunk lean forwards (flex)?	Y= N=
			Total Score	
1.4	Standing Hip Flexion Test	• Stand with your feet approximately hip width apart and the toes pointing forward. • Place your arms across your chest. • While keeping your body upright, keeping your pelvis steady and knee locked. Raise the opposite leg, bending your hip up to 110°. •Do you understand the instructions?		Rig
			Does the pelvis drop (hitch)?	Y=1 N=0
			Does the pelvis tilt backwards (posteriorly)?	Y=1 N=0
			Does the hip fail to bend (flex) just beyond 90 degrees (approximate 110 degrees)?	Y=1 N=0
			Does the trunk lean backwards (extend)?	Y=1 N=0
			Does the weight bearing knee bend (flex)?	Y=1 N=0
			Total Score	

	Test	Verbal Instruction	Outcome	
1.5	Deep Squat	• Stand with your feet approximately shoulder width apart and the toes pointing forward. •Place your arms forward. •While keeping your body upright, keeping your heels in position and your weight equal, move down as deep as possible aligning your knee to your 2nd toe. Your upper thigh needs to be horizontal with the floor. •Do you understand the instructions?	Does the trunk fail to stay paralled with the shin(tibia)? Does the thigh (femur) fail to be horizontal with the floor? Does the pelvis tilt forwards (anteriorly)? Does the bodyweight shift to one side?	Y=1 Y=1 Y=1 Y=1
			Total Score	
1.6	Sitting Hip Flexion Test	• Sit with your arms across your chest. • While keeping your body upright, keeping your pelvis steady raise the opposite leg, bending your hip to 110°, making sure to maintain your foot alignment with the ankle, knee and hip. • Do you understand the instructions?	Is there axial rotation of the pelvis? Does the pelvis hitch? Does the foot fail to align with the ankle, knee and hip? Does the pelvis tilt backwards (posteriorly)? Does the hip fail to bend (flex) just beyond 90 degrees (approximate 110 degrees)? Does the trunk lean backwards (extend)?	<u>Right</u> Y=1 N=0 Y=1 N=0 Y=1 N=0 Y=1 N=0 Y=1 N=0 Y=1 N=0
			Total Score	

	Test	Verbal Instruction	Outcome	
1.7	Hip Abduction lateral rotators Test	•Lie on your side with your bottom leg bent for support. •While maintaining the leg straight, with the upper body straight and your leg turned outward, lift your leg towards the ceiling 45° while keeping your pelvis steady. •Do you understand the instructions?		Ri
			Does the leg loose outwards (lateral) rotation?	Y= N=
			Does the hip/knee (leg) move forwards(flexion)?	Y= N=
			Does the pelvis rotate backwards (not stay vertical)?	Y= N=
			Does the pelvis hitch?	Y= N=
			Total Score	
1.8	Hip Abduction medial rotators Test	• Lie on your side with your bottom leg flexed for support. • While maintaining leg extension, a straight back and your leg turned downward, lift your leg towards the ceiling while keeping your pelvis steady. • Do you understand the instructions?		Ri
			Does the leg loose downwards (medial) rotation?	Y= N=
			Does the hip/knee (leg) move forward(flex)?	Y= N=
			Does the pelvis move backward (not stay vertical)?	Y= N=
			Does the pelvis hitch?	Y N
			Total Score	

Appendix C Movement control intervention to improve Hip and Pelvic Movement Patterns

<table>
<tr><td colspan="2">Level 1

Motor Control training, Strength, Balance</td></tr>
<tr><td rowspan="2">1</td><td></td></tr>
<tr><td>The Bench Static (FIFA 11+)

• HOLD FOR 20 seconds. REST

• REPEAT 3 times</td></tr>
<tr><td colspan="2">Level 1

Motor Control training, Strength, Balance</td></tr>
</table>

<table>
<tr><td rowspan="2">2</td><td></td></tr>
<tr><td>Sideways Bench Static knees flexed
• HOLD FOR 20 seconds. Rest
• REPEAT 3 times EACH SIDE</td></tr>
</table>

Level 1

Motor Control training, Strength, Balance

3

Hamstrings Beginner (FIFA 11+)

- REPEAT 3-5 times

Level 1

Motor Control training, Strength, Balance

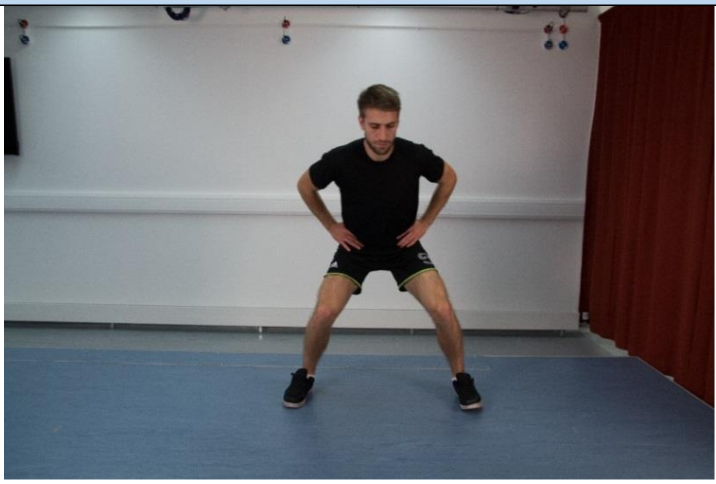
4

Single Leg Stance Hold Ball (FIFA 11+)

- HOLD FOR 30 seconds. Rest
- REPEAT 2 times ON EACH LEG

Motor Control training, Strength, Balance

5



Squat with Side Step (Selkowitz etal 2013)

SIDE STEP 30 seconds. REST.

REPEAT 2 times EACH SIDE

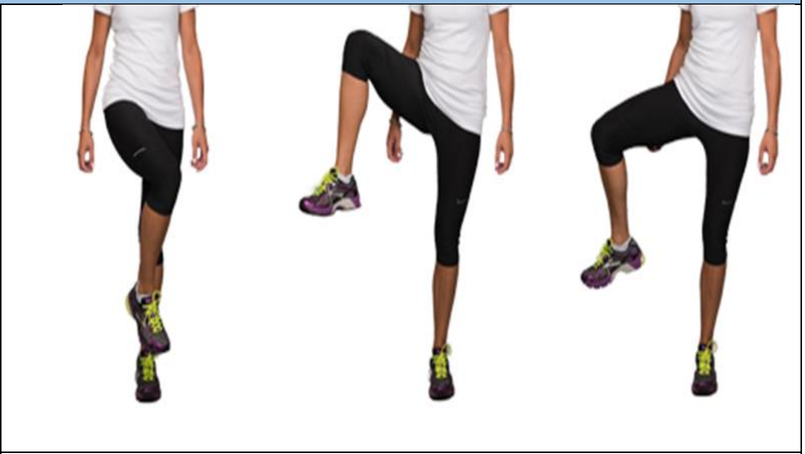
Motor Control training, Strength, Balance

6

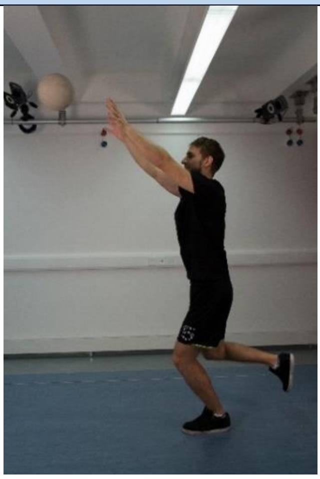
Clam Exercise (Selkowitz etal 2013)

- LIFT HOLD FOR 2 seconds. REPEAT 15 times.
- 2 SETS EACH SIDE

Level 1 **Motor Control training, Strength, Balance**	
7	 **Single Leg Bridge (Selkowitz etal 2013)** • LIFT HOLD 20 seconds. REST. • REPEAT 3 times EACH SIDE
Level 1 **Dynamic Stretches**	
8	 **Walking Lunges** • Lunge and step forward • 30 Steps EACH SIDE

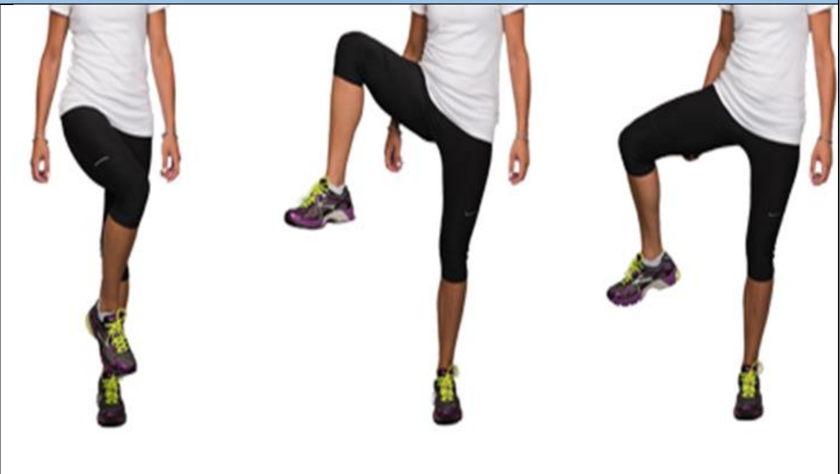
Level 1 **Dynamic Stretches**	
9	
	Hip Rotation Dynamic Stretch • Stand lift your leg and rotate outward to the side while stepping backward. • 30 Steps EACH SIDE

Level 2 **Motor Control training, Strength, Balance**	
1	
	The Bench Static (FIFA 11+) • LIFT LEG HOLD 2 seconds. Do 30 repetitions. REST • REPEAT on the other side
Level 2 **Motor Control training, Strength, Balance**	
2	
	Sideways Bench Raise with straight legs (FIFA 11+) • HOLD FOR 20 seconds. Rest • REPEAT 3 times EACH SIDE

Level 2 **Motor Control training, Strength, Balance**	
4	 **Single Leg Stance Throw Ball (FIFA 11+)** • Bend your knee. Throw a ball to your partner 30 times while holding your balance. REST. • REPEAT 2 times EACH SIDE
Level 2 **Motor Control training, Strength, Balance**	
3	 **Hamstrings Intermediate (FIFA 11+)** • REPEAT 7 TIMES

Level 2 **Motor Control training, Strength, Balance**	
5	 **Lunge hold with heel raise** • Get into a LUNGE position. RAISE THE HEEL 10 times. REST. • REPEAT 2 times EACH SIDE
Level 2 **Motor Control training, Strength, Balance**	
6	 **Clam Exercise (Selkowitz etal 2013)** • LIFT HOLD FOR 20 seconds. REST. • REPEAT 3 TIMES EACH SIDE

Level 2 Motor Control training, Strength, Balance	
7	
	Hip Extension knee bend (Selkowitz etal 2013) • LIFT HOLD 20 seconds. REST. • REPEAT 3 times EACH SIDE
Level 2 Dynamic Stretches	
8	
	Walking Lunges • Lunge and step forward • 30 Steps EACH SIDE

Level 2 **Dynamic Stretches**	
9	
	Hip Rotation Dynamic Stretch • Stand lift your leg and rotate outward to the side while stepping backward. • 30 Steps EACH SIDE

Level 3

Motor Control training, Strength, Balance

1

The Bench Static (FIFA 11+)

- LIFT LEG HOLD 20 seconds. REST
- REPEAT 3 times each side

Level 3

Motor Control training, Strength, Balance

2

Sideways Bench with Leg Lift (FIFA 11+)

- HOLD FOR 20 seconds. Rest
- REPEAT 3 times EACH SIDE

Level 3

Motor Control training, Strength, Balance

4

Single Leg Stance Test Partner (FIFA 11+)

- Bend your knee. Your Partner tries to push you off balance. Continue for 30 seconds. REST.
- REPEAT 2 times EACH SIDE

Level 3

Motor Control training, Strength, Balance

3

Hamstrings Advanced (FIFA 11+)

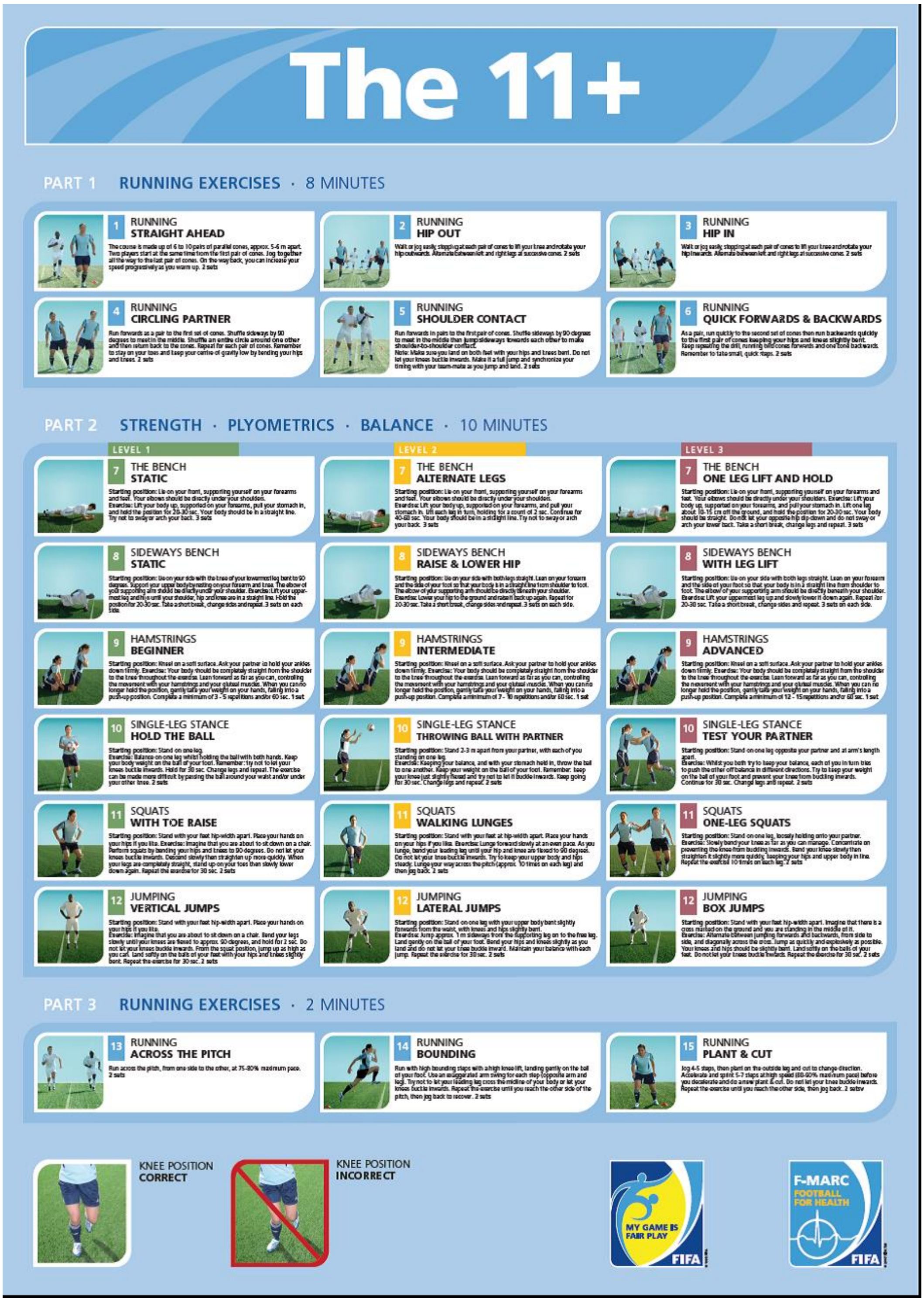
- REPEAT 15 TIMES

<table>
<tr><th colspan="2">Level 3
Motor Control training, Strength, Balance</th></tr>
<tr><td rowspan="2">5</td><td></td></tr>
<tr><td>Walking Lunges
• Lunge and step forward
• 20 Steps EACH SIDE</td></tr>
<tr><th colspan="2">Level 3
Motor Control training, Strength, Balance</th></tr>
<tr><td rowspan="2">6</td><td></td></tr>
<tr><td>Clam Advanced (Selkowitz etal 2013)
• LIFT HOLD FOR 20 seconds. REST.
• REPEAT 3 TIMES EACH SIDE</td></tr>
</table>

Level 3 Motor Control training, Strength, Balance	
7	 **Hip Extension knee straight (Selkowitz etal 2013)** • LIFT HOLD 20 seconds. REST. • REPEAT 3 times EACH SIDE

Level 3 Dynamic Stretches	
8	 **Hip Rotation Dynamic Stretch** • Stand lift your leg and rotate outward to the side while stepping backward. • 30 Steps EACH SIDE

Appendix D The new format of the 11+ movement quality warm-up intervention



Appendix E Information sheet

MINISTRY OF DEFENCE	International Movement Screening Group (Military Task Group) **PARTICIPANT INFORMATION SHEET;** vn 3.0; dated 25 January 2017 Improving Movement Quality to Protect Hips and Lower Limbs from Injury during Military Training (Study-2): Can Hip Movement Control be Trained? (MODREC protocol reference: 781/MODREC/16)

Invitation to take part

You are invited to take part in this study. Before you decide, it is important that you understand why the study is being carried out and what you would need to do. Please take time to read this information sheet and discuss it with others if you wish. Ask members of the study team if there is anything that is not clear or if you need more information.

What is the purpose of the research?

Injuries, and particularly lower limb injuries, are common during military training. Measuring the ability to control movement – with and without load – may identify individuals at increased risk of injury, where training movement control could reduce this injury risk.

Who is doing this research?

This study is being carried out by staff from the Institute of Naval Medicine (INM), Army Headquarters, Headley Court, and civilian colleagues from the University of Southampton.

Why have I been invited to take part?

You have been invited to participate in this study as you are fit and healthy for Army Phase-1 training.

Do I have to take part?

No, you do not have to take part in the study. Taking part in this study is entirely voluntary.

What will I be asked to do?

1, <u>Health History, Alcohol and Smoking Questionnaires</u>

You will be asked to complete two short questionnaires – one will ask questions about your previous health, and one will ask questions about your smoking and alcohol habits.

2. Body Shape Measurements

Your height, body weight, and waist circumference will be measured.

3. Hip and Lower-Limb Movement Screen (H&LLMS) Assessment

At the start of training, your movement control (during a number of exercises) will be assessed by qualified staff using the *Hip and Lower-Limb Movement Screen* (H&LLMS). The H&LLMS involves 7 exercises to assess your control of movement about your hip.

You will be asked to wear Army PT rig whilst performing the movements. Completion of the H&LLMS will take approximately 15 minutes and will not interfere with your daily schedule.

During training, a short movement based warm-up will be included as part of your normal physical training.

At the end of training, your movement control will be assessed again with the H&LLMS.

4. Physical Fitness Data

We will collate your physical fitness data from tests completed as part of your normal military training programme.

5. Injury Recording

We will also record if you suffer an injury during training and the type of injury. This information will be taken from your medical records and will be treated as confidential; it will only be seen by the study team.

The study will be compliant with the information governance policies of the MOD, the Data Protection Act and the NHS code of confidentiality.

What is the device or procedure that is being tested?

This study is evaluating if the hip and lower-limb movement screen (H&LLMS) intervention can change movement control.

What are the benefits of taking part?

The study will provide you with a better understanding of your range of movement, and in turn how this might influence your physical performance during training. The intervention has been shown to improve movement control, which would reduce injury risk, in sports people – and this may also benefit military personnel. But importantly, you will also be helping the MOD to improve the physical training for all Service personnel. An initial study brief will explain range of motion and physical performance, and the study team will fully describe the measurements and what they generally mean at the time of testing. On completion of the study, you will be provided with feedback to explain the findings of the study relative to your individual measures.

What are the possible disadvantages and risks of taking part?

There are no disadvantages to taking part. The risks associated with the exercises in this study will not add to the demands and risks of military training. But, if an adverse medical issue is discovered, your wellbeing is the priority. You will be provided with immediate care from a medical officer attached to the sudy and MODREC will be informed within 24 h.

Can I withdraw from the research and what happens if I don't want to carry on?

Yes you can withdraw at any time from this study without giving a reason. You can ask for any data collected to be destroyed at any time up to the end of the study. Data cannot be destroyed once the study has ended.

Are there any expenses and payments that I will get?

You will be eligible for MOD Experimental Test Allowance payments for participating in this study, where the total payment will be £59.01 on completion of all measures.

Will my taking part or not taking part affect my Service career?

No. You should only take part if you want to. Choosing not to take part, or choosing to withdraw from the study at any time, will not have any consequences for your Service career. Your Chain of Command will not have access to any of your individually identifiable data.

Whom do I contact if I have any questions or a complaint?

If you have any questions about this study you can contact the study team (contact details below).

The Independent Advocate will be available during the study. His/her role is to act independent to the study team and to ensure your safety.

If you are unhappy with any aspect of the study, you may contact the Independent Advocate.

What happens if I suffer any harm?

In the event of you coming to any harm you can apply for compensation under the 'No Fault Compensation Scheme' (see separate sheets for details).

What will happen to any measures made or samples I give?

Any measurements made during this study will be confidential.

Will my records be kept confidential?

Data from the study will be confidential, and Command will not see your data.

Who is organising and funding the research?

This study is being funded by the MOD and Southampton University.

Who has reviewed the study?

A protocol for this study has been reviewed by the Royal Navy Scientific Assessment Committee (RN SAC), and has been approved by The Ministry of Defence Research Ethics Committee (MODREC).

Further information and contact details.

Name and contact details of Independent Advocate:

Major Helen Stammers (OiC Rehab)

Rehab Department, Medical Centre, ATC(P), GU24 0QQ

Telephone: 01483 798053

E-mail: Helen.Stammers328@mod.uk

Name / Contact Details of the co-Chief Investigator (INM):

Dr Jo Fallowfield (Head of Applied Physiology)

Environmental Medicine and Science, Institute of Naval Medicine,

Crescent Road, Alverstoke, Hants. PO12 2DL

Telephone: 02392 768067

Email: Joanne.Fallowfield258@mod.uk

Name and contact details of the co-Chief Investigator (University of Southampton):

Prof Maria Stokes

University of Southampton, Building 45, Highfield Campus, Southampton, SO17 1BJ. UK

Telephone: +44 (0)2380 596868

E-mail: m.stokes@soton.ac.uk

Compliance with the Declaration of Helsinki.

This study complies, and at all times will comply, with the Declaration of Helsinki, as adopted at the 64th WMA General Assembly, Fortaleza, Brazil, October 2013, and with the Additional Protocol to the Convention on Human Rights and Biomedicine, concerning Biomedical Research, (Strasbourg 25.1.2005). Please ask the Chief Investigator if you would like further details of the approval or to see a copy of the full protocol.

Appendix F   Volitional consent

MINISTRY OF DEFENCE	International Movement Screening Group (Military Task Group) **CONSENT FORM;** vn 3.0; dated 25 January 2017 Improving Movement Quality to Protect Hips and Lower Limbs from Injury during Military Training (Study-2/ Study-3): Can Hip Movement Control be Trained? (MODREC protocol reference: 781/MODREC/16)

Please tick the box (☐) after each statement to confirm that you have understood what is being asked of you and that you agree to this requirement:

- The nature, aims and risks of the research have been explained to me. I have read and understood the Participant Information Sheet and understand what is expected of me. All my questions have been answered fully to my satisfaction. ☐
- I understand that if I decide at any time during the research that I no longer wish to participate in this project, I can notify the researchers involved and be withdrawn from it immediately without having to give a reason for my withdrawal. I also understand that I may be withdrawn from it at any time, and that in neither case will this be held against me in subsequent dealings with the Ministry of Defence. ☐
- I understand that the screening process to decide if I am suitable to be selected as a research participant may include completing a medical screening questionnaire and/or a physical examination by a medical officer and I consent to this. ☐
- I consent to the processing of my personal information for the purposes of this research study. I understand that such information will be treated as strictly confidential, it will not be made available in an individually identifiable form to anyone outside the Study Team, and it will be handled in accordance with the provisions of the Data Protection Act 1998. ☐
- I consent to the study team accessing my medical records to collate information on whether I suffered an injury during training and the type of injury. This will only be for the specific purposes of this research study. I understand that such information will be treated as strictly confidential, it will not be made available in an individually identifiable form to anyone outside the Study Team, and it will be handled in accordance with the provisions of the Data Protection Act 1998. ☐
- I consent to the study team accessing my training records to collate information on my physical fitness test results during training. This will only be for the specific purposes of this research study. I understand that such information will be treated as strictly confidential, it will not be made available in an individually identifiable form to anyone outside the Study Team, and it will be handled in accordance with the provisions of the Data Protection Act 1998. ☐
- I agree to volunteer as a research participant for the study described in the information sheet and I give full consent to my participation in this study. ☐
- This consent is specific to the particular study described in the Participant Information Sheet attached and shall not be taken to imply my consent to participate in any subsequent studies or experiments, or deviation from that detailed here. ☐

- I understand that in the event of my sustaining injury, illness or death as a result of participating as a volunteer in Ministry of Defence research, I or my dependants may enter a claim with the Ministry of Defence for compensation under the provisions of the no-fault compensation scheme. ☐

MINISTRY OF DEFENCE	International Movement Screening Group (Military Task Group) **CONSENT FORM;** vn 3.0; dated 25 January 2017 Improving Movement Quality to Protect Hips and Lower Limbs from Injury during Military Training (Study-2/ Study-3): Can Hip Movement Control be Trained? (MODREC protocol reference: 781/MODREC/16)

Research Participant's Statement:

I ____

agree that the research project named above has been explained to me to my satisfaction and I agree to take part in the study. I have read both the notes written above and the Participant Information Sheet about the project, and understand what the research study involves.

Signed ______________________________

Date ______________________________

Witness **Print Name** ______________________________

Signature ______________________________

Investigator's Statement:

I ____

confirm that I have carefully explained the nature, demands and any foreseeable risks (where applicable) of the proposed research to the Participant.

Signed ______________________________

Date ______________________________

2 copies 1 to Research Participant

1 to Project Officer

Appendix G Consent for the taking of Photographs

MINISTRY OF DEFENCE	International Movement Screening Group (Military Task Group) **CONSENT FOR THE TAKING AND USE OF PHOTOGRAPHS** Improving Movement Quality to Protect Hips and Lower Limbs from Injury during Military Training (Study-2): Can Hip Movement Control be Trained? (MODREC protocol reference: 781/MODREC/16)

I give my free and full consent for photographs to be taken during the study. I understand that these images will be stored and used as follows:

1. Photographs may be taken to illustrate the specific site and standardisation of the measures and standardisation of the test environment and test procedures.
2. Photographs will not be taken during all phases of data collection, of all personnel, nor for all measures; only exemplar pictorial records will be required to inform the data collection.
3. A copy will be kept within the study file at the Institute of Naval Medicine (INM), Alverstoke, Gosport, Hants, to which I have access in accordance with UK law. That copy will be identified with me, and will be stored and used in accordance with UK law and best practice covering such records.
4. Photographs will be anonymised through pixilation of the image.
5. Copies will not in any way reveal my identity may be shown to scientific groups for purposes of scientific education. My anonymity will be preserved at all times.
6. Copies not in any way revealing my identity may be included in published material in books and/or scientific journals intended for scientific readers. My anonymity will be preserved at all times.

These photographs will be kept indefinitely for the purposes identified in (1) above. Copies may be made for those purposes, but all originals and copies will remain under the control of the INM solely for the purpose detailed above.

I understand that I retain the right to modify or remove this consent at any time in the future, and will communicate any such change in writing to the INM. If at any time I direct that my consent for the use of these photographs be withdrawn then all originals and copies (other than those already published see 3 above) will be destroyed.

Should anyone ever wish to use these photographs for any other purposes, then separate and explicit consent will be obtained for that purpose.

Signed:

Name (printed):

Date:

2 copies 1 to Research Participant

1 to Project Officer

Appendix H Health history questionnaire

MINISTRY OF DEFENCE	International Movement Screening Group (Military Task Group) **HEALTH HISTORY QUESTIONNAIRE** Improving Movement Quality to Protect Hips and Lower Limbs from Injury during Military Training (MODREC protocol reference: 781/MODREC/16)

Surname: ____________________________ First Names: ________________________________

Service No. _________________ DoB: ______________ L/R Dominance: **LEFT ; RIGHT ; BOTH**

Date: _____________________ Ethnic Origin: _________________ Gender: _______________

Do you suffer from, or have you ever suffered from:

chest pain	Yes / No
breathlessness on exertion	Yes / No
dizziness on exertion	Yes / No
collapse when exercising	Yes / No
palpitations	Yes / No
asthma/wheezing	Yes / No
heat illness	Yes / No
anaemia	Yes / No
cold injury (freezing or non-freezing)	Yes / No
poor circulation (“Raynauds”)	Yes / No

If yes to any, please give details:

Have you ever been admitted to hospital? Yes / No

If yes, please give details

Have you ever had any limb injuries/broken bones? Yes / No

If yes, please give details

Do you take any medication regularly or to treat any condition? Yes / No

If yes, please give details

Do you have any known allergies? Yes / No

If yes, please give details

Signed______________________________**Name**___________________________**Date**___________
_

Appendix I Smoking and alcohol histories questionnaire

MINISTRY OF DEFENCE	International Movement Screening Group (Military Task Group) **SMOKING AND ALCOHOL HISTORIES QUESTIONNAIRE** Improving Movement Quality to Protect Hips and Lower Limbs from Injury during Military Training (MODREC protocol reference: 781/MODREC/16)

(Adapted from: Hardy CJ, Palmer BP, Muir HR et al (1998). Ann Rheum Dis 57: 451-455)

* Please delete as appropriate in the following questions:

1. What is your smoking status?

Have you ever smoked? Yes / No *

Are you an ex-smoker? Yes / No *

Date stopped smoking ____ /____/____ (DD/MM/YY)

Current Smoker? Yes / No *

(Current Smoker is defined as a person that smokes cigarettes, cigars, pipes, or roll ups.)

2. Number of Cigarettes:

0 (non-smoker) Yes / No *

1 – 10 Yes / No *

11 – 20 Yes / No *

Over 21 Yes / No *

Other (pipe, cigar, roll up) give answer here:

…………………………………………………………………..

3. **Approximately how many units of alcohol do you consume during a normal week?**

(N.B. 1 unit of alcohol = 1 small glass of wine **OR** ½ pint of beer **OR** one shot of spirit)

0	Yes / No *
1 – 5	Yes / No *
6 – 10	Yes / No *
11 – 15	Yes / No *
16 – 20	Yes / No *
Over 21	Yes / No *

Appendix J iHOT Questionnaire

MINISTRY OF DEFENCE	International Movement Screening Group (Military Task Group) **iHOT QUESTIONNAIRE** **Quality of Life Questionnaire for Young, Active Patients with Hip Problems** Improving Movement Quality to Protect Hips and Lower Limbs from Injury during Military Training (MODREC protocol reference: 781/MODREC/16)

Adapted From: Mohtadi, N.G., Griffin, D.R., Pedersen, M.E., Chan, D., Safran, M.R., Parsons, N., Sekiya, J.K., Kelly, B.T., Werle, J.R. and Leunig, M. (2012) The development and validation of a self-administered quality-of-life outcome measure for young, active patients with symptomatic hip disease: the International Hip Outcome Tool (iHOT-33). *Arthroscopy: The Journal of Arthroscopic & Related Surgery,* 28 (5), 595-610. e591.

Instructions

- These questions ask about the problems you may be experiencing in your hip, how these problems affect your life, and he emotions you may feel because of these problems.
- Please answer each question with respect to the current status, function, circumstances and beliefs related to your **hip**.
- Consider the last **month**.
- The questions are formatted so that you can indicate the severity of the problems by circling a number below the question.

Please note: Please circle the number most closely represents your situation.

- If you circle a number on the **left**, it means that you feel **you are significantly impaired**:

0-----1-------2------3------4------5------6------7------8------9------10

Significantly Impaired **No Problems At All**

- If you circle a number on the far **right**, it means that **you do not think that you have any problems with your hip**:

0------1-------2------3------4------5------6------7------8------9-----10

Significantly Impaired **No Problems At All**

- If a number is circled in the middle of the line, this indicates that you are moderately disabled, in other words, between the extremes of 'significantly imparied' and 'no problems at all'. It is important to circle a number at the appropriate end of the line if the extreme descriptions accurately reflect your situation.

- If the question asks about something that **you do not experience**, please mark the option:

☐ **I do not do this action in my activities**, where this is appropriate.

Continued Overleaf /

I: SYMPTOMS AND FUNCTIONAL LIMITATIONS

The following questions ask about symptoms that you may experience in your **hip** and about the function of your **hip** with respect to daily activities. Please think about how you have felt most of the time over the past **month** and answer accordingly.

1. How <u>often</u> does your hip/groin ache?

0------1-------2------3------4------5------6------7------8------9------10

Constantly **Never**

2. How stiff is your hip as a result of sitting/resting during the day?

0------1-------2------3------4------5------6------7------8------9------10

Extremely Stiff **Not Stiff At All**

3. How difficult is it for you to walk long distances?

0------1-------2------3------4------5------6------7------8------9------10

Extremely Difficult **Not Difficult At All**

Continued Overleaf /

4. **How much pain do you have in your hip while sitting?**

0------1-------2------3------4------5------6------7------8------9------10

Extreme Pain **No Pain At All**

5. **How much trouble do you have standing on your feet for long period of time?**

0------1-------2------3------4------5------6------7------8------9------10

Severe Trouble **No Trouble At All**

6. **How difficult is it for you to get up and down off the floor/ground?**

0------1-------2------3------4------5------6------7------8------9------10

Extremely Difficult **Not Difficult At All**

7. **How difficult is it for you to walk on uneven surfaces?**

0------1-------2------3------4------5------6------7------8------9------10

Extremely Difficult **Not Difficult At All**

Continued Overleaf /

8. How difficult is it for you to lie on your affected hip side?

0------1-------2------3------4------5------6------7------8------9------10

Extremely Difficult **Not Difficult At All**

9. How much trouble do you have with stepping over obstacles?

0------1-------2------3------4------5------6------7------8------9------10

Severe Trouble **No Trouble At All**

10. How much trouble do you have climbing up/downstairs?

0------1-------2------3------4------5------6------7------8------9------10

Severe Trouble **No Trouble At All**

11. How much trouble do you have with rising from a sitting position?

0------1-------2------3------4------5------6------7------8------9------10

Severe Trouble **No Trouble At All**

Continued Overleaf /

12. How much discomfort do you have with taking long strides?

0------1-------2------3------4------5------6------7------8------9------10

Extreme Discomfort **No Discomfort At All**

13. How much difficulty do you have with getting into and/or out of a car?

0 ------1-------2------3------4------5------6------7------8------9------10

Extreme Difficulty **No Difficulty At All**

14. How much trouble do you have with grinding, catching, or clicking in your hip?

0------1-------2------3------4------5------6------7------8------9------10

Severe Trouble **No Trouble At All**

15. How much difficulty do you have with putting on/taking off socks, stockings, or shoes?

0------1-------2------3------4------5------6------7------8------9------10

Extreme Difficulty **No Difficulty At All**

Continued Overleaf /

16. **Overall, how much pain do you have in your hip/groin?**

0------1-------2------3------4------5------6------7------8------9------10

Extreme Pain **No Pain At All**

II: SPORTS AND RECREATIONAL ACTIVITIES

The following questions ask about your **hip** when you participate in sports and recreational activities. Please think about how you have felt most of the time over the past **month** and answer accordingly.

17. **How concerned are you about your ability to maintain your desired fitness level?**

0------1-------2------3------4------5------6------7------8------9------10

Extremely Concerned **Not Concerned At All**

18. **How much pain do you experience in your hip after activity?**

0------1-------2------3------4------5------6------7------8------9------10

Extreme Pain **No Pain At All**

Continued Overleaf /

19. How concerned are you that the pain in your hip will increase if you participate in sports or recreational activities?

0------1-------2------3------4------5------6------7------8------9------10

Extremely Concerned | Not Concerned At All

20. How much was your quality of life deteriorated because you cannot participate in sport/recreational activities?

0------1-------2------3------4------5------6------7------8------9------10

Extremely Deteriorated | Not Deteriorated At All

21. How concerned are you about cutting/changing directions during your sports or recreational activities?

☐ I do not do this action in my activities.

0------1-------2------3------4------5------6------7------8------9------10

Extremely Concerned | Not Concerned At All

22. How much has your performance level decreased in your sport or recreational activities?

0------1-------2------3------4------5------6------7------8------9------10

Extremely Decreased | Not Decreased At All

Continued Overleaf /

III: JOB RELATED CONCERNS

The following questions relate to your **hip** with respect to your work or occupational activities. Please think about how you have felt most of the time over the past **month** and answer accordingly.

☐ **I am retired** (please skip section)

☐ **I do not work for reasons other than my hip condition** (please skip section)

23. How much trouble do you have pushing, pulling, lifting, or carrying heavy objects at work?

☐ **I do not do these actions in my work.**

0------1-------2------3------4------5------6------7------8------9------10

Severe Trouble **No Trouble At All**

24. How much trouble do you have with crouching/squatting?

0------1-------2------3------4------5------6------7------8------9------10

Severe Trouble **No Trouble At All**

Continued Overleaf /

25. How concerned are you that your job will make your hip worse?

0------1-------2------3------4------5------6------7------8------9------10

Extremely Concerned **Not Concerned At All**

26. How much trouble do you have at work because of reduced hip mobility?

0------1-------2------3------4------5------6------7------8------9------10

Extreme Difficulty **No Difficulty At All**

IV: SOCIAL, EMOTIONAL AND LIFESTYLE CONCERNS

The following questions ask about social, emotional and lifestyle concerns that you may feel with respect to your **hip** problem. Please think about how you have felt most of the time over the past **month** and answer accordingly.

27. How frustrated are you because of your hip problem?

0------1-------2------3------4------5------6------7------8------9------10

Extremely Frustrated **Not Frustrated At All**

Continued Overleaf /

28. How much trouble do you have with sexual activity because of your hip?

☐ This is not relevant to me.

0------1-------2------3------4------5------6------7------8------9------10

Severe Trouble — No Trouble At All

29. How much of a distraction is your hip problem?

0------1-------2------3------4------5------6------7------8------9------10

Extreme Distraction — No Distraction At All

30. How difficult is it for you to release tension and stress because of your hip problem?

0------1-------2------3------4------5------6------7------8------9------10

Extremely Difficult — Not Difficult At All

31. How discouraged are you because of your hip problem?

0------1-------2------3------4------5------6------7------8------9------10

Extremely Discouraged — Not Discouraged At All

Continued Overleaf /

32. **How concerned are you about picking up or carrying children because of your hip?**

☐ I do not do this action in my activities.

0------1-------2------3------4------5------6------7------8------9------10

Extremely Concerned **Not Concerned At All**

33. **How much of the time are you aware of the disability in your hip?**

0------1-------2------3------4------5------6------7------8------9------10

Constantly Aware **Not Aware At All**

QUESTIONNAIRE COMPLETE!

THANK YOU!

Appendix K HAGOS Questionnaire

MINISTRY OF DEFENCE	International Movement Screening Group (Military Task Group) **HAGOS QUESTIONNAIRE** Improving Movement Quality to Protect Hips and Lower Limbs from Injury during Military Training (MODREC protocol reference: 781/MODREC/16)

Adapted from: Thorborg, K., Hölmich, P., Christensen, R., Petersen, J. and Roos, E.M. (2011) The Copenhagen Hip and Groin Outcome Score (HAGOS): development and validation according to the COSMIN checklist. *British Journal of Sports Medicine,* 45 (6), 478-491.

Today's date: _____/______/______ Date of birth: _____/______/________

Name: ____

INSTRUCTIONS: This questionnaire asks for your view about your hip and/or groin problem. The questions should be answered considering your hip and/or groin function during the **past week**.This information will help us keep track of how you feel, and how well you are able to do your usual activities.

Answer **every** question by ticking the appropriate box. Tick only one box for each question. If a question does not pertain to you or you have not experienced it in the past week please make your "best guess" as to which response would be the most accurate.

Symptoms

These questions should be answered considering your hip and/or groin **symptoms** and difficulties during the **past week**.

S1 Do you feel discomfort in your hip and/or groin?

Never	Rarely	Sometimes	Often	Always
☐	☐	☐	☐	☐

S2 Do you hear clicking or any other type of noise from your hip and/or groin?

Never	Rarely	Sometimes	Often	All the time
☐	☐	☐	☐	☐

S3 Do you have difficulties stretching your legs far out to the side?

None	Mild	Moderate	Severe	Extreme
☐	☐	☐	☐	☐

S4 Do you have difficulties taking full strides when you walk?

None	Mild	Moderate	Severe	Extreme
☐	☐	☐	☐	☐

S5 Do you experience sudden twinging/stabbing sensations in your hip and/or groin?

Never	Rarely	Sometimes	Often	All the time
☐	☐	☐	☐	☐

Stiffness

The following questions concern the amount of stiffness you have experienced during the **past week** in your hip and/or groin. Stiffness is a sensation of restriction or slowness in the ease with which you move your hip and/or groin.

S6 How severe is your hip and/or groin stiffness after first awakening in the morning?

None	Mild	Moderate	Severe	Extreme
☐	☐	☐	☐	☐

S7 How severe is your hip and/or groin stiffness after sitting, lying or resting **later in the day**?

None	Mild	Moderate	Severe	Extreme
☐	☐	☐	☐	☐

Pain

P1 How often is your hip and/or groin painful?

Never	Monthly	Weekly	Daily	Always
☐	☐	☐	☐	☐

P2 How often do you have pain in areas other than your hip and/or groin that you think may be related to your hip and/or groin problem?

Never	Monthly	Weekly	Daily	Always
☐	☐	☐	☐	☐

The following questions concern the amount of pain you have experienced during the **past week** in your hip and/or groin. **What amount of hip and/or groin pain have you experienced during the following activities?**

P3 Straightening your hip fully

None	Mild	Moderate	Severe	Extreme
☐	☐	☐	☐	☐

P4 Bending your hip fully

None	Mild	Moderate	Severe	Extreme
☐	☐	☐	☐	☐

P5 Walking up or down stairs

None	Mild	Moderate	Severe	Extreme
☐	☐	☐	☐	☐

P6 At night while in bed (pain that disturbs your sleep)

None	Mild	Moderate	Severe	Extreme
☐	☐	☐	☐	☐

P7 Sitting or lying

None	Mild	Moderate	Severe	Extreme
☐	☐	☐	☐	☐

Continued Overleaf /

The following questions concern the amount of pain you have experienced during the **past week** in your hip and/or groin. **What amount of hip and/or groin pain have you experienced during the following activities?**

P8 Standing upright

None	Mild	Moderate	Severe	Extreme
☐	☐	☐	☐	☐

P9 Walking on a hard surface (asphalt, concrete, etc.)

None	Mild	Moderate	Severe	Extreme
☐	☐	☐	☐	☐

P10 Walking on an uneven surface

None	Mild	Moderate	Severe	Extreme
☐	☐	☐	☐	☐

Physical function, daily living

The following questions concern your physical function. **For each of the following activities please indicate the degree of difficulty you have experienced in the past week due to your hip and/or groin problem.**

A1 Walking up stairs

None	Mild	Moderate	Severe	Extreme
☐	☐	☐	☐	☐

A2 Bending down, e.g. to pick something up from the floor

None	Mild	Moderate	Severe	Extreme
☐	☐	☐	☐	☐

A3 Getting in/out of car

None	Mild	Moderate	Severe	Extreme
☐	☐	☐	☐	☐

A4 Lying in bed (turning over or maintaining the same hip position for a long time)

None	Mild	Moderate	Severe	Extreme
☐	☐	☐	☐	☐

A5 Heavy domestic duties (scrubbing floors, vacuuming, moving heavy boxes etc)

None	Mild	Moderate	Severe	Extreme
☐	☐	☐	☐	☐

Continued Overleaf /

Function, sports and recreational activities

The following questions concern your physical function when participating in higher-level activities. Answer **every** question by ticking the appropriate box. If a question does not pertain to you or you have not experienced it in the past week please make your "best guess" as to which response would be the most accurate. **The questions should be answered considering what degree of difficulty you have experienced during the following activities in the past week due to problems with your hip and/or groin.**

SP1 Squatting

None	Mild	Moderate	Severe	Extreme
☐	☐	☐	☐	☐

SP2 Running

None	Mild	Moderate	Severe	Extreme
☐	☐	☐	☐	☐

SP3 Twisting/pivoting on a weight bearing leg

None	Mild	Moderate	Severe	Extreme
☐	☐	☐	☐	☐

SP4 Walking on an uneven surface

None	Mild	Moderate	Severe	Extreme
☐	☐	☐	☐	☐

SP5 Running as fast as you can

None	Mild	Moderate	Severe	Extreme
☐	☐	☐	☐	☐

SP6 Bringing the leg forcefully forward and/or out to the side, such as in kicking, skating etc.

None	Mild	Moderate	Severe	Extreme
☐	☐	☐	☐	☐

SP7 Sudden explosive movements that involve quick footwork, such as accelerations, decelerations, change of directions etc.

None	Mild	Moderate	Severe	Extreme
☐	☐	☐	☐	☐

SP8 Situations where the leg is stretched into an outer position (such as when the leg is placed as far away from the body as possible)

None	Mild	Moderate	Severe	Extreme
☐	☐	☐	☐	☐

Continued Overleaf /

Participation in physical activities

The following questions are about your ability to participate in your preferred physical activities. Physical activities include sporting activities as well as all other forms of activity where you become slightly out of breath. **When you answer these questions consider to what degree your ability to participate in physical activities during the past week has been affected by your hip and/or groin problem.**

PA1 Are you able to participate in your preferred physical activities for as long as you would like?

Always	Often	Sometimes	Rarely	Never
☐	☐	☐	☐	☐

PA2 Are you able to participate in your preferred physical activities at your normal performance level?

Always	Often	Sometimes	Rarely	Never
☐	☐	☐	☐	☐

Quality of Life

Q1 How often are you aware of your hip and/or groin problem?

Never	Monthly	Weekly	Daily	Constantly
☐	☐	☐	☐	☐

Q2 Have you modified your life style to avoid activities potentially damaging to your hip and/or groin?

Not at all	Mildly	Moderately	Severely	Totally
☐	☐	☐	☐	☐

Q3 In general, how much difficulty do you have with your hip and/or groin?

None	Mild	Moderate	Severe	Extreme
☐	☐	☐	☐	☐

Q4 Does your hip and/or groin problem affect your mood in a negative way?

Not at all	Rarely	Sometimes	Often	All the time
☐	☐	☐	☐	☐

Q5 Do you feel restricted due to your hip and/or groin problem?

Not at all	Rarely	Sometimes	Often	All the time
☐	☐	☐	☐	☐

Thank you very much for completing all the questions in this questionnaire.

Appendix L Recuit focus group participant information sheet.

MINISTRY OF DEFENCE

International Movement Screening Group (Military Task Group)

PARTICIPANT INFORMATION SHEET FOR PARTICIPATING IN THE FOCUS GROUP – RECRUIT

Improving Movement Quality to Protect Hips and Lower Limbs from Injury during Military Training (Study-2): Can Hip Movement Control be Trained?

(MODREC protocol reference: 781/MODREC/16)

Invitation to take part

You are invited to take part in a focus group to determine your views and experiences of taking part in the warm-up exercises undertaken as part of the WGCC HIP Study. Before you decide, it is important that you understand why the focus group is being carried out and what you would need to do. Please take time to read this information and discuss it with others if you wish. Ask members of the study team if there is anything that is not clear or if you need more information.

What is the purpose of the research?

The HIP Study is investigating a warm-up exercise programme, to see if it improves movement control. The purpose of the focus group is to determine your views and experiences of taking part in the warm-up exercise programme.

Who is doing this research?

This study is being undertaken by MOD personnel from the Institute of Naval Medicine (INM), Army Headquarters, and civilian colleagues from the University of Southampton.

Why have I been invited to take part?

You have been invited to participate in this focus group as you have taken part in the HIP Study.

Do I have to take part?

No, you do not have to take part in the focus group.

What will I be asked to do?

At the end of Phase-1 training for the INTERVENTION platoons, we would like you to take part in a focus group, where you will be asked to share your thoughts, feelings and perceptions about the warm-up exercise programme. The discussions will last no more than 60 minutes, and will be recorded. However, you will not be identified and will remain anonymous. If you are not happy for a recorder to be used, field notes can be taken instead.

As soon after the focus group as possible, the audio recordings (if taken) will be transcribed. Following the transcription of the audio recordings, these recordings will be destroyed.

Any quotations from the focus groups in future reports and publications of this study will be anonymous.

The study will be compliant with the information governance policies of the MOD, the Data Protection Act and the NHS code of confidentiality.

What is the device or procedure that is being tested?

This study is evaluating the effectiveness of the warm-up exercise programme in terms of improving movement control and movement quality, and in terms of the practicalities of using such methods in physical training to reduce injury risk.

What are the benefits of taking part?

There are no specific benefits to you from taking part in this focus group. But importantly, you will be helping the MOD to improve the physical training and physical training delivery for all Service personnel.

What are the possible disadvantages and risks of taking part?

Participation in the focus groups will not add to the demands and risks of taking part in the HIP Study.

Can I withdraw from the research and what happens if I don't want to carry on?

You can withdraw at any time from the focus group without giving a reason. You can ask for any data collected to be destroyed at any time.

Are there any expenses and payments that I will get?

You will not receive payment for taking part in this focus group.

Will my taking part or not taking part affect my Service career?

You should only take part if you want to. Choosing not to take part, or choosing to withdraw from the focus group at any time, would not have any consequences for your Service career.

Whom do I contact if I have any questions or a complaint?

If you have any questions about this study you can contact the study team (contact details below).

The Independent Medical Officer (IMO) will be available during the study. His/her role is to act independently of the study team and to ensure your safety. The IMO may stop you taking part in the study on medical grounds at any time.

If you are unhappy with any aspect of the study, you may contact the IMO (contact details below).

What happens if I suffer any harm?

In the event of you coming to any harm you can apply for compensation under the 'No Fault Compensation Scheme' (see separate sheets for details).

What will happen to any measures made or samples I give?

Any information collected during the focus group will be confidential.

Will my records be kept confidential?

Data from the study will be confidential, and Command will not see your data.

Who is organising and funding the research?

This study is being funded by the MOD and the University of Southampton.

Who has reviewed the study?

A protocol for this study has been reviewed by the Royal Navy Scientific Assessment Committee (RN SAC), and has been approved by The Ministry of Defence Research Ethics Committee (MODREC).

Name / Contact Details of the co-Chief Investigator (INM):

Dr Jo Fallowfield (Head of Applied Physiology)

Environmental Medicine and Science, Institute of Naval Medicine,

Crescent Road, Alverstoke, Hants. PO12 2DL

Telephone: 02392 768067

Email: Joanne.Fallowfield258@mod.uk

Compliance with the Declaration of Helsinki.

This study complies, and at all times will comply, with the Declaration of Helsinki[1] as adopted at the 52nd WMA General Assembly, Edinburgh, October 2000 and with the Additional Protocol to the Convention on Human Rights and Biomedicine, concerning Biomedical Research, (Strasbourg 25.1.2005). Please ask the Chief Investigator if you would like further details of the approval or to see a copy of the full protocol.

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[1] World Medical Association (2000) Declaration of Helsinki. Ethical principles for medical research involving human subjects. 52nd World Medical Association General Assembly, Edinburgh, Scotland October 2000.

Appendix M Physical training instructor participant information sheet.

MINISTRY OF DEFENCE	International Movement Screening Group (Military Task Group) **PARTICIPANT INFORMATION SHEET FOR PARTICIPATING IN THE FOCUS GROUP – PTI** Improving Movement Quality to Protect Hips and Lower Limbs from Injury during Military Training (Study-2): Can Hip Movement Control be Trained? (MODREC protocol reference: 781/MODREC/16)

Invitation to take part

You are invited to take part in a focus group to determine your views and experiences of delivering the warm-up exercises undertaken as part of the WGCC HIP Study. Before you decide, it is important that you understand why the focus group is being carried out and what you would need to do. Please take time to read this information and discuss it with others if you wish. Ask members of the study team if there is anything that is not clear or if you need more information.

What is the purpose of the research?

The HIP Study is investigating a warm-up exercise programme, to see if it improves movement control. The purpose of the focus group is to determine your views and experiences of delivering the warm-up exercise programme.

Who is doing this research?

This study is being undertaken by MOD personnel from the Institute of Naval Medicine (INM), Army Headquarters, and civilian colleagues from the University of Southampton.

Why have I been invited to take part?

You have been invited to participate in this focus group as you have taken part in the HIP Study.

Do I have to take part?

No, you do not have to take part in the focus group.

What will I be asked to do?

At the end of Phase-1 training for the INTERVENTION platoons, we would like you to take part in a focus group, where you will be asked to share your thoughts, feelings and perceptions about the warm-up exercise programme. The discussions will last no more than 60 minutes, and will be recorded.

However, you will not be identified and will remain anonymous. If you are not happy for a recorder to be used, field notes can be taken instead.

As soon after the focus group as possible, the audio recordings (if taken) will be transcribed. Following the transcription of the audio recordings, these recordings will be destroyed.

Any quotations from the focus groups in future reports and publications of this study will be anonymous.

The study will be compliant with the information governance policies of the MOD, the Data Protection Act and the NHS code of confidentiality.

What is the device or procedure that is being tested?

This study is evaluating the effectiveness of the warm-up exercise programme in terms of improving movement control and movement quality, and in terms of the practicalities of using such methods in physical training to reduce injury risk.

What are the benefits of taking part?

There are no specific benefits to you from taking part in this focus group. But importantly, you will be helping the MOD to improve the physical training and physical training delivery for all Service personnel.

What are the possible disadvantages and risks of taking part?

Participation in the focus groups will not add to the demands and risks of taking part in the HIP Study.

Can I withdraw from the research and what happens if I don't want to carry on?

You can withdraw at any time from the focus group without giving a reason. You can ask for any data collected to be destroyed at any time.

Are there any expenses and payments that I will get?

You will not receive payment for taking part in this focus group.

Will my taking part or not taking part affect my Service career?

You should only take part if you want to. Choosing not to take part, or choosing to withdraw from the focus group at any time, would not have any consequences for your Service career.

Whom do I contact if I have any questions or a complaint?

If you have any questions about this study you can contact the study team (contact details below).

The Independent Medical Officer (IMO) will be available during the study. His/her role is to act independently of the study team and to ensure your safety. The IMO may stop you taking part in the study on medical grounds at any time.

If you are unhappy with any aspect of the study, you may contact the IMO (contact details below).

What happens if I suffer any harm?

In the event of you coming to any harm you can apply for compensation under the 'No Fault Compensation Scheme' (see separate sheets for details).

What will happen to any measures made or samples I give?

Any information collected during the focus group will be confidential.

Will my records be kept confidential?

Data from the study will be confidential, and Command will not see your data.

Who is organising and funding the research?

This study is being funded by the MOD and the University of Southampton.

Who has reviewed the study?

A protocol for this study has been reviewed by the Royal Navy Scientific Assessment Committee (RN SAC), and has been approved by The Ministry of Defence Research Ethics Committee (MODREC).

Name / Contact Details of the co-Chief Investigator (INM):

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Compliance with the Declaration of Helsinki.

This study complies, and at all times will comply, with the Declaration of Helsinki[2] as adopted at the 52nd WMA General Assembly, Edinburgh, October 2000 and with the Additional Protocol to the Convention on Human Rights and Biomedicine, concerning Biomedical Research, (Strasbourg 25.1.2005). Please ask the Chief Investigator if you would like further details of the approval or to see a copy of the full protocol.

[2] World Medical Association (2000) Declaration of Helsinki. Ethical principles for medical research involving human subjects. 52nd World Medical Association General Assembly, Edinburgh, Scotland October 2000.

Appendix N Recruit focus group question form

	International Movement Screening Group (Military Task Group) **FOCUS GROUP – INTERVIEW GUIDE – PTI and RECRUIT** Improving Movement Quality to Protect Hips and Lower Limbs from Injury during Military Training (Study-2): Can Hip Movement Control be Trained? (MODREC protocol reference: 781/MODREC/16)

RECRUIT –

1. Introductory question

1.1 To begin the discussion, can you tell me about your physical training experiences during recruit training?

1.2 How often did you do the warm-up exercise programme each week?

1.3 How much of the warm-up exercise programme did you manage to do during each session?

1.4 Did you undertake any of the warm-up exercises outside of our PTI-led training sessions?

2. Facilitators and Barriers to complete the movement control preventative warm-up exercise programme

2.1 Can you tell me how did you find doing the warm-up exercise programme?

Probes: *- Feel well prepared*

- Things liked/disliked

- Things hard/easy

2.2 Was there anything in particular that helped you do the programme?

Probes: *- Motivation*

- Time

- Allocated leader

- Part of routine

- Specific exercises

- Anything could help more

2.3 Can you tell me what were the things that made it harder for you to do the programme at every training or game?

Probes: *- Team buy-in*

- Exercises tiring/difficult

3. The movement control preventative warm-up exercise programme

3.1 Do you feel doing the programme made any difference to you?

Probes: *- Affect fitness, performance, ability to undertake training*

- Confidence in military training

- Prevent injuries

3.2 Do you think recruit training should continue using the programme now that the study is finished?

Probes: *- Why?*

4. Closing question

4.1 Is there anything we have not talked about that you would like to add before ending the interview?

Appendix O Physical training instructor focus group questions

	International Movement Screening Group (Military Task Group) **FOCUS GROUP – INTERVIEW GUIDE – PTI and RECRUIT** Improving Movement Quality to Protect Hips and Lower Limbs from Injury during Military Training (Study-2): Can Hip Movement Control be Trained? (MODREC protocol reference: 781/MODREC/16)

PTI –

1. Introductory questions

1.1 To begin the discussion, can you tell me about your PTI career so far? Experience of PTIs delivering the programme?

1.2 Were you delivering the programme?

1.3 How often were you able to implement the warm-up programme each week?

1.4 How much of the warm-up programme did you manage to do during each session?

2. Facilitators and Barriers to complete the movement control preventative warm-up exercise programme

2.1 Can you tell me how did you find delivering the programme?

Probes: - Receive enough preparation

- Feel well prepared

- Anything could help more

2.2 Was there anything in particular that helped you deliver the programme?

Probes: *- Use of the resources*

- Resources helpful

- Things not used

- Anything could help more

2.3 Can you tell me what were the things that made it difficult to lead and complete the programme at every training or game?

Probes: *- Time*

- Player buy-in, cooperation

- Absence

- Individual exercises

3. The movement control preventative warm-up exercise programme

3.1 Do you feel doing the programme made any difference to the recruits?

Probes: *- Affect fitness, performance, ability to complete military training*

- Confidence in recruit training

- Prevent injuries

3.2 Do you think recruit training could continue to use the programme now that the study is finished?

Probes: *- Why?*

4. Closing question

4.1 Is there anything we have not talked about that you would like to add before ending the interview?

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