Teesside University

The Development and Evaluation of a Management Plan for Musculoskeletal Injuries in British Army Recruits: A Series of Exploratory Trials on Medial Tibial Stress Syndrome

---

Jagannath Sharma

Thesis submitted in partial fullfilment of the requirements for the

Degree of Doctor of Philosophy, Teesside University.

Director of Studies

Professor Iain R. Spears

Supervisor

Dr Jim Golby

July, 2013

Declaration

I certify that the substance of this thesis has not been already submitted for any degree and is not currently being submitted for any other degree or degrees. I certify that to the best of my knowledge any help received in preparing this work, and all sources used, have been acknowledged in this thesis.

_____

Jagannath Sharma

July, 2013

Acknowledgements

I would like to express my thanks to all the people at Infantry Training Centre (ITC) Catterick, Army Primary Health Care Services and Headquarters Army Recruiting and Training Division for their funding, friendly behaviour, openness, sharing, humility and providing the equipment to facilitate data collection. I would also like to thank all the recruits who took part in this study. I wish to express my sincere gratitude to all the medical officers, nurses, medics and receptionists at the medical centre, as well as my Physiotherapy department colleagues at ITC Catterick. My thanks must also go to Colonel PN Gillespie, Dr James Bilzon, Dr. Julie Greeves, Major Goodwin, Mrs Jane Clayton and Rachel Izard.

I would like to express my sincere gratitude to my Director of Studies, Professor Iain Spears for his critical comments, valuable suggestions and encouragement throughout the study. Our regular discussions and reflection enriched my theoretical understanding of biomechanics and injury management. I would not have been able to reach the culmination of this thesis without his continued support, advice and knowledge throughout the years. His thoughts and advice are always welcomed and very much appreciated.

I am obliged to my supervisor Dr Jim Golby, who encouraged me to undertake this research and to help frame this study. His constant academic and moral support

inspired me to continue with my commitment to the study. His advice and guidance were always enlightening.

I must also thank Teesside University for enabling me to use their equipment and resources for data collection and analysis. I also thank academic and professionals as well as Debbie Harris at Teesside University for their involvement in my work.

Last but not least, I would like to thank my family and friends. My parents, brothers and sisters have taught me that a combination of hard work and self-belief can enable me to achieve my aims. I must thank them for their unfailing strength, support and continued encouragement, not only during the years that it has taken to write this thesis, but for their continued support of my academic pursuits over the years. My thanks must go to my brother Chiranjibi, my nephews Basu and Bharat and my nieces Pragya and Sharada. I would like to thank my wife Laxmi, and my two daughters Pratiksha and Pratibha for their understanding, co-operation and moral support that constantly inspired me to take this huge academic adventure.

I have reached the end of my Ph.D. journey. There were times when it flowed freely and others when it felt impossible. The support and encouragement I have received has motivated me forward and enabled me to reach the end of this marathon. The feelings of relief, pleasure and the superb sense of achievement will stay with me for the rest of my life, and for this I am eternally grateful to those mentioned above.

Table of Contents

Contents

List of Figures

List of Tables

List of Abbreviations

AKP = Anterior Knee Pain

ATR = Army Training Regiment

BES = Back Extension Strength

CI = Confidence Interval

CIC = Combat Infantryman Courses

DAOR = Discharge As of Right

DLS = Dynamic Lift Strength

GTI = General Trainability Index

ITBS = Ilio-Tibial Band Syndrome

ITC = Infantry Training Centre

LBP = Low Back Pain

MD = Medically Discharged

MRC = Medical Research Council

MSK = Musculoskeletal

MTSS = Medial Tibial Stress Syndrome

OR = Odds Ratio

PQAP = Personal Qualities Assessment Profile

SE = Standard Entry

SLS = Static Lift Strength

TPHR =Time to Reach Peak Heel Rotation

 UFAS = Unsuitable for Army Service

Overview of the Thesis

Musculoskeletal (MSK) injuries constitute a major socio-economic burden in many countries (Gruhn et al., 1999; Belechri et al., 2001; Conn et al., 2003; Knowles et al., 2007; Brushoj et al., 2008; Hincapie et al., 2008; Jones et al., 2010a; Jones et al., 2010b). Such injuries affect more than 10 million people in the United Kingdom (Arthritis Research UK, 2008) and cost approximately £5.7 billion per year (Health and Safety Executive, 2008a). Furthermore, the problem is not unique to Britain. For example, in Germany it has been reported that MSK injuries are the second most common type of injury (Schneider et al., 2006). MSK injury during military training is a major problem facing the British Army (Etherington et al., 2002; Blacker et al., 2008; Sharma, 2008; Wilkinson et al., 2011). In the transition from being a civilian to a combat-ready soldier, recruits undergo an intensive training program which places the body under high levels of stress. The incidence of MSK injury is unsurprisingly high. Moreover, over the last few decades, the general increase in sedentary lifestyle in civilian populations has exacerbated the problem and the British Army find it difficult to train new trainees up to the level required for service without causing MSK injury. Thus, the Army Recruiting and Training Division has commissioned this research (see Appendix B) with the aim of implementing an evidence-based injury reduction and management policy in the British Army. This thesis is the culmination of a series of research projects designed to quantify and improve the management of MSK injury at an infantry training centre (ITC) Catterick, UK. The approach to be adopted in this thesis (Figure I.I) is a combination of the 'sequence of prevention' model first

proposed by van Mechelen et al., (1992) and, where interventions are used, the Medical Research Council (MRC) Framework for complex interventions in public health (MRC, 2000). The 'sequence of prevention' model is based on four steps.
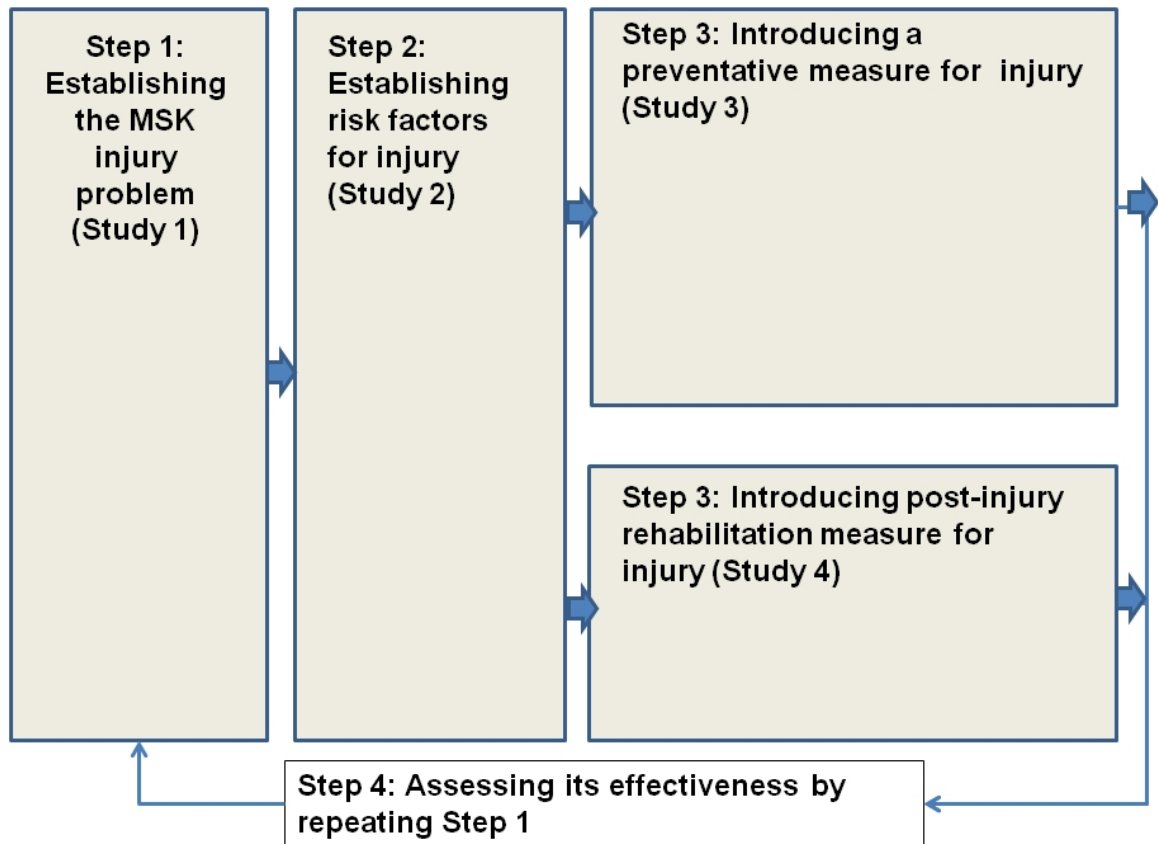
Figure I.I. The framework used to guide the structure of this thesis. Adapted from the 'sequence of prevention' model of van Mechelen et al. (1992).

The first step (Step 1) is to establish the extent of both the training injury problem and its impact on the individuals and stakeholders; the second (Step 2) is to establish the aetiology of injury. Building upon this information, an intervention can be developed (Step 3) and evaluated (Step 4) in a target setting. Accordingly, the structure of this

thesis will follow this logical approach. After reviewing the literature related to musculoskeletal injuries (Chapter 1), in Chapter 2 the problem of MSK injury in the British Army (Step 1) will be quantified. This chapter takes the form of an epidemiological study of MSK injuries at the infantry training centre (Catterick, UK). Based on this study, medial tibial stress syndrome (MTSS) is highlighted as an important injury and this type of injury is investigated further in the following chapters. In Chapter 3, the aetiology of MTSS (Step 2) is investigated and a risk factor model is created which is used to inform the subsequent chapters. Specifically, it enables the objective identification of those recruits at risk of developing MTSS, and therefore enables to identify those for whom a new preventative intervention may be suitable. In Chapters 4 and 5, two new interventions for MTSS are proposed (Steps 3) which are based on new approaches to prehabilitation and rehabilitation, respectively. These interventions comprise gait retraining for those at risk of MTSS which makes use of targeted exercises together with the provision of bio-feedback on the kinetics of movement. The rehabilitation intervention delivered to those already injured also included corticosteroid injections. Both interventions described in Chapters 4 and 5 were successful in reducing the impact of MTSS. Chapter 6 collates the knowledge created in this thesis and forms the basis for a new proactive injury management plan which is considered to be suitable for the armed forces and other large institutes with unacceptably high levels of MSK injury.

Thesis Abstract

This thesis is the culmination of a series of studies designed to improve the management of musculoskeletal (MSK) injury in an infantry training centre (ITC Catterick, UK). The overall aim of this thesis is to develop and evaluate a management strategy for MSK injury during Combat Infantryman's Courses (CIC) training. Included is an epidemiological study of MSK injuries in the British Army (Study1), a risk factor model for MTSS (Study 2) and two randomised controlled trials (RCTs) in which the effects of prevention (Study 3) and rehabilitation interventions (Study 4) were examined. The aim of Study 1 was to quantify incidence, type and impact of the MSK injuries during military CIC training (26 weeks). Over a two year period (April 2006 - March 2008), 6608 British infantry CIC trainees completed an informed consent form to take part in this study. A prospective epidemiological study was conducted. Data for the injuries were reported according to: onset, anatomical location, diagnosis and regiment-specific incidence, week and months, impact and occupational outcome. It was clearly demonstrated that MSK injuries are a substantial burden to the British Army. Injury rate was 48.65% and overuse injury was significantly higher than acute and recurrence. Most overuse injuries occurred in the lower limb (82.34%) and were more frequent ($p < 0.01$) in the first phase of training (Weeks 0-13). One third of the recruits (33%) were discharged prior to completion of training. A further 15% (n=991) were removed from training for further rehabilitation. Rehabilitation time ranged from 21 to 168 days and 12% of total training time was lost due to injury (equivalent to 155,403 days of training). Owing to its high severity index,

medial tibial stress syndrome (MTSS) is argued to be the most impactful of these injuries despite only being second most frequent. **Implications for practice and research (Study 1):** MSK injuries are a significant burden to the British Army and strategies to improve prevention and treatment need to be explored. An initial focus on MTSS is warranted.

In order to develop interventions for Studies 3 and 4 it is necessary to identify those risk factors for developing MTSS. The aim of Study 2 was to determine prospectively whether gait biomechanics and/or lifestyle factors can identify those at risk of developing MTSS. Again, British Infantry male recruits (n = 468) were selected for the study. Based on a review of the literature of known risk factors for MSK injury, plantar pressure variables, lifestyle factors comprising smoking habits and aerobic fitness as measured by a 1.5 mile timed-run were collected on the first day of training. A logistic regression model for membership of the MTSS and non-MTSS groups showed that an imbalance in foot pressure (heel rotation = pressure on the medial heel minus pressure on the lateral heel) was the primary risk factor for MTSS. Low aerobic fitness and smoking habit were also important, but were additive risk factors for MTSS. The logistic regression model combining all three risk factors was capable of predicting 96.9% of the non-injured group and 67.5% of the MTSS group with an overall accuracy of 87.7%. **Implications for practice and research (Study 2):** Foot pronation, as measure by heel rotation, is a primary risk factor for MTSS.

Previous studies have shown that gait retraining can change risk factors for injury. The aim of Study 3 was to examine the effectiveness of gait retraining on reducing risk factors associated with MTSS and on reducing the incidence of MTSS during the subsequent 26 week training period. British Infantry recruits (n = 450) volunteered for the study and baseline plantar pressure variables were recorded on the first day of training. Based on the findings of Study 2, those with abnormal foot pronation at baseline (n = 134, age 20.1 ± 2.03 years; height 167 ±1.4 cm; body mass 67 ± 2.4 kg) were randomly allocated to an intervention (n = 83) or control group (n = 83). The intervention group undertook a gait retraining program which included targeted exercises three times a week and biofeedback on risk factors once per week. Both groups continued with the CIC training concurrently. Injury diagnoses over the 26 week training regimen were made by physicians who were blinded to the study. Post-measures of plantar pressure were recorded at 26 weeks. There was a significant reduction in the pronation ($p < 0.001$) and overall difference survival function between MTSS and non-MTSS (Log rank test $X^2 = 6.12$, $p = 0.013$). The absolute risk reduction was 60% in the intervention group. **Implications for practice and research (Study 3):** Gait retraining can reduce risk factors and incidence of MTSS injury.

Based on such positive findings for the prevention of MTSS in Study 3, it was hypothesised that gait retraining may also have potential for the rehabilitation of MTSS. The aim of Study 4 was to examine the effectiveness of a gait retraining on plantar pressure variables, pain intensity and time spent in rehabilitation due to

MTSS. Recruits diagnosed with MTSS but not responding to current treatment were eligible for this study (n = 66, age 20.85 ± 2.03 years; height 167 ±1.4 cm; body mass 67 ± 2.4 kg). The participants were randomly allocated to an intervention (n = 32) or control group (n = 34). In order to overcome the debilitating pain suffered by MTSS patients during exercise, the intervention group received a corticosteroid injection prior to the gait retraining programme. The control group continued with the current rehabilitation programme. There were significant improvements in terms of time to reach peak heel rotation (p<0.001), pain intensity (p<0.001) and positive occupational outcome in the intervention group (p<0.019). **Implications for practice and research (Study 4):** A combined corticosteroid-exercise intervention is beneficial in normalising plantar pressure, reducing rehabilitation times, pain intensity and occupational outcome of MTSS.

Overall implications (Overall Thesis): Gait retraining and proactive management have the potential to reduce the impact of MSK injury in military and for other populations about to undergo an abrupt increase in physical activity.

Chapter1. Literature Review and Planning

1.1. Introduction

Musculoskeletal (MSK) injuries constitute a major socio-economic burden in many countries (Gruhn et al., 1999; Belechri et al., 2001; Conn et al., 2003; Knowles et al., 2007; Brushoj et al., 2008; Hincapie et al., 2008; Jones et al., 2010a; Jones et al., 2010b). Such injuries affect more than 10 million people in the United Kingdom (Arthritis Research UK, 2008) and cost approximately £5.7 billion per year (Health and Safety Executive, 2008a). Furthermore, the problem is not unique to Britain. For example, in Germany it has been reported that MSK injuries are the second most common type of injury (Schneider et al., 2006). MSK injury during military training is a major problem facing the British Army (Etherington et al., 2002; Blacker et al., 2008; Sharma, 2008; Wilkinson et al., 2011).

Military training is a high training load in terms of physical as well as mental parameters as strenuous preparatory training is necessary to cope and work effectively in versatile situations (Bullock et al., 2011). Overuse injuries develop when abruptly increasing both physical and mental stressors levels (Halson et al., 2004; Huovinen et al., 2009; Rudzki et al., 2012). This occurs frequently in a variety of scenarios. This includes people with a sedentary lifestyle taking up exercise to improve health, recreational athletes or talented athletes from lower leagues with challenging aspirations to practice with more advanced-level teams. Similarly, when deconditioned obese people want to increase fitness abruptly or when soldiers are undergoing basic military training. While it is generally recognised that the most

effective way to prevent overuse injuries is to ensure a gradual increase in activity levels, institutions like the army or sports schools have difficulties to accept slow training progressions due to time constraints (Finch, 2006; Brushoj et al., 2008).

Both sports and military personnel alike are exposed to a high intensity and high volume of endurance and strength/power training with the aim to improve performance within an allocated time period. The sports population have the freedom to enjoy food and sleep and they also have the choice to participate in fitness activities. However, the compulsory nature of the military training means that recruits experience physical as well as mental load (Rudzki et al., 2012).

Most tissues in the human body are able to adopt to physical imposed stress (Frost, 1994; Chen et al., 2010). Wolff's law, states that tissue adapts to the level of stress imposed on it, the level of adaptation in a tissue reflects the level of typical loading. Bone adapts by increasing mineralisation and aligning trabecullae in the direction of the imposed stress while muscle tissue increases by cross-sectional area as individual fibres increase in diameter (Wolff, 1986; Frost, 1994). The arrangement of collagen and elastic in tendon and ligament similarly reflects the exposure to tensile loading and is affected by different levels of training (McGinnis, 1999). Controlling the level of imposed stress in various tissues is important during training to avoid injury and facilitate the healing process (Chen et al., 2010). The body's response to micro damage is to initiate remodelling of the tissue. Systematic application of the physiological training zone is a basis of overload principle which involves imposing

tissue loading to purposely exceed loads to the tissue yield threshold in order to cause damage, but allow adequate rest time to facilitate tissue to remodel prior to the next overload training and the mechanism of developing overuse injury is due to mismatch between microscopic damage and remodelling (McGinnis, 1999). Physical stressors may be exceeded due to the abrupt exposure of physical load during training without adequate recovery time (Brushoj et al., 2008).

Additionally, the recruits are exposed to mental stressors which may be due to, for example, the unfamiliar environment, disruption to the working schedule, sleep deprivation due to sleeping in stressful environments such as outdoors or in a group, insufficient food availability (Wilkinson et al., 2008) and a restricted social life (Huovinen et al., 2009; Matos et al., 2011). As a consequence, military populations have a high injury rate compared to sports people (Rudzki et al., 2012). Moreover, recruit populations have an even higher incidence of injury and attrition rate when compared to trained soldiers (Almeida, 1999a; Petersen et al., 2007; Davidson et al., 2008; Rudzki et al., 2012).

In the transition from being a civilian to a combat-ready soldier, recruits undergo an intensive training program which places the body under high levels of stress. The incidence of MSK injury is unsurprisingly high. Moreover, over the last few decades, the general increase in sedentary lifestyle in civilian populations has exacerbated the problem and the British Army find it difficult to train new trainees up to the level required for service without causing MSK injury. Musculoskeletal injury and the

resulting attrition during military training is a well-known problem facing the British Army, as it is in other military and civilian populations (Almeida, 1999a; Almeida et al., 1999b; Gamboa et al., 2008; Health and Safety executive, 2008a; 2008b; Hauret et al., 2010; Knapik et al., 2013a). Approximately 46 to 63% of trainees sustain MSK injuries during CIC training in the British Army (Colclough, 1999; Etherington et al., 2002; Greeves, 2002). Some injuries lead to recruits being medically discharged (MD) (Blacker et al., 2008; Sharma, 2008) and/or voluntarily withdrawing under the category of 'Discharged as of Right' (Rayson et al., 2004). It has been observed that as many as 33% of trainees are back-squadded (back-termed) due to failure to meet training requirements (Wills et al., 2004). In addition, 38% of injured recruits also suffered a secondary injury (Campbell, 2002).

Over the last decade there have been numerous attempts by the British Army to reduce the incidence of injury and attrition due to MSK injury in CIC training (Bilzon, 2003). For example, new selection criteria has been introduced which is more rigorous in terms of fitness and other variables on entry (Carter et al., 2006). In addition, there have also been adjustments made to the CIC training programme (Blacker et al., 2008; Wilkinson et al., 2008). However, unpublished data at ITC shows that the attrition and incidence rate is increasing. The medical discharge rate at ITC is twice as high when compared to other Army training regiments (Blacker et al., 2005; Blacker et al., 2008). Thus, the Army Recruiting and Training Division (ARTD) formerly Army Training and Recruiting Agency (ATRA), has commissioned

this research with the aim of implementing an evidence-based approach to injury reduction and management in the British Army (Appendix B).

1.2. The sequence of injury prevention model.

The sequence of prevention model (Figure I.I) first proposed by van Mechelen et al., (1992) is widely used as a framework on which to build an injury prevention programme (Parkkari et al., 2001; Chalmers, 2002; Hootman, 2007; Brushoj et al., 2008). The first step (Step 1) in this model to identify the size of the problem in that particular organisation (van Mechelen et al., 1992; Caine et al., 1996; Willems, 2004). Once the size of the problem has been established then risk factors for injury (Fletcher et al., 1996; Jones et al., 1999; Jones et al., 2010a; Jones et al., 2010b), either by review of the existing literature or by new research can commence (MRC, 2000) (Step 2). Once risk factors are identified, those which could logically be causal factors, which could be manipulated to reduce risk, and which account for a clinically significant proportion of total risk can be more closely investigated for preventive potential (Fletcher et al., 1996; Jones et al., 1999; Pope, 2002b). This point the way to the developing preventive strategies (Step 3), which involves assessing the effect of various manipulations on incidence of injury, and assessing the acceptability of the interventions to participants and intervention providers (Fletcher et al.,1996; Engebretsen et al., 2005). This step allows to assess the potential that exists to affect risk factors through viable means. Again, this phase might be addressed by review of the existing literature or by new research (MRC, 2000). In the fourth and final phase

(Step 4), once promising preventive strategies are developed, they should be trialled in various settings to confirm efficacy and compliance by replication (Gorsky et al., 1995). The fourth step fulfils the requirements of the context-specific validation process, mentioned above and helps organisations and individuals to accept the finding and to implement their findings to reduce injury (Finch, 2006; Hootman, 2007; Jones et al., 2010a).

1.2.1. Step 1: Establishing the injury problem

82,000 working days lost each year in the British Army are related to MSK injuries (DGAMS, 1998). The total cost for time loss is likely to be in the order of £16 million a year (Jones et al., 2001). The British Army medical services lower limb injury study estimated that training recruits, who were subsequently discharged from the army due to injury, wasted 39,060 training days and cost £585,900 per annum. In addition, soldiers who, successfully completed training, were responsible for a further 43,900 training days lost at a cost of £658,560 per annum (Harwood et al., 1989).

The incidence of MSK injuries ranges from 20% (Franklyn-Miller et al., 2011) to 50% in military persnnel (Kaufman et al., 2000; Sharma et al., 2011b). Between 46 and 49% of incidence of MSK injuries have been reported during phase 1 British Army recruit training (Etherington et al., 2002; Greeves, 2002). Further research also found an average incidence of injury of 36.8% in military male UK personnel (Neely, 1997) and other studies on the phase 1 training in British Army recruits reported 63% of recruits sustained some form of MSK injury during training (Colclough, 1999). Some

recruits successfully recovered from these injuries but 38% of them suffered a second injury (Campbell, 2002; Etherington et al., 2002).

Dropout rates during recruit training have been reported to be 14% in the Australian army (Pope et al., 1999a), 6% in the U.S. Air Force (Talcott et al., 1999), 13% in the U.S. Army (Knapik, et al., 2001a), 4.6% and 16.3% male and female respectively in the U.S. military police (Knapik, et al., 2013b) and 10% in the U.S. Marine Corps (Reis et al., 2007). At ITC approximately one-third of the recruits were discharged prior to completion of the recruit training (Sharma et al., 2011b) and the medical discharge rate at ITC was 8% (Blacker et al., 2005; Blacker et al., 2008). Recruits who completed recruit training when compared to drop outs, had lower injury rates and higher physical performance (Talcott et al., 1999; Knapik et al., 2001a).

The majority of MSK injuries in military populations are overuse injuries and these include back pain, MTSS, stress fracture, anterior knee pain and patellofemoral pain, iliotibial band syndrome, achilles tendinopathy and planter fasciitis (Almeida, 1999a; Almeida et al., 1999b; Shaffer et al., 1999; Brushoj et al., 2008; Coppack et al., 2011; Franklyn-Miller et al., 2011). For a more detailed description of these injuries the reader is directed to Appendix D. In a previous study it was found that 72% of medical discharges were due to MSK injuries to the lower limb (Sharma, 2008). Most of these injuries require medical care and rehabilitation with emphasis on returning to training as soon as possible with the highest level of functioning.

Treatment of these injuries can be difficult, expensive and time-consuming (Greeves, 2001; Parkkari et al., 2001; Yates et al.,2004) and has the possibility to temporarily set back training (Wills et al., 2004) or result in medical discharge (Blacker et al., 2008). The impact of injuries among military recruits are; loss of training time, a reduction in population size, delays to complete basic training and decreased military readiness (Cowan et al., 1996; Jones et al., 2010a; Ruscio et al., 2010). The consequences of MSK injury clearly incur a substantial human and financial burden to the British Army and individual recruits, as well the British taxpayer.

1.2.2. Step 2: Establishing the aetiology and mechanisms of injury

An important approach aiming at reducing injury and attrition is to identify the risk factors and initiate a training programme which can alter or even eliminate such risk factors (Pope, 2002b). Such an approach is advocated for acute lower limb injuries (Pope, 2002b; Olsen et al., 2005) and recommended to prevent overuse injury (Parkkari et al., 2001).

Training injury risk factors can be divided into extrinsic and intrinsic factors (Neely, 1998; Murphy, et al., 2003). It is widely accepted that risk factors for injury are specific to the population being investigated and, therefore, risk factors for injuries during recruit training may not be identical between different military organisations since differences exsist in terms of training regimes and study populations (Caine et al., 1996). There is a diverse mix of recruit characteristics in most military populations and all initial military training requires high physical demands (Knapik et al., 2011).

However, similarities in injury risk factors between military populations are to be expected (Almeida, 1999a). The following section discusses extrinsic and intrinsic risk factors found within the literature and examines what might be done to amend these factors, hence improve injury prevention.

1.3.2.1. Extrinsic risk factors

Extrinsic risk factors are external to the participants and include the training programme, terrain, shoes, equipment and environmental conditions in which the recruits participate (Brukner et al., 1999; Peterson et al., 2000; Pegrum et al., 2012). The majority of investigations into risk factors for sports and military training injury have been carried out on extrinsic risk factors (Neely 1998; Pope, 2002b; Milgrom et al., 2003; Murphyet al., 2003). A study by Jones et al., (1994) found that the risk of injury was increased relative to an increased running distance. An average of 11 miles per week experienced 27% more lower extremity injury than those running 5 mile per week during military training. Similar findings were found with civilian distance runners which suggested greater running mileage per week increased the risk of running injury (Koplan et al., 1982). There is a general agreement among researchers that injury incidence is greater during competition. Environmental conditions, such as terrain, climate and correct equipment, also play a major role in the outcome of an injury (Taimela et al., 1990a). These factors have been extensively reported in the literature (Pegrum et al., 2012). Training regimen and training error including mileage (Harrast et al., 2010), number of training cycles (Edwards et

al.,2008), inadequate recovery/training with fatigued muscles (Ross et al.,2002; Milgrom et al., 2007), running pace (Taunton et al., 2002), downhill running (Ross et al., 2002) and harder training surface (Milgrom et al., 2003) are also reported risk factors for overuse injuries including medial tibial stress syndrome, tibia stress fracture and anterior knee pain (for more details on injury types see Appendix D). Training courses vary greatly from regiment to regiment and country to country (Almeida, 1999a; Jones et al., 1993a; Jones et al., 1993b; Rayson et al., 2003; Wilkinson et al., 2008; Angioi et al., 2009). This makes it difficult to generalise the injury rate due to the variability of intensity and volume of training across military populations.

The evidence for seasonal variation and MSK injury in the extant literature is mixed (Knapik et al., 2002; Pope, 2002a). In the Australian army the incidence of injury did not significantly vary throughout the year (Pope, 2002a). However, Knapik et al., (2002) showed seasonal variations in the incidence of injury in American recruits. After adjustment for physical characteristics the risk of males and females sustaining an injury or time loss injury were 2.0 and 1.4 times greater, respectively, in the summer than in the autumn. The results also showed a positive linear correlation between maximal daily temperature and injury incidence. The researchers suggested that the heat may increase the risk of injury through several mechanisms; exercise in the heat compared to cool environments results in dehydration, increased perceived exertion, movement of blood from the muscles to the skin and a higher core (rectal) temperature which will put more stress on the cardiovascular system leading to more

rapid fatigue (Blacker et al., 2005). In addition, exercise in the heat increases metabolic stress by increasing muscle glycogenolysis, liver glucose output and lactate accumulation. The increased cardiovascular and metabolic stress may make injuries more likely due to reduced muscle blood flow which may exacerbate minor injuries due to a reduction in substrates and blood flow (muscle ischemia). Muscle damage impairs glycogen repletion and in conditions of heat this would make the onset of fatigue more rapid in subsequent bouts of exercise, this may lead to traumatic or overuse injuries due to changes in gait and a reduction of the muscle's ability to absorb eccentric force (Brukner et al., 1999; Yates et al., 2004). The authors (Knapik et al., 2002) also suggested that during the summer months the recruits had more rest breaks during the day due to the higher temperatures and the longer days. However, during the autumn when there is less daylight and the temperature is lower, the intensity of training is increased to complete the same volume of training in the day.

1.3.2.2. Intrinsic risk factors

There are a number of intrinsic risk factors which have been associated with injury in military and athletic populations which have been reported in the literature (Figure 1.4). Among them, some are modifiable, while others are not. There is some agreement among researchers with regard to a few intrinsic risk factors; however, considerable controversy remains (Beynnon et al., 2002; Murphy et al., 2003).

Previous Injury: One of the most important and well-established intrinsic risk factors for future injury of the lower extremity is a history of an injury and inadequate rehabilitation (Ekstrand et al., 1990; Marshall et al., 2003; Plisky et al., 2007; Reis et al., 2007; Hubbard et al., 2009). The impact of previous injury before commencing military training has been widely investigated as a risk factor for injury (Etherington et al., 2002; Reis et al., 2007; Knapik et al., 2013a; Knapik et al., 2013b). In separate reviews of the literature Neely (1998) and Kaufman et al., (2000) associated having previous injuries prior to beginning military training with an increased risk of injury during training.
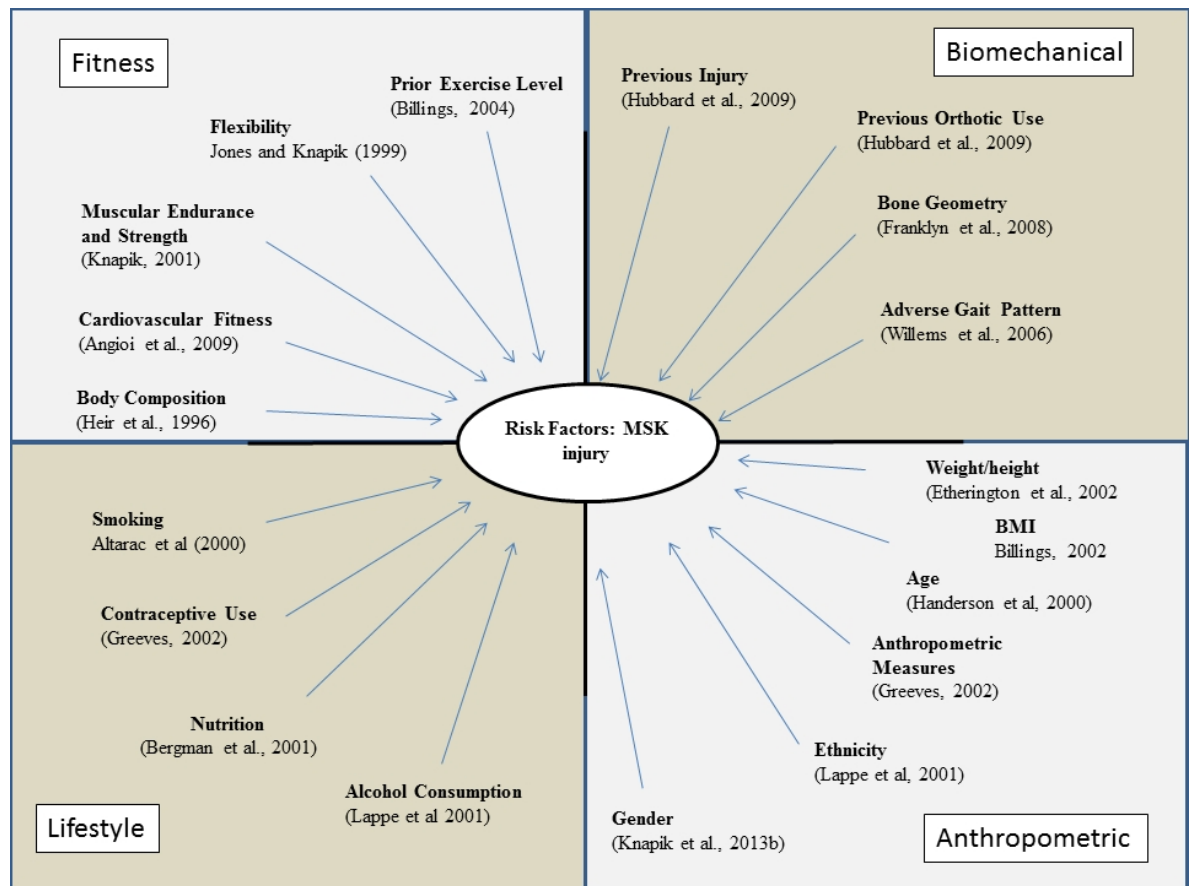
Figure 1.4. The possible risk factors in the development of MSK injuries.

Age: Several studies showed an increased incidence of injury in older athletes (Ostenberg et al., 2000; Knapik et al., 2001a; Knapik et al., 2001b; Knapik et al., 2013a), another found an increased incidence of injury in younger athletes (Peterson et al., 2000; Wilkinson et al., 2011) and others found no association between age and injury (Bennell et al. 1996). Other studies on recruits undertaking the 14 week recruit training found no association between age and risk of injury (Colclough, 1999; Rauh, 2006; Blacker et al., 2008). A study into phase 1 recruits training in the British Army,

Etherington et al., (2002) ranked age as the 6th highest impact ratio of 24 risk factors in predicting musculoskeletal injury in recruits. In contrast, research in the American Army has shown recruits undertaking advanced individual training to be at greater risk of injury over the age of 25 years (Henderson et al., 2000) and older females are more susceptible to stress fracture during American recruit training (Lappe et al., 2001). These findings are supported by data on Norwegian recruits which show risk of injury to increase over the age of 22 years (Heir et al., 1997). Further support of differences in injury rates related to age are found in a study on 1317 Australian recruits aged 17 to 35 years which showed that injury was more likely in older recruits (Pope, 2002a). Another prospective study assessed risk factors for discharge from basic training among 2,137 male Marine Corps recruits found older age (>23 years) is a risk factor to development of stress fracture and other lower limb injury (Reis et al., 2007).

Gender: The relation between gender and MSK injury in military and civilian athletes is also mixed in the existing literature. Some researchers have found females to be at increased risk, (Hosea et al., 2000; Knapik et al., 2001b; Yates et al., 2004; Knapik et al., 2013a; Knapik et al., 2013b) others found no relationship (Bennell et al., 1996; Beynnonet al., 2001). Female recruits have a greater risk of injury or illness (Neely, 1998; Almeida et al 1999b; Billings, 2002, Yates et al., 2004) during military training. Gemmell (2002) reported female recruits are four times more likely to be discharged from the British Army due to chronic injuries of the lower back and lower-limb than

their male counterpart and overall medical discharge (MD) rates for recruits were 3.1% and 9.3% for males and females, respectively (Folkes, 2004).

Ethnicity: There are very few reported differences in injury rates between ethnic groups despite ethnicity being varied amongst military populations (Lappe et al., 2001). A study of females undertaking American basic training (Lappe et al., 2001) showed black women to be less likely to sustain fractures than whites and other races. Another prospective study assessed risk factors for discharge from Marine basic training which showed that non-Hispanics were also more likely to be discharged (Reis et al., 2007). However, another study by Rauh et al., (2006) found no association with lower-extremity stress fracture or other lower limb overuse injury and race/ethnicity (Knapik et al., 2013a).

Lifestyle: In terms of smoking, Etherington et al., (2002) ranked a smoking habit as the highest impact ratio factor, in the prediction of musculoskeletal injuries in recruits undertaking phase 1 training in the British Army. Smoking has also been positively associated with an increased risk of injury in American military populations (Jones et al., 1999; Gilchrist et al., 2000; Kaufman et al., 2000; Knapik et al., 2001b; Knapik et al., 2013a) and British Military populations (Munnoch et al., 2007). The results also showed that recruits who were medically discharged smoked significantly more cigarettes per day than recruits who successfully completed training. In contrast, (Greeves, 2002) the results showed no association between smoking and risk of musculoskeletal injury. Lappe et al., (2001) showed stress fractures were more likely

during American Basic Training if the recruits had reported current or past smoking. These findings are further supported by Heir et al., (1997) when looking at Norwegian recruits populations who had smoked more than 10 cigarettes per day they found recruits had a greater risk of injury which further supported another American study (Shaffer et al., 2006). Smoking is thought to increase the incidence of injury. Firstly, by a reduction in aerobic fitness as well as endurance capacity (Marti et al., 1988), secondly, by a decreased bone mineral density (Kanis et al., 2005), and thirdly, by a reduction in the effectiveness of tissue healing (Jorgensen et al., 1998; Wong et al., 2004; Castillo et al., 2005).

Dietary Intake: The potential link between dietary intake and injury risk was also reported in the literature (Tenforde et al., 2010). In a review of the literature, Bergman et al., (2001) identified restricted dietary intake as a risk factor of injury. Dietary iron and zinc content appeared to be important in determining the susceptibility to overuse injury, these minerals are lacking in both a vegetarian diet and ration packs (King et al., 1993). During strenuous physical activity, energy expenditure and demand increase significantly and energy levels must be matched in order to maintain activity levels (Wilkinson et al., 2008). The recommended dietary consumption levels are 60% carbohydrates, 25% fat and 15% protein for individuals who are involved in strenuous physical activity (Harrison et al., 2000). It has been noted that energy requirements from dietary intake were not met during recruit training (Casey, 2001; Raysonet al., 2002; Wilkinson et al., 2008). There is limited research investigating injury rates and alcohol consumption in military populations.

Lappe et al., (2001) found that American female recruits who consumed more than 10 drinks per week were more susceptible to stress fractures than those who consumed less than 10 drinks per week. Etherington et al., (2002) ranked the impact ratio of alcohol consumption a modest 12th out of 24 factors used to predict musculoskeletal injury. In contrast, others (Greeves, 2002; Henderson et al., 2000) found no association between alcohol consumption and risk of musculoskeletal injury.

Cardiovascular Fitness: There are several studies which show an association between physiological profiles including cardiovascular fitness and aerobic fitness, muscular strength, and muscular endurance characteristics and injury (Jones et al., 1992; Jones et al., 1993b; Hopper et al., 1995; Bennell et al., 2004; Blacker et al., 2008). Cardiovascular fitness assessed by treadmill tests, distance run times or shuttle run scores is most frequently listed as a risk factor for injury, where recruits with poor physical fitness experience a high incidence of injury and are often back-squadded (Heir et al., 1996; Harwoodet al., 1999;Jones et al.,1999; Colclough, 1999;Knapik et al., 2001b; Gemmell, 2002; Angioi et al., 2009). Colclough (1999) also reported an association between low cardiovascular fitness and a higher incidence of injury in recruits. Recruits had a 28% higher incidence of injury if they scored a time below 07:30 mins on the multistage fitness test, whereas for those who scored above 10:39 mins the injury incidence was reduced to 3%. Further support for these findings is provided by Greeves (2002) who showed in a group of females undertaking recruit training that injured recruits had attained a slower 2.4 km run time than uninjured recruits. A study on Officer Cadets undertaking the Commissioning Course at the

Royal Military Academy Sandhurst found initial levels of aerobic fitness to be the only significant risk factor for injury during training (Rayson et al.,1997; Harwood et al., 1999). Similarly, a study on 1641 recruits undertaking Royal Navy basic training found 50% of the incidence rate in the least fit group compared to 10% incidence rate for the fittest group (Allsopp et al., 2003). However, another UK study did not support the other findings and concluded that the 1.5 mile timed-run test was a poor predictor of musculoskeletal injuries (Etherington et al., 2002).

The relationship between muscular endurance scores and risk of injury has also been investigated in males and females undertaking recruit training in the American army. The ability to complete fewer push-ups and fewer sit-ups was associated with a higher risk of injury (Knapik et al., 2001b). Colclough (1999) found the risk of injury during recruit training was negatively correlated with pull-up scores and Allsopp et al., (2003) showed that press-ups scores were negatively associated with the incidence of injury. Several studies have shown that recruits who had a sedentary and /or less active lifestyle prior recruit training were at a greater risk of injury during training (Jones et al., 1999; Knapik et al., 2001a; Knapik et al., 2001b; Kaufmanet al., 2000; Heir et al., 1997; Reis et al., 2007; Knapik et al., 2013a). In addition, no experience in competitive exercise prior to basic training increased the risk of discharge by 45% (Reis et al., 2007). The risk of injury is amplified as recruits move from a low physical activity (sedentary lifestyle) to high physical activity during military training. Recruits with a self reported poor or fair fitness level prior to basic training were nearly three times more likely to be discharged during training (Reis et al., 2007). However,

Billings et al., (2002) correlated high exercise levels prior to beginning basic training as a risk factor for higher incidence of injury and suggested curvilinear association between exercise levels and the risk of injury. However, the author suggested that this trend may be due to intercollegiate athletes wanting to continue their sports training into later life, and so seeking rehabilitation assistance more readily, and therefore, more frequently reporting their injuries.

Psycho-social Attributes: The psycho-social attributes of British Army recruits can be assessed through the candidates' assessments and interviews at recruit selection which provide scores for a number of personality and psychological profiles including the General Trainability Index, Personal Qualities Assessment Profile and a sociability score (Blacker et al., 2008). Etherington et al., (2002) ranked Personal Qualities Assessment Profile as the 5th highest impact ratio factor and General Trainability Index as the 11th highest impact ratio factor (of 24) in the prediction of MSK injuries undertaking recruit training. They also showed that injured recruits scored significantly lower on their Personal Qualities Assessment Profile than the uninjured recruits. Similarly, a study by Gregg et al., (2002) found that traumatic injury occurrence is influenced by tension, anxiety and disturbance in sleep habits. Blacker et al., (2008) found that General Trainability Index is a significant factor in the risk of injury and medical discharge but not the Personal Qualities Assessment Profile. There is some evidence to suggest that recruits experience not only a physical training load but also mental stressors for example: lack of support, lack of motivation (Meehan et al., 2002), daily pressure and external expectations (Matos et al.,2011). These also

contribute to the development of injury and some recruits feel that they are unable to continue training and execute'Discharged as of Right' (Dixon et al., 2003).

Anthropometrics: Anthropometric and body composition measurements including body mass, height, body mass index (BMI) and percentage body fat also show contradictory findings (Larsson, et al., 2009; Knapik et al., 2013a). Rayson et al., (2003) found no relationship between BMI, percentage body fat or body mass with training outcome. Similarly, Colclough's (1999) study of recruits during training also found no relationship between body mass or BMI and the incidence of injury. A study by Etherington et al., (2002) found height and weight to be weak predictors of injury, ranking the impact ratios as 14th and 15th out of 24, respectively. Similarly, Pope (2002a) found no association between weight, height and BMI and the risk of injury in Australian recruits. However, another study showed BMI was associated with a higher incidence of injury (Heir et al., 1996; Henderson et al., 2000; Billings, 2002; Allsopp et al., 2003; Blacker et al., 2008).

Bone geometry: Bone geometry studies also found contradictory findings (e.g. Magnusson et al., 2001; Ozgurbuz et al., 2011). Bone geometry, especially cross-sectional and section modules, are found to be risk factors of MTSS and stress fracture development (Franklyn et al., 2008). Similarly, another study found that tibial bone density in the pain region was lower in participants with a history of medial tibial stress syndrome (MTSS) (Magnusson et al., 2001). However, another study investigated tibial bone density in athletes with a history of MTSS and a total of 11

athletes (7 males, 4 females) diagnosed with medial tibial stress syndrome were compared with a control group consisting of 11 regularly exercising individuals (7 males, 4 females). Tibial, femoral and vertebral bone densities were measured using dual energy x-ray absorptiometry. No differences were found in the tibial, femoral and vertebral bone densities between the groups (Ozgurbuz et al., 2011).

Biomechanics-based variables: Many risk factors, gait related and biomechanical that have been identified, although little conclusive evidence has been found in terms of injury prevention to date (Johnston et al., 2006; Franklyn-Miller et al., 2011). There seems to be limited research associating biomechanics and the risk of injury during military training despite the fact that a connection is frequently seen in clinical practice,where higher injury rates appear to be linked with poor biomechanics (Viitasalo et al.,1983; Messier et al., 1988; Wills et al., 2004; Willson et al., 2005; Willems et al., 2006; Willemset al., 2007;Craig, 2008a;Craig, 2008b; Willson et al., 2008). Research has found that there is a link between biomechanics and development of lower limb injury (Yates et al., 2004).

Biomechanics concerning abnormal foot and hip rotation have been implicated in numerous functional kinetic changes which result in overuse injuries including lower back, hip, knee, lower leg, ankle and foot (Knutzen et al.,1994; Bird et al., 1999; Abboud, 2002; Wills et al., 2004; Harradine et al., 2006). The proposed mechanism of injury is through the propagation of abnormal kinetics and vice versa (Bellchamber et al., 2000). However, prospective studies on foot pronation and lower limb overuse

injury have mixed results in both military and civilian populations (Kaufman et al., 1999; Willems et al., 2006; Willems et al., 2007; Hesar et al., 2009). A recent study by Hesar et al., (2009) investigated prospectively gait-related risk factors for lower leg overuse injury utilising plantar pressure measurements in healthy subjects during running. Logistic regression analysis revealed that a less pronated heel strike and a more laterally directed roll-off can be considered as risk factors for developing lower limb overuse injury. Muscle imbalance especially between the inversion and eversion muscles is also a risk factor in developing MTSS (Yuksel et al., 2011). Similarly, altered neuromuscular control of gluteus medius and lateral gastrocnemius were also risk factors for exercise related leg pain (Franettovich et al., 2010).

1.2.3. Step 3: Introducing preventative measures

Given the widespread problem asscociated with MSK injury in military populations, it is not surprising that there have been numerous interventions designed to reduce the impact of MSK injury on military training. Exercise interventions including prehabilitation, rehabilitation and drugs have all been attempted. Preventative strategies can include screening, health promotion activity, and exercise interventions (Buschbacher et al., 2009). These interventions can be themed into four main groups: lifestyle, pharmacological, surgical and rehabilitation (Akesson et al., 2007). Intereventions include, movement screening, rehabilitation exercises, rest and the administering of drugs to promote the healing of soft-tissues (Kesson et al., 1998).

1.3.3.1. Screening at selection

The British Army currently undertakes a rudimentary process of screening when assessing potential recruits. Specifically, in order to qualify for military training the potential recruits must demonstrate a reasonable level of fitness and perform reasonably well on psycho-social tests. The fitness element involves assessment of muscular endurance and aerobic fitness. The battery of selection tests involves; muscular endurance, physical fitness and psycho-social attributes (Blacker et al., 2008) and these tests are organised at the Recruit Selection Centres in the British Army. Muscular endurance is measured by press-ups and sit-ups, back extension strength, static lift strength and dynamic lift strength. Aerobic fitness is measured by the time taken to complete a 1.5 mile (Blacker et al., 2008). The psycho-social attributes are assessed from the candidate's assessments and interviews at recruit selection which provide scores for a number of personality and psycho-social profiles including the General Trainability Index, Personal Qualities Assessment Profile and a sociability score (Etherington et al., 2002). However, screening on the basis of these tests has been questioned and the incidence of MSK injuries has not been found to correlate significantly with 1.5 mile run times (Rayson et al., 2002), number of push-ups (Knapik et al., 2001a; Knapik et al., 2001b) or the number of sit-ups (Knapik et al., 2001b) that the recruits can perform. Consequently, several researchers have questioned the effectiveness of current protocols in terms of their effectiveness in preventing injuries.

In the literature on sports, more rigorous screening tests have been developed to identify those at risk of developing specific MSK injuries (Gabbe et al., 2004b; Barter, 2010). Scoring systems based on the performance of an athlete in a variety of tests such as physical activity tests, functional assessment and questionnaires have been created (Cook et al., 2006a; Cook et al., 2006a; Comerford, 2007; Kiesel, et al., 2007; Dawson et al., 2009). One of the more popular is the extended Nordic musculoskeletal health screening questionnaire which involves the assessment of nine regions of the body. Each score is used to identify possible musculoskeletal pain and consequential problems (Dawson et al., 2009). It has been suggested that this screening tool, in combination with functional assessment scoring, helps to diagnose a range of MSK problems (Barter, 2010). Another example is the Revels model which provides a screening test for low back pain and enables identification of any change in pre and post assessment in term of pain intensity (Revel et al., 1998; Laslett et al., 2004). Other screening methods used for sporting populations include psychological response to injury and pain avoidance (Westman et al., 2008), functional assessment, strength and neuromuscular control, misalignment and functional movement screen (Barter, 2010; Kiesel et al., 2007).

Other tests which include the assessment of movements and neuromuscular control utilise a variety of movements such as single leg hop, one-leg vertical jump, timed hop, figure of eight running, side stepping (Lephart et al., 1991) and star excursion test (Plisky et al., 2006). The scores achieved are an objective assessment of function and challenge of dynamic stability during landing and deceleration (Bonci,

1999) and it is argued that these tests give an indication of the force of distribution through the body. Another test is the Gait Arm Legs and Spine (GALS) which is used to identify musculoskeletal abnormalities (Beattie et al., 2008). The test is able to classify normal or abnormal movements, based on the perceived gait cycle, movements of the arm, legs, as well as spine. The scores also include questionnaires on whether the participants encounter any pain or stiffness in their muscles or joints. Unfortunately these tests involves subjective measures and their reliability has been questioned (Beattie et al., 2008).

A popular technique currently in operation in several sport institutes is a functional movement screening test (Cook et al., 2006a). The test enables the user to quantify muscle strength, flexibility, range of motion, coordination, balance, and proprioception by assessing seven fundamental movement patterns (Cook et al., 2006a). The seven movements are: 1) the deep squat which assesses bilateral, symmetrical, and functional mobility of the hips, knees and ankles, 2) the hurdle step which examines the body's stride mechanics during the asymmetrical pattern of a stepping motion, 3) the in-line lunge which assesses hip and trunk mobility and stability, quadriceps flexibility, and ankle and knee stability, 4) shoulder mobility which assesses bilateral shoulder range of motion, scapular mobility, and thoracic spine extension, 5) the active straight leg raise which determines active hamstring and gastroc-soleus flexibility while maintaining a stable pelvis, 6) the trunk stability push-up which examines trunk stability while a symmetrical upper-extremity motion is performed, and 7) the rotation stability test which assesses multi-plane trunk stability while the upper

and lower extremities are in combined motion. A score between (0-3) is given for each of the seven movement patterns with a score of 3 considered normal. The summation of the scores from the seven movement patterns is considered to quantify mobility and stability and its limitations and asymmetries. It has been suggested that this type of test enables the user to identify movement pattern dysfunction which may predict likelihood of sustaining a musculoskeletal injury (Cook et al., 2006a). In addition, it has been suggested that the results of these tests enable the practitioner to prescribe corrective treatment through corrective exercise programmes. Recently, it has been shown that functional movement screening (Kiesel et al., 2007) can be used to predict injury in professional footballers. Specifically, they found that a score of below 14 is an identifiable risk factor. However, the reliability of this technique has been assessed between raters using video recordings only and at present there is no reliability study on real-time scoring of the functional movement screening.

Gait analysis, the quantification of human gait using biomechanics equipment is believed to provide more objective measures of movement (Boakes et al., 2006). Gait involves a functional integration of all skeletal, muscular and neurological components that work together while performing activities (McGinnis, 1999; Brukner et al., 2012).

Specifically, the important features of the athlete's gait cycle are quantified using video analysis, force plate or pressure plates (Franklyn-Miller et al., 2011). These gait analysis methods are used to screen for prevention of injury by identifying where the forces travel during locomotion and their possible impact (Paul, 2005). These

techniques enable identification of potential problems and the results can be used to inform any potential intervention. For example, screening tests using plantar pressure data have been successful in the identification of those at risk of injury and also enable the prescription of gait correcting exercises or orthotic insoles (Franklyn-Miller et al., 2011). Notably, in a recent study (Franklyn-Miller et al., 2011), the dynamic plantar pressure distributions of 400 military officer trainees were analysed. Those considered at risk were issued with gait-modifying orthotic insoles which resulted in a significant reduction in the incidence of injury. A similar, but much simpler test, currently in operation is the navicular drop test used to assess over-pronation of the foot (Buchanan et al., 2005). However, this test has been shown to have low specificity and sensitivity (Bonci, 1999) and this test was found to be unable to predict values on MTSS (Hubbard et al., 2009) presumably because of the large differences occurring in foot mechanics in the static tests compared with the dynamic conditions.

1.3.3.2. Exercise interventions

The summary of published papers are presented in Appendix F. Exercise intervention regimes include stretching (Hartig et al., 1999), multi-intervention programme and balance (Emery et al., 2005). Stretching may decrease injury by direct and indirect mechanisms. In direct mechanisms, stretching decreases muscle stiffness due to a change in passive viscoelatic properties while indirect mechanisms work because stretching decreases muscle stiffness through reflex muscle inhibition and subsequent changes in viscoelastic properties by decreasing actin-myosin cross-

bridges (Shrier, 2007). Muscles may have become stiff as a result of injury, over-activity and inactivity, stretching may decrease musculotendinous injury (Sharma et al., 2004b), minimise muscle soreness and strain as well as improving performance (Brukner et al., 2007). However, studies on the military and athletic populations, have shown contradictory findings (Hartig et al., 1999; Pope et al., 2000).

The effectiveness of stretching exercises in the prevention of MSK injuries has been evaluated in many studies (Andrishet al., 1974; Hartig et al., 1999; Pope et al., 2000; Liuet al., 2008; Coppack et al., 2011). In general, systematic stretching programmes reduce the overall injury risk (Yeung et al., 2011). The contradictory results could be due to the varied stretching protocols amongst the studies. For example, some studies use the effect of gastrocnemius and soleus stretching exercises (Andrish et al., 1974; Liu et al., 2008) whilst in other studies only hamstring muscles were involved in the stretching study (Hartig et al., 1999).

Other exercises are prevention programmes that include multi-intervention exercise programmes with an emphasis on lower-limb muscle strength, coordination and flexibility (conditioning exercises). A study of Army recruits undergoing 12 weeks of military training showed that this intervention did not affect the injury incidence rate (Brushoj et al., 2008).

Another study (Coppack et al., 2011) conducted in British Army phase 1 recruits training, undergoing 14 weeks training, found that stretching and strengthening exercises reduced anterior knee pain incidence. These exercises comprised warm-up

(closed kinetic chain, quadriceps and gluteal strengthening exercises) and four stretching exercises for quadriceps, hamstrings, gastrocnemious and iliotibial band.

In a study Emery et al., (2005) on balance exercises involving 114 physical education students, a wobble board was used for balance training. The author found a significantly lower incidence of all sports injuries in the intervention group compared to the control. In addition, static and dynamic balance ability were also improved in the intervention groups (Emery et al., 2005). Another single leg balance and balance board training intervention study showed that those exercises significantly reduced ankle sprain incidence in the intervention group compared with the control group (McGuine, 2006). Participants of this study were 765 basketball and soccer players and the intervention programme was use of a single leg stance and balance board each for 10 minutes. This was conducted five times a week for four weeks before the start of the season and then reduced to three times a week during the season.

In a separate study, Emery et al., (2007) found significant reductions in the number of acute sports injuries induced by balance training compared to the control group. Further subgroup analyses showed non-significant effects with respect to 1) all injury 2) injuries of the lower extremity and 3) ankle injuries. Furthermore, no significant group differences in the severity of injuries were reported. Gilchrist et al., (2008) used multi-intervention training programmes including running exercises, stretching, strengthening and plyometric agilities within an in-season warm-up programme, each for 20 minutes three times a week for 12 weeks. They found significant reductions in

the incidence of anterior cruciate ligament (ACL) injuries during practice. No ACL injuries occurred in the intervention group compared to six in the control group. Among athletes with a history of previous ACL injury, no intervention athletes suffered a noncontact ACL injury compared with four in the control group. No significant group differences were found in athletes without previous ACL injuries.

Olsen et al., (2005) investigated the effects of a training programme which included running exercises, cutting and landing technique training, balance training, strength and power training on the outcome of injury incidence. They found significantly fewer injured athletes in the intervention group for a range of injuries. Furthermore, they argued that the severity of the injuries due to the training programme was reduced. Pasanen et al., (2008) implemented neuromuscular training when investigating the risk of leg injury in female floorball players. A neuromuscular training programme was targeted to enhance players' motor skills and body control, as well as to activate and prepare their neuromuscular system for sports specific manoeuvres. The programmes use of multi-dimensional exercises including: running techniques, balance and body control, plyometrics, and strengthening exercises. Results demonstrated that the overall risk of leg injury was significantly lower in the intervention group. Moreover, significantly fewer acute leg injuries occurred in the intervention group compared to the control group. However, when injuries were analysed by location, only ankle injuries were significantly reduced. No significant differences were found between the groups for acute knee injuries.

In contrast, Steffen et al., (2008) utilised exercises for core stability, lower extremity strength, neuromuscular control and agility. They were used during a 15-min warm-up program for female football players over an 8-month season. The study found no differences in both the overall injury rate and/or in any type of injury incidence between the intervention and the control groups (Steffen et al., 2008).

Previous studies on neuromuscular training for sports injury prevention show that balance training was effective in reducing the risk of ankle sprain injuries by 36%. Individual studies found that balance exercises were more effective in athletes with a history of sports injury than in those without injury (Emery et al., 2005; Knowles et al., 2007). However, there was no evidence that balance training decreased the incidence of knee ligament injuries or upper extremity injuries or that it influenced the severity of injuries (Emery et al., 2007).

Some trials contained more than one intervention arm: (Andrish et al., 1974) compared interventions from several different categories with a control group, while other trials compared two interventions from within the same category with a control group (Withnall et al., 2006; Van Tiggelen et al., 2009). Appendix F shows that the studies have methodological variations including the duration of intervention range from six to 20 weeks, comprising single intervention to multi-intervention programmes and intensity of training schedules.

Prevention intervention in terms of a modification of the training programme, a graduated running programme in the intervention group, to examine the prevention of

shin splints in one study was utilised and no evidence was found to reduce injury rate (Andrish et al., 1974). While further research evaluated the prevalence of running-related injuries in novice runners training for a four-mile race, by comparing a graded training programme that followed the 10% training rule for 13 weeks with a standard training programme for eight weeks (Buist et al., 2008). No reduction in injury rate was observed.

1.3.3.3. Use of orthoses

Foot orthosis is the term that has been used to describe any type of shoe insert designed to alter the function of the foot and lower limb. They are commonly prescribed for the prevention and treatment of MSK injury (Landorf et al., 2007). It has been suggested that orthotics alter the biomechanical effects by realigning the skeletal structure and altering movement patterns of the foot by means of measuring kinematic, kinetic or plantar pressure or electromyographic (EMG) assessment (Landorf et al., 2007). However, the evidence is contradictory in terms of the relationship between foot posture and injury as well as for the prevention of injury (Withnall et al., 2006; Landforf et al., 2007; Franklyn-Miller et al., 2011). A study by Andrish et al., (1974) did not reduce shin pain injury in 1797 participants during Naval Academy training. Finestone et al., (2004) with 417 participants in a military population found no significant difference in the injury rate between groups. Other studies (Bensel et al., 1986; Gardner et al., 1988; Sherman et al., 1996; Withnall et al., 2006) compared the effect of shock-absorbing insoles versus non shock-

absorbing in-soles, but did not show any significant reduction in the rate of lower limb injuries.

Withnall et al., (2006) investigated subjects from the British Royal Air Force using three different types of insole but found no significant difference between the groups. Modified foot wear and sock trials in military personnel, evaluated the effectiveness of prescribing running shoes based on foot shape for the Army (Knapik et al., 2009) and Air Force (Knapik et al., 2010). Recruits underwent a nine week training programme but no difference was found for injury rates between groups. Another study of 130 participants (Van Tiggelen et al., 2009) evaluated the effects of a padded polyester sock against the use of double socks compared with the standard issue sock for preventing overuse injuries in army recruits, they found no significant difference in lower limb soft-tissue injuries.

A study conducted by Schwellnus et al., (1990) on South African military recruits during a 9 weeks training period, found that the shock absorbing orthotic insole significantly reduced lower leg overuse injury and tibial stress syndrome in the intervention group. Similarly, a study by Fauno et al., (1993) on soccer referees during a five day soccer tournament found that a prefabricated shock absorbing orthosis significantly reduced lower leg and back pain. Another study on Australian Air Force subjects during an 8 week training period, utilising prefabricated motion control orthosis did not demonstrate a significant reduction of injury (Esterman et al., 2005). However, other trials utilising motion controlling orthoses demonstrated that injury

rate was reduced (Simkin et al., 1989; Finestone et al., 1999; Larsen et al., 2002; Franklyn-Miller et al., 2011). Larsen et al., (2002) investigated 146 army recruits and found that wearing custom-made biomechanical shoe orthoses significantly reduced shin pain injury rate, however, it did not reduce other soft tissue injuries in other locations. Given the broad definition of orthotic therapy including discrepancy in the manufacture of the device, type of material used, diverse philosophy of orthotic function and rational of orthotic prescription influenced by subjective clinicians and the result is that there is a considerable variation in the types of orthoses prescribed, even for the same condition, making it difficult to evaluate the effectiveness of orthotic use (Landorf et al., 2007). There is considerable discussion among professionals regarding the consistency of production guidelines and descriptions, however, there is no consensus among the professional group due to different philosophies of orthotic fabrication and terminology (Petchell et al., 1998). A recent review by Yeung et al., (2011) concluded that more well-designed randomised trials are needed due to there being no consensus on how orthoses work and further research utilising kinetic, electromyographic and comfort as an outcome measure is recommended.

1.3.3.4. Gait retraining

Repetitive loading is a key part of the pathophysiology of stress fractures (Beck, 1998; Bennell et al., 1999). Studies suggest that tibial stress fractures are related to tibial acceleration and vertical force loading rates at the initial stance phase in running (Davis et al., 2004). Studies have shown that participants can have altered gait mechanics in unilateral hip replacement and reduce the knee adduction moment (Barrios et al., 2010). Plantar pressure measurement for the analysis of the gait pattern has been used and it was found that an altered gait pattern was another factor for developing injury (Willems et al., 2007). However, there remain many questions regarding which intervention programme is most effective in altering the risk factors for the required training adaptations and what effects the characteristics of the training programme have on subsequent activation of normal neuromuscular control and normalised gait patterns as well as reduction of injury. Some evidence suggests that gait pattern can be altered as long as bio-feedback is provided (Messier et al., 1989; Barrios et al., 2010) in patellofemoral pain syndrome patient (Noehren et al., 2011).

Another study demonstrated that impact peak and loading rate is reduced with gait re-training using bio-feedback (Crowell et al., 2010; Crowell et al., 2011). However, no studies found a connection between gait re-training and incidence of injury rate. It is impossible to establish unless gait biomechanics data are collected at baseline and subsequently tested for outcome measures. Therefore, it is proposed that the use of

objective measures for gait analysis could provide this information and enable effectiveness of exercise on modifying risk factors and reduction of injury as an outcome measure. Most of the prevention components are generalised and gait re-education has not been included in the prevention programme since adverse gait pattern is a risk factor (Wills et al., 2004; Willems et al., 2007).

To summarise, there have been a range of exercise interventions designed to prevent specific injuries. However, the implementation of these interventions into the ITC recruit populations is complicated due to a variety of reasons. First, recent studies examining proprioceptive or neuromuscular training interventions for the prevention of sports injuries demonstrated a large variety of exercises. Secondly, the methodological quality of published studies reveals substantial differences in key criteria concerned predominantly with internal validity (Yeung et al., 2011). Consequently, systematic reviews using a methodological quality assessment are needed to determine the effectiveness of proprioception and neuromuscular training in prevention of sports injuries. A recent systematic review by Hubscher et al., (2010) concluded that research should concentrate on the physiological mechanisms of neuromuscular training to promote a more varied and mechanism-based application and to identify the most appropriate and effective training components for preventing injuries in the military and sports population. Furthermore, the review concluded that the results in relation to other high-risk sports and age groups remains unclear.

1.3. Conclusion.

The literature review highlights that injuries during military training results in both a high financial cost for the British Army and personal costs to the recruits. It also appears that the incidence of injury in military populations is generally high but there is limited evidence with regard to the extent of the problem in ITC Catterick. Similarly, while a wide range of socio-economical and physiological risk factors for injury have been identified in both British and International military populations, the risk factors for recruits undertaking combined phase 1 and 2 training at ITC have not been investigated. In addition, while there have been several attempts to introduce preventative measures for MSK injuries, there have been no consensus on the most appropriate strategy to manage MSK injuries. For the purpose of this thesis, the size of the problem during training, risk factors associated with MSK injuries and potential strategies to reduce the impact of injury clearly need to be established.

Chapter 2.An Epidemiological Study into Musculoskeletal Injuries in an Infantry

Training Centre: Establishing the Injury Problem (Study 1)

2.1. Introduction

Physical fitness including strength, endurance and stamina are important components for soldiers (Heir et al., 1996; Greeves, 2001). In the transition from civilian to combat-ready soldier (Powell et al., 1986), British infantry recruits undergo 26 weeks of intense CIC training. For many, this abrupt increase in physical activity is widely believed to lead to the development of MSK injury (Cowan et al., 1996; Almeida, 1999a; Wills et al., 2004; Brushoj et al., 2008; Knapik et al., 2011). MSK injuries have been shown to have a negative impact on morbidity, training time, physical fitness and time-spent developing specific skills (Kowal, 1980; Linenger et al., 1992; Jones et al., 1993a; Heir et al., 1996; Almeida, 1999a; Franklyn-Miller et al., 2011). While it is clear that MSK injuries are detrimental to the British Army, it is not clear what constitutes an effective management strategy. In the general population, a well-proven treatment for MSK injury is a prolonged period of rest followed by a gradual return to physical activity (Yates et al., 2004; Rudzki et al., 2012). In the British Army, however, such a "hands-off" approach is not feasible and a more proactive and strategic approach is clearly desirable.

The "sequence of prevention of injuries" model (van Mechelen et al., 1992) is a popular approach to the management of MSK injuries. The cycle presented in the Overview section of the thesis (Figure I.I) involves four vital steps which include the introduction and evaluation of specific measures designed to prevent MSK injury. The first step in the cycle, and a necessary precursor to any intervention, is to quantify the

problem. Such baseline measures are fundamental in order to assess the success of any given intervention, but particularly important in large institutes such as the British Army. In such institutes, budgets are determined by policy-makers who require evidence as to the scale of the problem in order that the allocation of resources can be optimally allocated (Finch, 2006; Jones et al., 2010a). Unfortunately, at present only basic data on MSK injuries is currently collected by the British Army which in some cases can lead to misleading or contradictory findings. For example, incidences of MSK injuries acquired during military training are reported to range from 20% (Franklyn-Miller et al., 2011), 47% (Knapik et al., 2013a), 59.7% (Linenger et al., 1992) to 63% (Colclough, 1999) depending on location. On one hand, the lower incidences could be considered acceptable and purely the result of natural attrition. From this perspective, changes to the management of MSK injuries would be unnecessary. In contrast, the higher incidence is quite alarming and the problem would need urgent attention (Jones et al., 2010a; 2010b). In addition, it is not always clear whether data collection protocols are consistent across recruit training centres. For example, it was found that recruits training at ATR Lichfield had a significantly greater risk of injury, compared with those training at ATR Pirbright and ATR Winchester (Blacker, et al., 2005; Blacker, et al., 2008). These large differences, may be due to different environmental factors, or could simply be due to differences in protocol. Whichever case is not clear but it remains that until reliable data based on identical protocols of data collection can be adopted, British Army policy-makers will

always have impossible decisions to make regarding the most effective use of resources.

An unambiguous, universally applicable definition of injury is a prerequisite to any injury-related study (Willems, 2004). The Council of Europe offers an extensive definition of general MSK injury (Junge, 2000). Sports injury has been defined as any injury that occurs as a result of participation in sport with one or more consequences proposed by the Council of Europe. These consequences include a reduction in the amount or level of sports activity; a need for medical advice or treatment; or adverse social or economic effects (Council of Europe, 1989). Some studies include blistering (Linenger et al., 1992) as an MSK injury whereas others argue that blistering is a skin condition (Almeida 1999a). Other studies only include injury definitions that resulted in a compensation claim record (Pritchett, 1981; Davidson et al., 2008). The wide range of incidence rates reported in the relevant literature may be a function of the definition of injury, inclusion criteria, duration of study period and availability of qualified clinicians (Junge, 2000).

Various research methods and techniques are used that serve to carefully isolate the factors under study. This type of research serves to unravel individual questions within the much larger sphere of the overall problem. In some cases clinical research lacks precision and confounding or extraneous variables are many and the error terms are large (Brukner et al., 1999). If the underlying mechanisms remain elusive or the threat to validity remain unanswered the result remains open to speculation. The

prospective study design, all data were collected in a standardised manner including predefined injury definition as well as data collection (Thomas et al., 2005) which enabled the author to establish causative relationships (Atkinson et al., 2001).

The prospective epidemiological study approach involves defining the injury, diagnosis criteria and study period prior to conducting the research (Brukner et al., 1999; Thomas et al., 2005). This approach also involves measuring the potential risk factors prior to the injury occurring and reported during a period of follow up (Bahr et al., 2003). The prospective cohort study design is preferable since it is the least biased method for establishing the putative risk factors and determining the causative relationships of the risk of injury or attrition in any population (Fletcher et al., 1996; Hodgson, 2000; Atkinson et al., 2001).

Epidemiology is the study of the patterns, causes, and effects of health and disease conditions in defined populations (Thomas et al., 2005). It is used by public health authorities, and is fundamental in policy decision-making and evidence-based medicine for identifying risk factors for disease and targets for preventive medicine (Thomas et al., 2005). Epidemiology has helped develop methodology used in clinical research, public health studies and, to a lesser extent, basic research in the biological sciences. Usually, epidemiological research includes disease aetiology, outbreak investigation, disease surveillance and screening, bio-monitoring, and comparisons of treatment effects such as in clinical trials (Thomas et al., 2005). The important components in epidemiology studies are the distribution, determinants and pattern of

injury occurrence in a population (Thomas et al., 2005). Injury experienced by army recruits, however, may not be the same as for other sports or military forces in other countries due to varied factors such as: personal characteristics, environment and time, influence of the pattern of injury occurrence. Therefore, evaluating the basic pattern of disease occurrence in specific population with a clearly defined injury included in the study is vital (Caine et al., 1996; Thomas et al., 2005). There are three broad categories of athletic and recruit training related injuries, which may differ in their aetiology.

The acute injuries are those associated with a macro-traumatic inciting event involving a usually strong force (Holz et al., 2009). The inciting event is readily identified by the application of some external force with resultant tissue disruption (Brukner et al., 2007) and these injuries primarily involve direct tissue damage or secondary damage due to transmission of force or release of inflammatory mediators (Holz et al., 2009). On the other hand, in micro-traumatic injuries that result from overuse, the inciting event is often less apparent, and the resultant tissue damage is due more to overstress/overload (Holz et al., 2009). The relative contribution of intrinsic and extrinsic risk factors differs for these two types of injury. In overuse injuries, there is likely to be a greater contribution from intrinsic risk factors. With acute injuries, the relative contribution of factors that constitutes a nearly sufficient constellation often is less clear (Meeuwisse, 1994) and recurrence may be a mixture of both (Brukner et al., 2012).The aforementioned issues as well as the appropriate research design were considered to minimise confounding or extraneous variables

that may influence bias or chance during the designing of studies (Bowers, 2008). This enables the researchers to make valid conclusions about MSK injury and treatment.

In this study, epimediology may be a useful approach to the quantification of the problem of MSK injuries in the British Army. As alluded to in the previous paragraph, the British Army requires precise evidence of injury patterns in terms of weeks of training, months of training, injury site, anatomical body area, the rate of specific diagnosis and cumulative incidence based on training company in military recruit populations in order to justify and priorities any changes in management strategy.

2.1.1. Aim

The aim of this study is to apply epidemiological methodology to the problem of MSK injuries in the British Army. In doing so, incidence rate, injury types, the onset of injuries, and impact on British Army recruits during a 26 week training period would be quantified.

2.2. Materials and methods

2.2.1. Participants.

During the study period from 1 April 2006 to 30 March 2008, 7726 recruits arrived at ITC Catterick and were invited during the mandatory initial medical assessment to take part in the study. Of these 1118 (14%) left prior to the completion of training because of either failing an initial medical, transferring into other regiment, or being

'Discharged as of Right' without any injury. These were excluded from this study. The remaining sample (n=6608, mean age 18.9 years (SD ± 2.3), height 176.5 cm (SD ±7.8), mass 69 kg (SD ± 9.7) and body mass index 22.14 kg/m^2 (SD ± 2.5) comprised recruits from four different regiments. These were; Line (69.7%), Guards (15.8%), Parachute (11.1%) and Gurkha (6.9%) regiments. Subjects who were discharged prior to completion of the training programme due to injury (medically discharged) or for other reasons such as being 'Discharged as of Right' and who had at least one musculoskeletal injury were included in the analysis. It is noteworthy that the Gurkha regiment train for 39 weeks. Thus, for the purposes of maintaining consistency across regiments, injury data only up to the 26th week were included in the analysis. All participants gave written consent to take part in this study. The local army (ITC) approval was gained prior to conducting the study. Ethical approval was obtained from the Teesside University Ethics Committee.

2.2.2. Training.

Background information of the infantry training course and organisation are presented more details in Appendix A. Briefly, all infantry basic training provided by the British Army is conducted at the Infantry Training Centre, (ITC) Catterick under one and two infantry Training Battalions (1 ITB and 2 ITB). The 26-week training course is divided into phases 1 (weeks 1-13) and phase 2 (weeks 14-26) with two weeks leave between phases. The training programme involves the learning of military skills and physical fitness work in a progressive and structured programme (Blacker et al.,

2008). The training programme is standardised and has been validated for regiment specific task requirements by the Army Training and Recruiting Division (ARTD). There is some variation in terms of the volume of hours of physical training intensity for different regiments. The volume of physical activity is highest for the Parachute and least for the Line Regiment (Wilkinson et al., 2008). The physical training curriculum is designed to improve aerobic power, muscular endurance, strength and stamina through running, gym work, battle physical training and loaded marches, culminating with a combat fitness test (Blacker, et al., 2005). In addition to the formal physical training programme, the CIC offers the opportunity for recruits to engage in a wide variety of sports and some adventure training designed to improve fitness and teamwork. The remainder of the course gives additional training in first aid, radio communications, drill, chemical, biological, radiological and nuclear warfare and navigational skills.

2.2.3. Data collection.

Injury data were collected over a 26 week training period. All injured recruits initially report to the medical centre for a doctor's assessment and diagnosis and in cases of MSK injury they are referred to the Physiotherapy department for treatment. The MSK injuries diagnosis were recorded in the database by the Physiotherapy department. MSK injury was defined as a pain, inflammation or functional disorder that involves the bones, joints, muscles, tendons, ligaments, and associated connective tissue injury but not blistering or cellulitis (Almeida, 1999a; Brushoj et al., 2008). In addition,

injury had to be serious enough for recruits to seek medical consultation and could only be included in this analysis if it had occurred entirely or partly as a consequence of an external trauma sustained during the CIC training (Heir et al., 1996).

The accuracy of injury diagnoses is sometimes affected by intra-observer differences (Junge, 2000). Where possible the definitions according to Almeida, (1999a) and Heir et al., (1996) were applied in this study. However, in some cases further definitions had to be clarified. For example, for the purpose of this study, MTSS group membership was defined according to previous literature in this field (Yates et al., 2004, Yates et al., 2003). Specifically, MTSS is a pain experienced along the posterior-medial border of the tibia occurring during exercise and is pain which is not caused by ischemic disorders or stress fractures (Yates et al., 2004). Thus, in order to exclude patients who have ischemic disorders or stress fractures (including those possibly being preceded by MTSS), X-ray and MRI scan were used to confirm/reject the initial clinical diagnosis (Fredericson, et al.,1995; Fredericson et al., 2003).

Injury onset was categorised as acute, overuse and recurrent (Almeida, 1999a; Holz et al., 2009). Acute injury is defined as an injury that occurred during direct trauma, while overuse has a gradual onset in nature and recurrent is a combination of both. Diagnosis was made by a qualified clinician. Those injuries without a definitive diagnosis were classified as 'other' (Heir et al., 1996). The time of injury and the discharge time from physiotherapy treatment were also recorded. The process continued for the 26 weeks of CIC training. Following Ekstrand et al., (1983), the

severity of injuries was defined as minor (absence for 1-7 days), moderate (absence

for 8-28 days) and major (absence for >28 days).

2.2.4. Data analysis.

In order to quantify the problem of MSK injury, the probability of recruits surviving

from MSK injury were calculated using a Kaplan-Meier survival analysis (Clark et al.,

2003; Coppack, et al., 2011). Kaplan-Meier (KM) survival function curves were

calculated for four training regiment arms, and the log rank test was used to examine

overall differences in survival probability of MSK injury. The cumulative incidence at a

time point was simply one minus the survival probability (Clark, et al., 2003). This

model is appropriate and widely used in comparing two or more groups and both

censored and events of interest data (Clark et al., 2003; Bowers, 2008). Exposure

time was defined as the length of time recruits spend in training without MSK injury.

Censored cases were represented at the point when recruits left training without MSK

injury and had no MSK injury over 26 week periods. In recruits developing MSK

injury, proportion of survival was calculated to the point of diagnosis.

A chi-square test was used to test the differences in injury onset (acute, overuse and

recurrence) as well as to investigate whether there was any difference in overall MSK

injury between the first phase and second phase of training. Data were collapsed in 1-

13 weeks for the first phase and 14-26 for the second phase. Data also descriptively

analysed the distribution of injury by anatomical site, diagnosis specific, the month of

training injury and training outcomes and attrition.

2.3. Results

Overall, almost half the recruits (48.65%) sustained at least one musculoskeletal injury during the 26 weeks of CIC training. The Kaplan-Meier curve showed (Figure 2.1(a) the proportion of recruits who were free of the events at each week of point. Each time MSK injury occurred the curve stepped down. The lower curve has a poor survival time. Figure 2.1 (a) displays the section of the curve where the slope is steep indicating the periods when recruits are most at risk for experiencing the event. Injuries were reported most frequently in the first nine weeks of training, with the highest rate of injury occurring in week two in the first phase of training and after that injury gradually declined until week 12. Another injury peak emerged in week 17 with the highest rate (4.17%) in the second phase of training. For the Parachute regiment, week 17-20 had a higher injury rate. The log rank survival curves (Figure 2.1a) show significant differences (X^2 = 792.5, p< 0.001) among the four regiments for surviving from MSK injuries. The probabilities of being free from MSK injury were 14, 54, 52, and 90% for the Parachute, Guards, Line and Gurkha Regiments, respectively. The cumulative incidence at a time point is simply one minus the survival probability (Clark et al., 2003); therefore, Figure 2.1(a) could also be read as cumulative incidence among training regiments with the highest in the Parachute Regiment (86%) and the lowest in the Gurkha Regiment (10%).
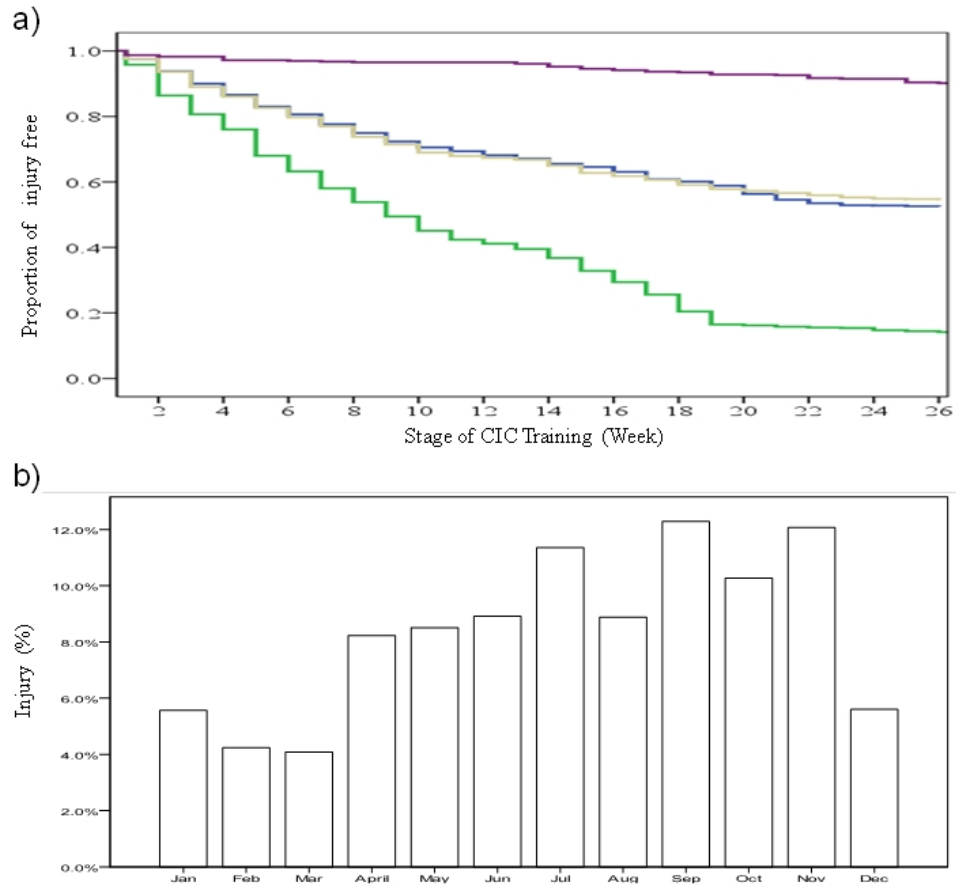
Figure 2.1. a) The Kaplan-Meier survival curve for the proportion of survival among four regiments survival curves for the Parachute (green), Line (blue), Guards (gray) and Gurkha (purple) Regiments, b) Number of recruits encountered musculoskeletal injury by months.

The least reported injury months were March (4.11%), February (4.25%), January (5.60%), December (5.76%), while, the most reported were in November (12.10%), September (12.07%) and July (11.33%) (Figure 2.1b).

There was a significant difference in the onset of injury types (X^2 = 688.01, p< 0.01), the injury pattern was; overuse (43%) followed by acute (32.8%) and recurrence (24.16%) (Table 2.1). Among the recurrence, 18% was also overuse injury, representing an overuse injury total of 61.39%.

Table 2.1. Injury onset pattern based on training regiments				
Training Company	Injury Onset			Total
	Acute	Recurrent	Overuse	
Line (n=4372)	704 (33.9%)	530 (25.5%)	845 (40.6%)	2079 (100.0%)
PARA (N=734)	168 (26.6%)	118 (18.7%)	345 (54.7%)	631 (100.0%)
Guards (n=1044)	162 (34.0%)	121 (25.4%)	193 (40.5%)	476 (100.0%)
Gurkha (n=458)	18 (39.1%)	8 (17.4%)	20 (43.5%)	46 (100.0%)
Total (n=6608)	1052 (32.5%)	777 (24.0%)	1403 (43.4%)	3232 (100.0%)

Most injuries were found in the lower limb (82.34%). Injuries most frequently occurred in the knee (28.43%) followed by the ankle (17.20%), the lower leg (15.65%), the foot (11.10%), the hip (9.95%) and the back (9.42%) while combined upper body and neck injuries accounted for only 8.25%. Table 2.2 shows the cumulative diagnosis specific injury during training periods. The most common diagnoses were iliotibial band syndrome (ITBS) (6.19%), the second most common was medial tibial stress syndrome (5.67%) followed by ankle sprains (5.02%).

Table 2.2. Distribution of injuries based on diagnosis profile during the entire 26 week of CIC training

Injury Diagnosis	Frequency	Incidence % (n=6608)
Achilles Tendinopathy/bursitis	97	1.47
Adductor strain	27	0.41
Ankle sprain (medial/lateral)	332	5.02
Anterior knee pain	135	2.04
Back pain	303	4.59
Calcaneum stress fracture	16	0.24
Calf strain	81	1.23
Compartment syndrome	18	0.27
Femur stress fracture	17	0.26
Greater trochanteritis	38	0.58
Groin strain	97	1.47
Hamstring strain	129	1.95
Internal derangement	43	0.65
Ilio-tibial band syndrome (ITBS)	409	6.19
Metatarsal stress fracture	82	1.24
Medial tibial stress syndrome (MTSS)	375	5.67
Other lower limb injury	304	4.34
Other stress fracture	6	0.09
Patellar tendinitis	156	2.36
Plantar fasciitis	56	0.85
Sprain/strain knee	87	1.32
Tibialis posterior Tendinitis	67	1.01
Tibia stress fracture	92	1.39
Upper body, head & neck	265	4.01

Occupational outcome (number passing out first time) and attrition were also analysed using the X^2 test. Results showed significant difference (p = 0.02) among regiments. The orders of first time completed training were; 38%, 51%, 56% and 98% for the Parachute, Guards, Line and Gurkha Regiments, respectively.

One-third of the recruits were discharged prior to completion of the training (Table 2.3). Among the discharged (n=2596, i.e. 33% of the total sample), a far greater number of recruits were 'Discharged as of Right' (n= 1037, 39.95%), followed by service no longer required (n = 748, 28.81%) and medical discharge (n = 597, 23%) due to both pre-enlistment and injuries acquired during training. Furthermore, 991 (15%) recruits were taken completely out of training for further rehabilitation. Mean rehabilitation time was 68 (SD ±15) days and this ranged from 21 to 168 days depending on injury type. Over the period of 26 weeks, a total of 155,403 training days were lost due to injury. These lost training days were due to excused duty as well as during rehabilitation time which are equivalent to 853 (12%) recruits CIC training time.

Table 2.3. Reason for discharge during recruit training

Discharge reason	Frequency	% amongst total discharge	% amongst total intake
MD- Defect in enlistment	135	5.20	1.75
MD injury during training	462	17.80	5.98
UFAS	190	7.32	2.46
DAOR	1037	39.95	13.42
Service no longer required.	748	28.81	9.68
Misconduct/Others	24	0.92	0.31
Total	2596	100	33.60
MD = medical discharge, DAOR = discharge as of right, UFAS = unsuitable for army service			

The severity of injuries were defined as minor (1-7 days), moderate (8-28 days), and major (>28 days) (Ekstrand et al., 1983; Pasanen et al., 2008). Based on these criteria, stress fracture and MTSS are all major injuries while knee pain (including ITBS and PFJP) and ankle injuries are minor to moderate. The incidence rate for stress fracture and MTSS are lower than ITBS but the mean loss of training time was greater. Hence, the loss of actual training days for MTSS was much higher than for ITBS (61 and 8 days, respectively).

2.4. Discussion

Epidemiological studies of MSK injuries are often based on civilian participants (Marti et al., 1984; Taunton et al., 2003) are similar to those seen in military personnel

(Jones et al., 1993a; Kaufman et al., 2000) indicating some common aetiologies (Almeida, 1999a). However, research on civilian participants is based on self-report questionnaires. These studies have been criticised for heterogeneity of injury definitions as well as participants, medical facilities and selection bias (Koplan et al., 1985; Junge, 2000). In contrast, the training at the ITC in the British Army offers a controlled environment providing a relatively homogeneous sample. The aim of this investigation was to provide baseline evidence as to the scale of the problem and in doing so provide a systematic approach to planning and setting priorities for further research (Jones et al., 2010b).

The incidence rate of musculoskeletal injury in our study (48.65%) is somewhere within the range of runners (25 to 65%) (Taunton et al., 2003) but considerably lower than the 67 to 95% of professional dancers (Garrick et al., 1993; Garrick et al., 2001; Luke et al., 2002). This present study and other military (Almeida, 1999a) and civilian population studies suggest that volume, intensity, type and rate of progression of training variable could be modified to introduce cost effective preventive measures. Overall the incidence of injuries in this study is comparable to other military studies with a range of 20% to 50% (Joneset al., 1993b; Heir et al.,1996; Almeida, 1999a; Kaufman et al., 2000; Franklyn-Miller et al., 2011). However, a higher injury rate (60%) was reported in a study of American recruits during a 12 week training cycle (Linenger et al., 1992) and another study of British Army recruits reported a higher injury rate (63%) (Colclough, 1999). The differences, however, may be explained by the inclusion of blisters in the definition of the injury, which is a common injury

(Linenger et al., 1992). This would certainly show a higher rate compared to this study where this condition was excluded from the definition of musculoskeletal injury (Almeida, 1999a).

The injuries pattern in terms of anatomical site and onset of injury are also similar to other investigations of military populations (Jones et al., 1993a; Jones et al., 1993b; Almeida, 1999a) and other sports populations (Gamboa et al., 2008). In terms of overuse injuries, the highest among the injuries found by other researchers (Almeida, 1999a; Broshoj et al., 2008) are also comparable with our study. The previous history of injuries prior to beginning military training is an identified risk factor (Neely, 1997; Kaufman et al., 2000; Hubbard et al., 2009); however, the impact of recurrence injury during recruit training was not recorded and has not been widely investigated. There is no study on recurrent injury in army populations. This makes it difficult to make a direct comparison regarding the rate of recurrence injury. This is the first study to examine rates of overuse, acute and recurrence in recruits. The onset pattern of injury demonstrated that overuse injury is higher compared to acute and recurrence injury. The patterns are similar to other studies (eg. Heir et al., 1996; Almeida, 1999a; Brushoj et al., 2008).

The majority of all types of injuries occurred in the lower limb (Almeida, 1999a; Heir et al., 1996). Heir et al., (1996) found 63% of the injuries were sited on the lower limb. However, Almeida (1999a) reported a higher rate of 82% in the American recruit population in the lower limb. The difference Almeida (1999a) found was that the

majority of injuries were in the ankle/foot region followed by the knee, but the present study found the highest injury occurred in the knee and shin which are similar to Brushoj et al., (2008). 5.67% of injuries were attributed to MTSS which was found to be comparable with Brushoj et al., (2008) study but lower compared to the Yates et al., study (2004).

Higher injury rates were found during the first phase of training (weeks 1-13) compared to the second phase (weeks 14-26). Such findings are similar to previous studies and the initial weeks of training are an important area in terms of injury prevention (Almeida, 1999a; Brushoj et al., 2008; Hubbard et al., 2009). A possible explanation is that recruits have had minimal previous physical activity and may be lacking fitness prior to starting training. A study by Carter et al., (2006) to assess the physical demands on CIC Guards at ITC found that the physical demand was highest in the first 9 weeks of training while the highest degree of physiological stress and strain was in week 2. Furthermore, they found that average physical activity levels were 2.5 times the basal metabolic rate which is the upper limit for maintaining energy balance. 60% of recruits who did not complete the course were above this threshold in week 1-2. In such cases, the sudden increase in training levels may overload the MSK system early and lead to the development of injuries. Notably, a lack of previous physical experience and poor fitness have been identified previously as risk factors for MSK injuries (Knapik et al., 2001b; Sharma, 2008; Knapik et al., 2013b). In addition to the physical stress, researchers also suggested that recruits may feel

mental stress due to daily hassles, lack of support and sleep deprivation, plus working in an unfamiliar environment (Meehan et al., 2002) also play a role.

In addition to the relative timing of injuries with respect to training time, there were also some interesting observations with regard to seasonal variation. Injury rates in July, September and November were significantly higher than during the other months of the year. Such findings are in agreement with a study conducted in the US military (Knapik et al., 2002) but not with seasonal differences of injury pattern found in a study on the Australian military (Pope, 2002a). On the one hand, the high rates observed during July and September may be caused by higher temperatures leading to firmer ground on which the trainees are expected to march. However, this variation in mechanical properties due to temperature variations would not explain the peak also observed inNovember, normally a much cooler month in the UK. However, it could be possible that after mid-September there is no 2 week leave period despite having finished the first phase of training. Recruits continue training until Christmas leave, causing an increased overload and subsequently injury may develop.

Increased injury in November could be due to training error and inadequate recovery and rest as well as training cycles which are risk factors reported in the literature (Lappe, et al., 2001; Ross et al., 2002; Pegrum et al., 2012). Generally, less injuries occurred in the winter sessions in the period following Christmas. These training sessions were often held indoors and the reduced daylight hours may have restricted the recruits from undergoing extra-curricular activities. Another explanation may be 2

weeks leave which allowed recovery of overloaded tissue and the tissue becoming stronger (McGinnis, 1999).

This study found attrition rates to be very high. The first time pass rate found in this study was slightly higher (38%) than the previous study (35%) by Wilkinson et al., (2008) in the Parachute regiment. About 12% of recruit training time loss were due to injury alone. The direct estimated cost has not been calculated in this study, however, Commando Training Centre, British Royal Marines, estimate the cost of injury rehabilitation at £ 1.6K per week per recruit (Munnoch et al., 2009). The severity of injuries need to be examined in terms of risk factors and evidence based management the duration and nature of treatment, training time lost, and the medical cost of injuries. This suggests that given this unwanted side effect during training, a preventive approach towards reducing injuries and attrition during recruit training should have a high priority. This study contributes to the knowledge of the extent of the problem at ITC. Training based on research evidence is urgently required to reduce injury.

The first time pass out rate ranged from 35-98% on average depending on training company division at ITC. Unpublished data shows approximately 2,000 (65%) finished training for a variety of reasons either on first attempt or after repeated training. This is lower than many other army training courses (Carter et al., 2006; Knapik et al., 2013a), suggesting a mismatch between the capability of the recruits and the requirements imposed by the course. Some of the proportions of this pass-fail

attrition are related to the nature of the physical and psychological demands of training and changing in working condition (Huovinen et al., 2009); however, some of the wastage may be reducible/avoidable if factors such as smarter selection, evidence based training programmes, evidence based injury prevention and treatment were considered (Bilzon, 2003; Carter et al., 2006; Jones et al., 2010a). These factors have the potential to reduce injury rates and thus improve pass out rate.

There are several limitations to this study. Firstly, it was limited to the data available on the number of recruits there were in each week of training. Data was collected on injuries which occurred in the weeks of training; however, some recruits may have been back-squadded and the number of recruits may have increased on that week and possibly increased the number of injuries on particular weeks especially during the first phase of training. Another problem with the present study was that the sample was not homogeneous. Parachute regiments are known to have a lower pass out rate (35%) than other regiments (Wilkinson et al., 2008), the CIC Guards 40-50% (Carter et al 2006) and the Gurkha 98% (Sharma et al., 2011b). CIC Parachute regiment had P-Company training which involved extra fitness including running and loaded marches (20 miles) (Wilkinson et al., 2008). In contrast, cultural differences may exist. Firstly, Gurkha recruits physical training had a 7-8 week cyclical interval for language courses, each interval lasting two to three weeks. These two to three weeks language periods promote the rate of remodelling/healing on overloaded structure and training effects achieved (McGinnis, 1999). Moreover, those MSK systems

became biomechanically stronger and were able to cope with extra bouts of impact stress without failure (Winter, 2009). Another reason might be due to tough selection criteria in terms of fitness and socio-psychological factors. Traditionally, Gurkhas are considered to be naturally warlike and possess qualities of courage. Psycho-social factors may restrict recruits from seeking medical help for soft-tissue injuries (Vickers et al., 1983). Further refinement of the data to identify the diagnosis-specific injury by regiment may serve to identify trends occuring accross regiments.

In summary, this study demonstrates that musculoskeletal injury has a high impact during recruit training in the British Army. The overall cumulative injury rate was 48.65% which is within the middle of the range reported previously 20% to 85.5% (Stacy, 1984; Joneset al., 1993a; Franklyn-Miller et al., 2011). Among these injuries, 82.34% were found in the lower limb.This study has demonstrated that MSK training injuries are common during basic infantry training in the British Army and significant attrition rates have also been found due to back-squadding (back term), 'Discharged as of Right', injury, medical discharge and rehabilitation. Our findings highlight that due to a high overuse and lower limb injury incidence rate, an injury reduction strategy should be sought for use in infantry recruit populations with high priority. Shin injury is the second most common overuse injury in sports populations (Gooch et al., 1993) and MTSS has been the most frequently recorded injury in the British Royal Navy (Franklyn-Miller et al., 2011). The incidence rate is high ranging from 4-35% in athletic and military populations (Almeida et al., 1999a; Almeida et al., 1999b;Yates et

al., 2004; Willems et al., 2006), however, the optimum management solution for these injuries remains unanswered (Galbraith et al., 2009).

2.5. Conclusions

This epidemiological study highlights the problem of MSK injury and attrition is large and costly enough to warrant the time and resource allocation to effectively implement evidence-based of injury prevention priorities for the British Army. The significance of injury is defined as minor, moderate and major based on training days lost (Pasanen et al., 2008). Based on these definitions, MTSS is highlighted as the most significant injury, in terms of incidence rate and training time loss. Therefore, the reduction of the impact of the problem should have high priority. Based on the van Mechelen et al., (1992) sequence of prevention of injuries model (Figure I.I), the next logical step is to establish the aetiology and mechanisms of this injury. Thus, the next stage of this thesis is to identify the risk factors for development of MTSS.

2.6. Implications for practice and research

MSK injuries are a significant burden to the British Army and strategies to improve prevention and treatment need to be explored. An initial focus on the risk factors of MTSS is warranted.

Chapter 3. Development of a Risk Factor Model for MTSS: Establishing the Aetiology

and Mechanisms of Injury (Study 2)

3.1. Introduction

Lower limb overuse injuries generally are common problems in athletic and military populations (Beck, 1998; Yates et al, 2004; Bettcher, et al.,2008 ; Franklyn-Miller et al., 2011; Rudzki et al., 2012). Medial tibial stress syndrome (MTSS) is a common lower limb overuse injury predominantly observed in weight bearing activities (Craig, 2008a). MTSS is a pain experienced along the posterior-medial border of the tibia during exercise (Yates, et al., 2004; Brukner et al., 2012). MTSS is often diagnosed as shin splints, shin pain, periostitis and exercise related lower leg pain (Touliopolous et al., 1999; Tweed, et al., 2008a; Franklyn-Miller et al., 2011). In some serious cases it may progress to a tibial stress fracture (Matin, 1988; Beck et al. 1994; Thacker et al., 2002; Craig, 2008a). In recreational runners MTSS is one of the most frequently diagnosed injuries (Moen, et al., 2009) and accounts for about 60% of lower leg overuse injuries (Couture et al., 2002). Incidence rates are particularly high in military personnel (Yates et al., 2004; Craig, 2009; Moen et al., 2009; Rudzki et al., 2012).

The aetiology of training injuries is multifactorial in nature (Bouche, 1999; Thacker et al., 2002; Blacker et al., 2008; Sharma et al., 2011a) and any prevention programme must be based on risk factors (Meeuwisse, 1994; Brushoj et al., 2008; Meeuwisse et al., 2009; Knapik et al., 2013a). There is emerging evidence that adverse gait patterns are present in individuals with MTSS (Yates et al., 2004; Willems et al., 2006; Willems et al., 2007; Moen et al., 2012) as well as other lower limb injuries (Moen et al., 2009; Stolwijk et al., 2010; Chuter et al., 2012). Most researchers

suggest that overuse injury is, in part, due to the poor lower-limb biomechanics applied during dynamic activities (Cavanagh et al., 1997; Christina et al., 2001; Wills et al., 2004; Bressel et al., 2005; Willems et al., 2007). In particular, there is growing evidence which suggests a connection between core stability and lower limb biomechanics with overuse injury (Bellchamber et al., 2000; Chuter et al., 2012; Kelly et al., 2012). Several investigators have examined the effect of hip abductor and external rotation strengthening on patellofemoral pain syndrome (Ireland et al., 2003; Willson, et al., 2008; Souza et al., 2010). They have found that individuals with patellofemoral pain syndrome run, jump and squat with greater hip adduction and greater contra-lateral pelvic drop. Similarly, another study has found greater peak hip internal rotation during running in individuals with patellofemoral pain syndrome (Wills et al., 2004; Souza et al., 2009; Souza et al., 2010). For this reason, physiotherapists and sports medicine physicians concentrate biomechanical assessment on the lower limb to identify the contributing factor of injury. Movement dysfunction in gait can be the cause of repetitive motion injury and pathology at the sites of uncontrolled movement (Donatelli, 1990; Hunter et al., 2004). Overuse injuries are due to repetitive motions and a rapid increase in activity that finally leads to symptoms (Whiting et al., 1998; Stolwijk et al., 2010), rather than an acute, single event (Meeuwisse, 1994; Holz et al., 2009). Overuse injuries cause a fatigue effect over time, leading to repetitive micro-trauma which lowers stress threshold capabilities (Hreljac et al., 2000). During running vertical ground reaction force can reach two to five times body weight (Cavanagh et al., 1980) while other activities such as jumping and landing can

reach 12 times body weight (McNitt-Gray, 19991). Gait consists of a series of repeated jumps followed by repeated landings which can be attributed to injury even though there are small deviations from normal (Schmid et al., 2013). Craik et al., (1988) state that poor biomechanics can place tremendous stress on the lower limb, whilst normalising biomechanics can reduce impact loading (Crowell, 2010).

Despite numerous suggestions the knowledge of pathological lesions and pathophysiological mechanisms of MTSS are still limited (Bouche, 2007; Craig, 2008a; Ozgurbuzet al., 2011). Suggested extrinsic risk factors include; activity type, intensity, terrain and footwear (Bennett et al., 2001; Tweed et al., 2008b). Intrinsic factors (Gooch et al., 1993; Craig, 2009; Pegrum et al., 2012) include; muscle tightness, weakness of the tibialis posterior, lower extremity mal-alignment, low bone mineral density (Franklyn et al., 2008), high BMI (Plisky et al., 2007), decreased range of motion in internal hip rotation and increased ankle plantar flexion (Moen et al., 2012) and a previous history of MTSS/stress fractureor use of orthotics (Hubbard et al., 2009; Moen et al., 2009). Literature has a mixed view upon the cause of MTSS (Couture et al., 2002; Bouche et al., 2007; Reinking et al. 2007). Prevention of MTSS is challenging until an understanding of the risk factors and causes is achieved (Craig, 2008a; Craig, 2008b; Craig, 2008c). A recent literature review concluded that an understanding of the cause of injury is still limited and that more prospective studies with proper experimental designs and a sufficiently large sample size are needed (Thacker et al., 2002; Barnes et al., 2008).

The recent prospective review study highlighted that previous history of MTSS is the most important factor (Hubbard et al., 2009; Moen et al., 2009). However, in military recruits such data are not always available and the reliance on self-reported medical questionnaires leads to questionable validity. Plantar pressure analysis has also been shown to be a powerful tool with which to model risk factors for exercise-related lower leg injuries, including MTSS. A series of studies have shown that higher medial pressure, central heel strike and general over-pronation during walking and running contribute to the risk of injury (Willems et al., 2006, Willems et al., 2007). Thus, pressure plate analysis provides an objective tool on which to base prospective studies. However, these studies (Willems et al., 2007) have focused purely on biomechanical risk factors. Other factors such as lifestyle choices have been shown to influence the risk of injury to both hard and soft-tissues. For example, smoking is often linked with musculoskeletal pain and impaired healing (Jones et al., 1993b; Knapik et al., 2001b; Munnoch et al., 2007) and development of stress fracture (Kanis et al., 2005). In addition, a poor level of fitness is also reported to be a risk factor for overuse injury (Shaffer et al., 1999; Sharma et al., 2008, Sharma et al., 2009).

3.1.1. Aims.

The aim of this study was to examine prospectively the differences between MTSS and non-MTSS recruits in terms of baseline foot pressure, smoking habit and fitness level; to explore the relative importance of these variables on the risk of MTSS and in doing so to develop a risk-factor model which has the potential for predicting MTSS

development. It was hypothesised that foot pressure distribution and lifestyle factors would have a significant impact on the risk of development of MTSS in a sample of recruits.

3.2. Methods

3.2.1. Participants.

468 healthy male British infantry recruits were invited to take part in this study during their obligatory initial medical assessment. The participants included in this study (mean age = 19.8 years; SD = 2.3, body mass = 70.4kg; SD = 9.7, height =176.5 cm; SD = 6.8, and BMI = 22.5; SD= 2.5). They had no known injury at the time of testing and all signed an informed consent form and the local army (ITC) approval was gained prior to conducting the study. The study was approved by the Ethics Committee of Teesside University, UK.

3.2.2. Training.

Immediately after completing the trials, the participants underwent a 26 week standard recruit training programme (Army Recruiting and Training Division, UK). Background information of the infantry training course and organisation structure are presented in more detail in Chapter 2 and Appendix A. Briefly, the programme consisted of Phase 1 (weeks 1-13), two weeks rest (leave) and Phase 2 (weeks 14-26). Injury data were collected during the 26-week training period, including clinical diagnosis and the week of training in which the injury occurred. Each injured subject

reported to the Medical Centre for assessment and treatment. For the purpose of this study, MTSS group membership was defined according to previous literature in this field (Detmer, 1986; Yates et al., 2004; Willems et al., 2006; Brukner et al., 2012). Specifically, MTSS is a pain experienced along the posterior-medial border of the tibia occurring during exercise and is a pain which is not caused by ischemic disorders or stress fractures (Yates et al., 2004; Franettovich et al., 2010). Thus, in order to exclude patients who had ischemic disorders or stress fractures (including those possibly being preceded by MTSS), X-ray, MRI scan and intracompartmental pressure measurements were used to confirm/reject the initial clinical diagnosis (Fredericson et al.,1995; Young et al., 2006; Craig, 2009; Moen et al., 2012).

3.2.3. Data collection.

Aerobic fitness was measured by a 1.5-mile timed-run which was conducted prior to the start of basic training. This test has been shown to be a valid measure of aerobic fitness and is widely used in military populations as a personal fitness test (Colclough,1999; Blacker et al., 2008). Whether or not participants smoked was also recorded. Other military selection data from the army database were extracted on the first day of training.

The measurement of the pressure beneath the foot is a specialised form of gait analysis and the distribution of pressure over its surface is naturally of great interest and has a particular value when pressure is excessive (Whittle, 2007). The sole of the foot is uniquely responsible for transmitting forces/pressure from the ground to the

body (Lord, 1981; Kirtley, 2006). There are five technologies which have been developed for measuring plantar pressures. These are; optical (pedobarography), capacitance, piezo-electric, piezo-resistive and laser (Hughes et al., 2000; Kirtley, 2006). There are two types of foot pressure measurement systems which are the floor mounted, flat-plate (Cavanagh et al., 1982; De Cock et al., 2005; De Cock et al., 2006) and the insole system (Kirtley, 2006). These systems measure the pressure between the foot and the floor (Cavanagh et al., 1982; Franklyn-Miller et al., 2011). The spatial and temporal resolutions of the images generated by plantar pressure systems range from approximately 3 to 10 mm and 25 to 500 Hz, respectively. Finer resolution is limited by sensor technology. Such resolutions yield a contact area of approximately 500 sensors. For a stance phase duration of approximately 0.6 seconds during normal walking (Blanc et al., 1999) approximately 150,000 pressure values, depending on the hardware specifications, are recorded for each step. Plantar pressure analysis is widely used for research and clinical application in diabetic, (van Schie, 2005), post-surgery biomechanical assessment (Hahn et al., 2008) and orthotics intervention (Hodge et al., 1999; Franklyn-Miller et al., 2011). In addition, plantar pressure measurement is also used to understand the mechanisms governing human gait and posture and injury prediction (Alexander et al., 1990; Rosenbaum et al., 1997; Willems et al., 2006; Willems et al., 2007). Many review articles and normative studies on plantar pressure have been published (Alexander et al., 1990; Razeghi et al., 2002; De Cock et al., 2005; De Cock et al., 2006). Plantar pressure assessment can provide information pertaining to the dynamic loading of the foot, as

well as information specific to each region in contact with the ground (Rosenbaum, et al., 1997; Stolwijk et al., 2010; Cousins et al., 2012). Willems et al., (2006; 2007) utilised both kinematic and plantar pressure measurements (RsScan International, Belgium, plate size = 200cm x 40cm, sensor size = 5mm x 7mm and sampling frequency = 126 Hz) in order to determine risk factors associated with exercise-related lower leg pain and found plantar pressures to be a more valid and better predictor of injury than kinematic analysis. Accordingly, a similar system to that used in the Willems et al. studies was hidden in the middle of a 9 meter long purpose-built walkway. Following a weight calibration stage, the subjects walked unshod across the plate at their natural walking speed. For each participant six left and six right plantar pressure distributions during the stance phase of gait were recorded. This ensured that enough trials were performed to familiarise the participants with the equipment and protocols, thereby reducing the error variance and increasing reliability (Tabachnick et al., 2001; Sharma et al 2004a). Plantar pressure analysis software (Footscan software 7.0, RsScan International) was configured to measure plantar pressures (N/cm^2) under both feet. The plantar pressure data for each foot were segmented into 9 regions. The resulting local pressures (N/cm^2) were: the medial heel (HM), lateral heel (HL), five metatarsals (M1-5), hallux (T1) and the other toes (T2-5). Several variables were then calculated using the pressure plate software. These were; foot balance (= M1+M2+HM-M3-M4-M5-HL), heel rotation (= HM-HL) (Figure3.1) and time to reach peak heel rotation (TPHR). TPHR was defined as the instant (i.e. % of stance phase of gait cycle) at which the heel rotation variable

peaked. The study was restricted to the analysis of barefoot walking which has been shown to be most sensitive and effective for developing risk factor models of this nature (Willems et al., 2007).
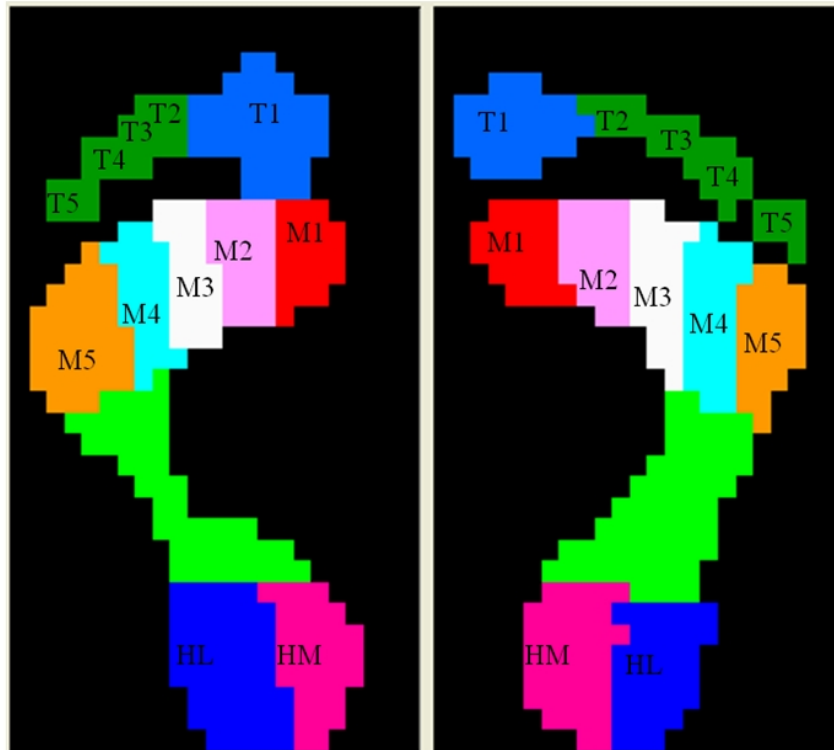
Figure 3.1. The location of peak pressure left and right foot print (RsScan International Software 7.0).

3.3.4. Data analysis.

Separate statistical tests were used to assess each of the two study aims. To test the differences between the MTSS and non-MTSS groups (Aim 1), analysis of variance (ANOVA) and independent t-test were used on the continuous variables and chi-square tests on the categorical variables. To test their relative importance and to

develop the predictor of MTSS (Aim 2) a multiple hierarchical logistic regression (HLR) model was developed (Ullrich-French et al., 2009).

Foot balance at each percent of gait was analysed using ANOVA with repeated measures (Nadeau, et al., 1997) with appropriate post-hoc analysis. To analyse for differences during the stance phase, the plantar pressure data on foot balance for the MTSS group were compared to the non-MTSS group on the variables of time and pressure. The repeated measures within-subject effect was each percentage of the stance phase. The between subject effect was MTSS and non-MTSS (group). Foot balance values were averaged with respect to time over 0-20% of the gait cycle yielding a representative discrete value for foot balance. The data for the foot balance were then dichotomized into "good" and "poor" based on mean values for the sample. Performance was determined as "good" if the value lay within one standard deviation of the mean, and "poor" if the values were outside one standard deviation (Pohl et al., 2008a) and in a positive direction. By definition, ''poor'' foot balance effectively means that medial pressures are dominate and are generally considered to be indicative of pronation; a triplaner motion consisting of eversion, abduction, and dorsiflexion (Abboud, 2002; Willems et al., 2007). In contrast, ''good'' effectively means that the medial and lateral pressures are either even, or the lateral pressures are greater than the medial. A similar approach was also adopted for the 1.5 mile timed-runs. Fitness level was determined as "poor" when the run time lies outside one standard deviation of the mean and in the positive direction. Independent t-tests were performed on other continuous variables and X^2 tests were performed on the categorical variables.

The second aim was to develop a MTSS predictor tool for use with army recruits. Accordingly, the HLR model (Ullrich-French et al., 2009) was conducted in seven steps (Table 3.3) to include all independent variables which may have predictive capacity. This method is an appropriate to establish the probability on the dichotomous dependent variable (MTSS or non-injury) and also minimised some of the potential random variation (Tabachnick et al., 2001).

Those variables which showed statistically significant differences between the groups (p<0.05) in the initial analysis (i.e. ANOVA, independent t-tests and X^2 tests) were subsequently entered into a HLR model (Hubbard et al., 2009). Post-hoc analysis on ANOVA indicated that foot balance during the first 20% of gait was significant. Therefore, an average single value (foot balance, % gait cycle) during this period was calculated and entered into the HLR. This approach overcomes some of the weaknesses of taking single discrete points from continuous data (Nadeau et al., 1997). Since previous research has shown smoking and lack of fitness to be risk factors (Munnoch et al., 2007; Shaffer et al., 1999), these variables were entered as predictors at step 1 and step 2, respectively. At Step 3, a combination of smoking and fitness level were entered in pursuit of an improvement in the model. At Step 4 foot balance was entered in isolation to check its contribution to predictive capacity. At Step 5 TPHR and fitness were added and at Step 6 foot balance and smoking behaviour were entered. At Step 7 all independent variables were entered (Ullrich-French et al., 2009). Alpha was set at 0.05 and data was analysed using SPSS 16.0 software (SPSS Inc., Chicago, IL).

3.3. Results

The non-MTSS group (n=239) in this study included those with upper arm injury and non-related medical conditions. Subjects sustaining lower leg injuries other than MTSS (Yates et al., 2004) and/or lower back pain (n= 193) were excluded from all analysis. During the 26 week period, 37 of the 468 subjects developed MTSS (n = 37, bilateral in 15, left 11 and right 11). In cases of bilateral MTSS the limb with the worse injury diagnosis was included. The overall incidence rate of MTSS was 7.9%. These injuries occurred predominantly in the first phase of training (n = 31, between weeks 3 and 10).

In order to determine whether the foot pressures were different between groups over the stance phase, plantar pressure on foot balance data were analysed using a 2(Group) X 100 (%gait) 2-way ANOVA with repeated measures of gait cycle on foot balance. Results revealed a significant interaction effect (percent of gait cycle x group) for foot balance ($F_{93,184}$= 1.62, p <0.01). Follow-up independent t-tests revealed significant differences (p = 0.03) between groups during the first phase of gait (1-20%). During this phase, the MTSS group had consistently higher medial pressure and a more rapid increase in medial pressure (Figure 3.2a). Regional peak pressure (Figure 3.2b), TPHR (Figure 3.2c) and 1.5 mile timed-run (Figure 3.2d), results revealed that there was significantly higher peak pressure in the MTSS group than in the non-MTSS group in both the region underneath the medial heel (p = 0.03) and 1st metatarsal (p < 0.01), but lower pressure beneath the 5th metatarsal (p =

0.03). The MTSS group had a shorter time to peak heel rotation (TPHR) (p < 0.01)

and a slower 1.5 mile timed-run (p < 0.01). In contrast, there were no significant

differences (p > 0.23) in lateral heel pressure, age, weight, height, BMI, press up, sit

up, BES, DLS, SLS, GTI and PQAP (Table 3.1).
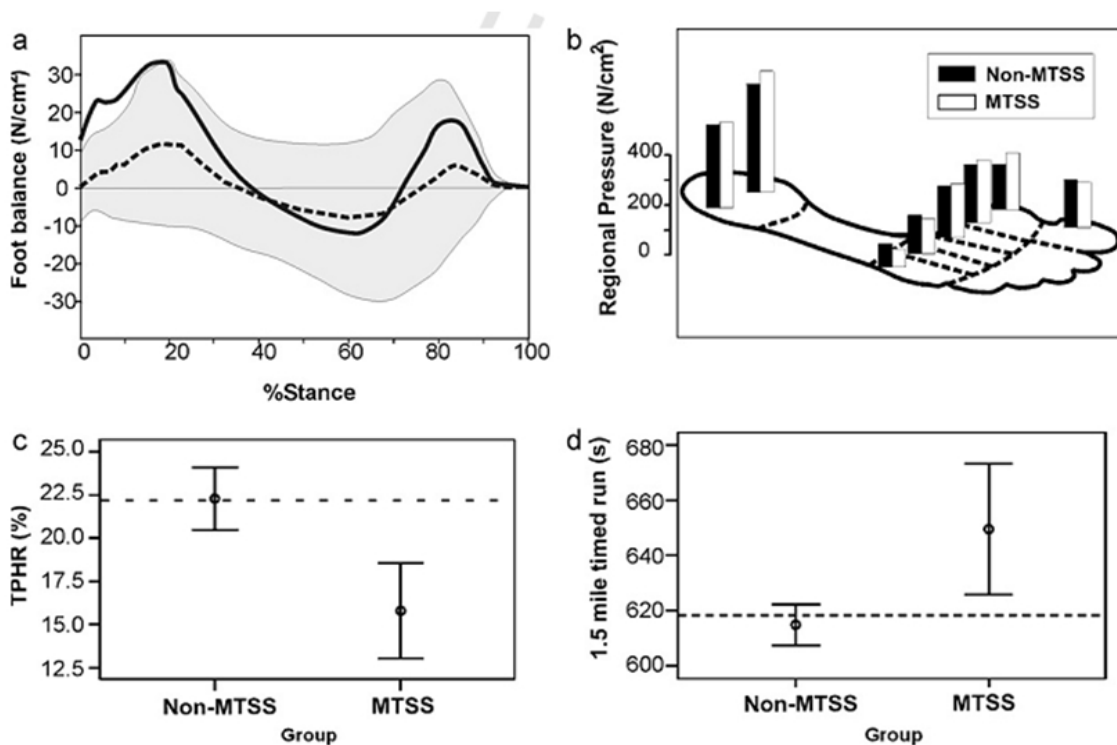
Figure 3.2.a) Mean ensemble data for foot balance (N/cm2) for the MTSS (continuous line) and non-MTSS (dashed line, grey area ±1SD) groups during the stance phase of gait cycle. Positive valuesindicate pronation (i.e. greater medial pressure) and negative values indicate supination (i.e. greater lateral pressure). b)Regional peak pressures (N/cm2) in 8 segmented regions of the foot during the stance phase of the gait cycle. c) Time to reach peak heel rotation (TPHR) expressed as percentage of stance phaseof gait cycle (%). The dotted line represents the group mean value and the 95% confidence intervals are shown. d) Fitness as measured by the 1.5 mile timed-run (s). The dotted line represents the group mean value and the 95% confidence intervals are shown.

3.1. Descriptive statistics for participants' physical characteristics and selection test scores					
Variable	MTSS		Non-MTSS		p
	Mean	SD	Mean	SD	
Age (yr)	20.9	2.6	19.2	2.54	0.92
Height (cm)	177	6.3	176	6.45	0.28
Mass (kg)	69.4	9.8	69.2	8.66	0.34
BMI (kg/m^2)	22.15	6.1	22.33	6.31	0.41
Press ups (number in 2 min)	44.6	16.8	45.2	17.4	0.67
Sit ups (number in 2 min)	63.3	11.2	63.8	11.9	0.89
BES (kg)	94	16.2	95	15.8	0.78
DLS (kg)	60	11.2	59	10.5	0.76
SLS (kg)	119	23.1	117	24.2	0.27
GTI	49	10.3	48	9.6	0.23
PQAP	56	4.55	55.5	5.32	0.42
BES=back extension strength, SLS= static lift strength , DLS = dynamic lift strength, GTI = General Trainability Index, PQAP = Personal Qualities Assessment Profile					

The Chi-squared test revealed significant differences between the MTSS and the non-MTSS group for the dichotomised biomechanics variables ($p < 0.001$), smoking habit ($p < 0.001$) and fitness level ($p < 0.001$). The participants who developed MTSS were more likely to have poor biomechanics as well as a smoking habit and poor fitness (Table 3.2).

Table 3.2. Chi-square test for association between group						
Variables		MTSS n=37 (%)	non-MTSS n=239 (%)	Test statistics	p-value	Odds ratio (95% CI)
Biomechanics	"Good"	11 (29.72%)	206 (86.20%)	41.85	<0.001	9.16 (4.32-19.42)
	"Poor"	26 (70.27%)	33 (14.17%)			
Fitness	"Good"	16 (43.24%)	176 (73.40%)	13.56	<0.001	3.62 (1.77-7.38)
	"Poor"	21 (56.76%)	63 (26.67%)			
Smoking	Yes	25 (67.60%)	58 (24.20%)	28.78	<0.001	6.54 (3.09-13.82)
	No	12 (32.40%)	181 (75.80%)			
CI = confidence interval						

Logistic regression with the membership categories of MTSS and non-MTSS participants as the dependent variables and foot balance (average single value from the first 20% gait cycle), TPHR, 1.5 mile timed-run and smoking habit as predictor variables showed the full model to predict MTSS significantly (p = 0.02). The model was capable of predicting 96.9% of the non-MTSS and 67.5% of the MTSS membership and overall 87.7% accuracy for membership was observed. The odds ratio for both foot balance and 1.5 mile timed-run were greater than one indicating that an increase of each unit is associated with an increased probability of developing MTSS. For example, an increase of each unit of foot balance during heel strike is associated with an increase in probability of developing MTSS by a factor of 1.14 (95% CI 1.08 and 1.21) (Table 3.3).

Table 3.3. Logistic regression model for the prediction of MTSS									
Predictors		B	SE	Sig	OR	95% CI		Predicted % Correct	
						Lower	Upper	MTSS	non-MTSS	Overall
Step 1	Smoke Constant	1.88 -2.71	0.38 0.30	<0.001 <0.001	6.54	3.09	13.83	0.00	100	86.60
Step 2	Fitness (s) Constant	0.01 -7.65	0.001 1.87	<0.001 <0.001	1.01	1.01	1.02	0.00	100	86.10
Step 3	Fitness (s) Smoke Constant	0.01 2.05 -9.59	0.001 0.40 2.07	<0.001 <0.001 <0.001	1.01 7.745	1.01 3.51	1.02 17.11	16.50	97.80	86.10
Step 4	Foot balance (N/cm^2) Constant	0.14 -2.62	0.04 0.27	<0.001 <0.001	1.15	1.09	1.20	31.62	98.59	89.20
Step 5	Foot balance (N/cm^2) TPHR (%gait cycle) Fitness (s) Constant	0.12 -0.04 0.001 -5.80	0.05 0.03 0.001 2.19	<0.001 0.1 0.03 <0.01	1.13 0.94 1.01	1.07 0.92 1.00	1.18 1.02 1.02	40.50	95.70	89.10
Step 6	Foot balance (N/cm^2) Smoke Constant	0.14 2.01 -3.58	0.03 0.45 0.41	<0.001 <0.001 <0.001	1.15 7.50	1.09 3.12	1.21 18.03	48.6	97.10	89.90
Step 7	Foot balance (N/cm^2) TPHR (%gait cycle) Fitness (s) smoke Constant	0.13 -0.05 .009 2.25 -8.57	0.03 0.03 .003 0.48 2.41	<0.001 0.1 <0.01 <0.001 <0.001	1.14 0.95 1.01 9.50	1.08 0.93 1.01 3.73	1.21 1.04 1.02 24.21	67.50	96.90	87.70
CI= Confidence Interval, TPHR= Time to Reach Peak Heel Rotation, OR= Odds Ratio										

3.4. Discussion

The principle aim of this study was to develop a prospective risk factor model for the development of MTSS in a military recruit population. The overall incidence of MTSS in this study is 7.9% which is comparable with previous studies (Bennett et al., 2001). The most effective management of MTSS is prolonged rest followed by a graduated return to fitness (Yates et al., 2004; Craig, 2009). This condition often leads to a loss of training days, increased cost of medical support and reduction in operational readiness or participation in physical training as well as limitation of performance in military and sports populations. For example, MTSS caused a 50-60% training interruption of runners (Reinking et al., 2007) and 67% loss of training time in military recruits (Yates et al., 2004). Therefore, injury is a significant problem to the military population. The study revealed that dominant medial plantar pressures as well as quick heel rotation, low aerobic fitness (as measured by 1.5 mile timed-run) and a smoking habit are all risk factors for developing MTSS. The logistic regression model combining all three of these risk factors is capable of predicting 96.9% of the non-injured group and 67.5% of the MTSS group. Overall the model has an accuracy of 87.7%.

To date, this is the first prospective study to examine biomechanical variables along side lifestyle variables to assess potential risk factors for MTSS. The sample size is relatively large when compared to previous studies (Yates et al., 2004; Hubbard et al., 2009; Franettovich et al., 2010). In addition, by using army recruits on a recognised

training protocol, it is suggested that the external potential risk factors are well-controlled. Specifically, over the 26 week training period recruits wear the same shoes, walk over the same surfaces and undergo similar levels of activity. It is therefore possible to interpret the results of the model with reasonable confidence.

As noted, the MTSS group in this study were characterised by greater medial pressure than the non-MTSS group. These trends are similar to those reported previously (Willems, et al., 2006; Willems et al., 2007). An additional feature, not previously identified during running was that the MTSS group had higher peak pressure on the heel which may be indicative of a more rigorous heel-strike during walking. Overall, these patterns of "poor" biomechanics occurred in more that 70% of the MTSS group but in only 14% of the non-MTSS group. It is therefore suggested that these biomechanical variables are primary risk factors. However, when biomechanics variables are considered in isolation, the logistic regression model is only capable of predicting 31.6% of the MTSS group. This is much lower than the 67.5% when smoking and fitness are included. Hence, the risk of injury appears to be determined by the additive and/or interaction effects of other factors (Meeuwisse, 1994).

The result revealed that those recruits with lower fitness were 3.6 times more likely to develop MTSS during the training period. Such findings are supportive of a link between lack of fitness and overuse injuries developed during an intense training period (Gardner et al., 1988; Wang et al., 2003a). However, it should be noted that

the regression model was not able to predict injury based on fitness in isolation and thus fitness should not be considered a primary risk factor. However, the inclusion of fitness improved the model's ability to predict MTSS by almost 10%. It is therefore logical to suggest that "poor" aerobic fitness is additive to "poor" biomechanics as a risk factor for MTSS. Running and walking gait requires tonic and phasic both local and global muscle activity and peak periods muscle occurs with heel strike (Chuter et al., 2012). In load bearing both passive and active mechanisms support the medial arch. Passive support is achieved by a tensioned planter fascia and actively by intrinsic foot muscles (Lewit et al., 2012) and the tibialis posterior muscle (Brunt et al., 2003). A potential reason is more rapid fatigue of the intrinsic plantar musculature during activity (Headlee, et al., 2008; Lewit et al. 2012). Furthermore, poor core stability increases femoral adduction and internal rotation with valgus knee positioning and may have an impact on distal biomechanical function which may lead to greater foot pronation during landing and subsequent mechanisms of leg and foot injury (Chuter et al., 2012). A recent study demonstrated that muscle imbalance especially between the inversion and eversion muscles, (Yuksel et al., 2011) and altered neuromuscular control of gluteus medius and lateral gastrocnemius were also risk factors for exercise related leg pain (Franettovich et al.,2010).

Similar findings occur for smoking which is known to be a risk factor for a range of lower limb injuries (Jones et al., 1999, Knapik et al., 2001a; Kanis et al., 2005; Munnoch et al., 2007). The presented model was not able to predict MTSS based on smoking habit in isolation and thus partially disagrees with the general consensus that

smoking increases injury risk. However, when smoking is considered alongside "poor" biomechanics as a risk factor, the model's accuracy in predicting MTSS injury is increased by almost 20%. From this perspective, smoking clearly increases the risk of injury but does this predominantly in subjects with "poor" biomechanics. A potential reason is that the "poor" biomechanics predispose the lower limb to elevated stresses through traction and/or tibial torsion. Smoking affects microcirculatory function (Siafaka et al., 2007) and hypoperfusion and impairs the microcirculation in trauma or overloaded tissue. Smoking is associated with delaying/impairing tissue repair (Jorgensen, et al., 1998; Raikin et al., 1998; Wong et al., 2004; El-Zawawy et al., 2006; Gill et al., 2006; Karim et al., 2006). In addition, smoking may have negative impact on the Wolff Law training effects/stress principle. These principle state that microscopic tissue damage is required to get training effects. These areas of microscopic tissue damage are filled by new tissue and the tissue becomes stronger (McGinnis,1999). However, since cigarettes release tissue damaging oxygen free radicals (Huang et al., 2005) and delay tissue healing these stresses are likely to have a more detrimental effect on the tissues of the smoker's body.

All other variables age, weight, height, BMI, press up, sit up, BES, DLS, SLS, GTI and PQAP are not influences in development of MTSS. They are comparable with those in another study (Colclough, 1999; Pope 2002a; Allsopp et al., 2003; Rayson et al., 2003; Blacker et al., 2008). This research poses questions as to whether the typical selection battery test used in army selection centres has internal validity problems.

Not surprisingly, the model combining the three variables was able to predict MTSS with the greatest confidence. The efficiency of this predictive model to consider the parameters simultaneously could be an important stage in identifying those at risk, particularly in a group where previous history of injury is difficult to obtain. The predictive power of this combined risk factor model is greater than that demonstrated by a previous model (Hubbard et al., 2009). They used discriminate analysis which revealed that four factors - plantarflexion range of motion, running years, orthotic wear, and previous history explained 44.6% of MTSS group membership.

An important aspect of this model for the purpose of predicting injury in recruit population, is that it is able to function efficiently in a sample with no known previous injury. However, a limitation of the model is that it has not been tested on a different cohort from the same population in order to verify its suggested validity. In addition, a further limitation was that it was not able to predict the remaining 32.5% of MTSS group membership. Consequently, there is clearly room for improvement and it is suggested that the predictive ability may be increased by overcoming some of the limitations of the data collection process. For example future improvements could include a more detailed quantitative examination of the current variables. 3-D dimensional motion data to measure pronation of the foot, breath-by-breath analysis to measure fitness, pulse oximeters to measure tobacco smoking could all improve the quality of data. Furthermore, an improved model may also include the addition of other potentially discriminating variables.

These discriminating variables may include bone density, inflammatory markers and nutritional status all of which are shown to be potential risk factors for MTSS (Bennell et al., 1996; Franklyn et al., 2008; Craig, 2009) even though a recent study demonstrates that tibial bone densities were not lower in athletes with MTSS compared to the healthy control group (Ozgurbuz et al., 2011). Nonetheless, the model in its current form is shown to have potential in predicting non-MTSS and is reasonably accurate in predicting MTSS over a 26 week training period. It therefore provides a potential screening tool to identify those recruits at risk of developing MTSS and could form the basis for intervention-based studies to target the primary risk factor (i.e. over-pronation) by correcting "poor" gait patterns prior to the intensive training programme.

3.5. Conclusions

The model combining biomechanics and lifestyle factors is shown to be effective in predicting non-MTSS and reasonably effective in predicting MTSS over a 26 week training period. Excessive medial pressure on the plantar surface of the foot as well as fast heel rotation during walking, collectively termed over-pronation, are the primary risk factor variables for the development of MTSS. Further research is necessary to explore whether adverse gait pattern can be modified.

3.6. Implications for practice and research

Foot pronation, as measured by heel rotation, is a primary risk factor for MTSS.

Chapter4. The Effect of a Gait Retraining Programme on Plantar Pressure Variables

and the Incidence of MTSS in a 26 Week CIC Training Period: Introduction and

Evaluation of a Preventative Measure (Study 3).

4.1. Introduction

As revealed in Chapter 3, abnormal forces and movement placed on the body or normal magnitude of force applied to the body incorrectly, during walking or running can cause impaired performance and injury (Lord, 1981; Norris, 1998; Hodge et al., 1999; Jones et al., 2001; Abboud, 2002; Pohl et al., 2008b). Primary prevention entails identification and elimination or minimisation of factors which place the individual at risk (Fletcher et al., 1996; Meeuwisse et al., 2009). Some of these abnormalities can be identified by eye include lower limb alignment and posture as well as movement-related problems (Dahle et al., 1991; Jonson et al., 1997; Razeghi et al., 2002), however, others can only be identified objectively through the use of an appropriate measurement system (Whittle, 2007).

A normal pattern of gait is believed to allow the leg to pivot over the point of ground contact with normal pronation and supination with these pronation and supination movements occurring via the subtalar joint (Donatelli, 1990; Rockar, 1995; Hintermann et al., 1998; Hunter et al., 2004) which through the kinetic chain controls internal and external rotation of the tibia (Harradine et al., 2006; Chuter et al., 2012). Gait biomechanics involves the functional integration of all skeletal, muscular and neurological components that work together while performing activities (McGinnis, 1999; Brukner et al., 2012). It involves the analysis of forces and motions and their effects on the human body during gait and sporting activities (Dugan et al., 2005; Winter, 2009). Biomechanically, the skeletal system contributes an arrangement of

rigid links connected to each other at joints which enable specific movement (McGinnis, 1999). The skeletal muscles are the motor and active force generators which produce movement of the limbs, maintain posture and impart stiffness to the joints while the nervous system collects and analyses information from external and internal stimuli and then initiates and controls musculoskeletal system response to stimuli (McGinnis, 1999). For this reason, biomechanical knowledge is vital to clinical professionals in identifying what mechanism is responsible for injury and to prevent injury.

A possible cause of MTSS injury has been suggested to be excessive or prolonged pronation of the foot which manifests itself in the form of over-pronation (Hunter et al., 2004; Williems et al., 2007; Sharma et al 2011a). It has been postulated that over-pronation causes an increase in the magnitude and velocity of internal tibial rotation due to muscle weakness, poor neuromuscular control or misalignment of joint centres which in turn leads to over loading of the tibial muscles and results in tensile stresses ultimately leading to MTSS (Yates et al., 2004; Wearinget al., 2006; Bouche et al., 2007).

Abnormal gait pattern including plantar pressure variables have been linked to overuse injuries (Willems et al., 2007, Sharma et al., 2009; Stolwijk et al., 2010). Traditionally, the data from plantar pressure analyses are used to prescribe custom-made orthotic insoles (Hodge et al., 1999; Franklyn-Miller et al., 2011) which in the case of over-pronation are designed so as to ensure alignment of the subtalar joint to

minimise the risk of imbalances and hence, reduce the muscle activity required to stabilise the foot (Hunter et al., 1995; Landorf et al., 2007). In a recent study (Franklyn-Miller et al., 2011) the dynamic plantar pressure distributions of military officers were assessed and they were issued with gait-modifying orthotic insoles. The study found a significant reduction in the incidence of injury and the use of orthotics was recommended for recruits with abnormal plantar pressure distributions. However, the use of custom-made insoles is an expensive option for the British Army and, although currently adopted for cases of continued lower-limb injury, orthotic insoles are not considered as an ideal solution. In addition to the cost, the participants tend to become over-reliant on orthoses and the underlying biomechanical problem remains unaddressed (Hubbard et al., 2009; Noehren et al., 2011).

Although not yet tested in the foot and ankle, there is emerging evidence to indicate that individuals are able to modify their gait to overcome gait-related problems as long as they can visualise what the underlying problems are. The process of providing gait bio-feedback has been tested in unilateral hip replacement participants and running economics (Messier et al., 1989; White, 2005). Specifically, gait retraining, involving real-time bio-feedback, has been shown to improve loading symmetry of the hip joint (White, 2005). Another study by Crowell et al., (2010) with repeated study design using five subjects found that real-time visual feedback is effective to reduce in impact peak and loading rate. A recent study by Noehren et al., (2011) used patellofemoral pain syndrome participants to determine whether gait retraining using real-time feedback improves hip mechanics and reduce pain. They found significant

improvement of hip mechanics while running. However, although demonstrating "remarkable" potential these studies have so far been restricted to patients suffering from hip and knee disorders and abnormal gait may be due to the presence of pain (Whittle, 2007; Schmid et al., 2013). These studies contribute to the knowledge that participants can learn to alter their gait pattern using real time feedback, however, it is not known whether such benefits can also be achieved with healthy individuals in order to gain control of over-pronation thereby reducing MTSS injury during recruits training. It remains to be seen whether gait retraining could provide a viable and sustainable solution to over-pronation as opposed to the prescription of orthotics.

4.1.1. Aim.

The aims of this study were to quantify the effects of a gait re-education programme on plantar pressures and MTSS incidence over a 26 week recruit training period.

4.2. Methods

4.2.1. Participants.

The study design was a prospective randomised trial. It was a 4 block size randomisation which was used to assign the participants in intervention (I) and control group (C).The order of randomisation was CCII, CICI, IICC, ICIC based on the order the recruits were waiting in the queue. A pool of 450 British infantry recruits volunteered for the study and were assessed during initial medical for MTSS risk factors using the protocol described in Chapter 3. The participants had no known

injury at the time of testing and all signed an informed consent form. The local army (ITC) approval was gained prior to conducting the study. The study was approved by the Ethics Committee of Teesside University, UK. All participants underwent 26 weeks of CIC training (see Appendix A).

4.2.2. Data collection.

During the obligatory initial medical assessment as part of the research process the new trainees underwent a 3-minute treadmill barefoot walking session whilst being observed by a trained physiotherapist. The Army physiotherapists working at ITC all had at least 5 years of practice in the clinic and were under instructions to identify trainees with abnormal gait using a published screening process (Comerford, 2007; Brukner et al., 2012). Those with observable abnormal gait biomechanics were then assessed objectively using plantar pressure analysis protocol described in Chapter 3. The plantar pressures were collected by the Ph.D. candidate. The variables, heel pressures (medial and lateral), foot balance and time to reach peak heel rotation were then used to objectively quantify those at risk of MTSS. For the purpose of this study the inclusion and exclusion criteria is presented in Table 4.1.

Table 4.1. Inclusion and exclusion criteria for prehabilitation study	
Inclusion criteria	**Exclusion criteria**
All new line regiment recruit Initial gait assessment using RSscanPlanter pressure measurement showed poor gait pattern away from one standard deviation from mean in peak foot balance were eligible to participate in this study. Signed inform consent form	Previous any lower limb injury affecting gait pattern over 3 weeks Any neurological involvement Pre-existing orthotic use had good gait pattern on baseline measurement Withdraw consent form.

The total 166 participants at risk of developing MTSS based on the risk factor model in Chapter 3, were randomly allocated to the intervention or control group in accordance with CONSORT statement shown in Figure 4.1. Among these 166 participants, 134 recruits (age 20.1 ± 2.03 years; height 167 ±1.4 cm; body mass 67 ± 2.4 kg) were used for final data analysis. Baseline demographic participant characteristics in both groups are presented in Table 4.2. The plantar pressure variables were stored and used as baseline measurements in the subsequent analyses. Injured recruits presented to the medical centre for assessment, diagnosis and treatment. Medical officers who made diagnosis' were unaware of the study groups. Injury data was collected prospectively over the 26 weeks of training period. Post-testing data of plantar pressure measurements of the 134 recruits were taken on the last day of the programme.

4.2. Baseline demographic group characteristics for prehabilitation study					
	Control		**Intervention**		
Variable	Mean	SD	Mean	SD	p
Age (yr)	21.41	2.8	20.26	2.54	0.82
Height (cm)	176.9	6.4	177.23	6.25	0.58
Mass (kg)	70.4	9.8	69.9	8.46	0.39
BMI (kg/m^2)	22.49	6.24	22.25	6.12	0.31
Press ups (number in 2 min)	46.6	15.8	45.2	16.4	0.37
Sit ups (number in 2 min)	64.3	10.2	64.8	10.9	0.89
BES (kg)	95	15.2	96	14.8	0.72
DLS (kg)	62	10.23	61	10.15	0.73
SLS (kg)	118	22.1	117	23.3	0.27
GTI	50	11.3	49	10.6	0.43
PQAP	58	4.45	57.5	5.12	0.42
BES=back extension strength, SLS= static lift strength , DLS = dynamic lift strength, GTI = General Trainability Index, PQAP = Personal Qualities Assessment Profile					
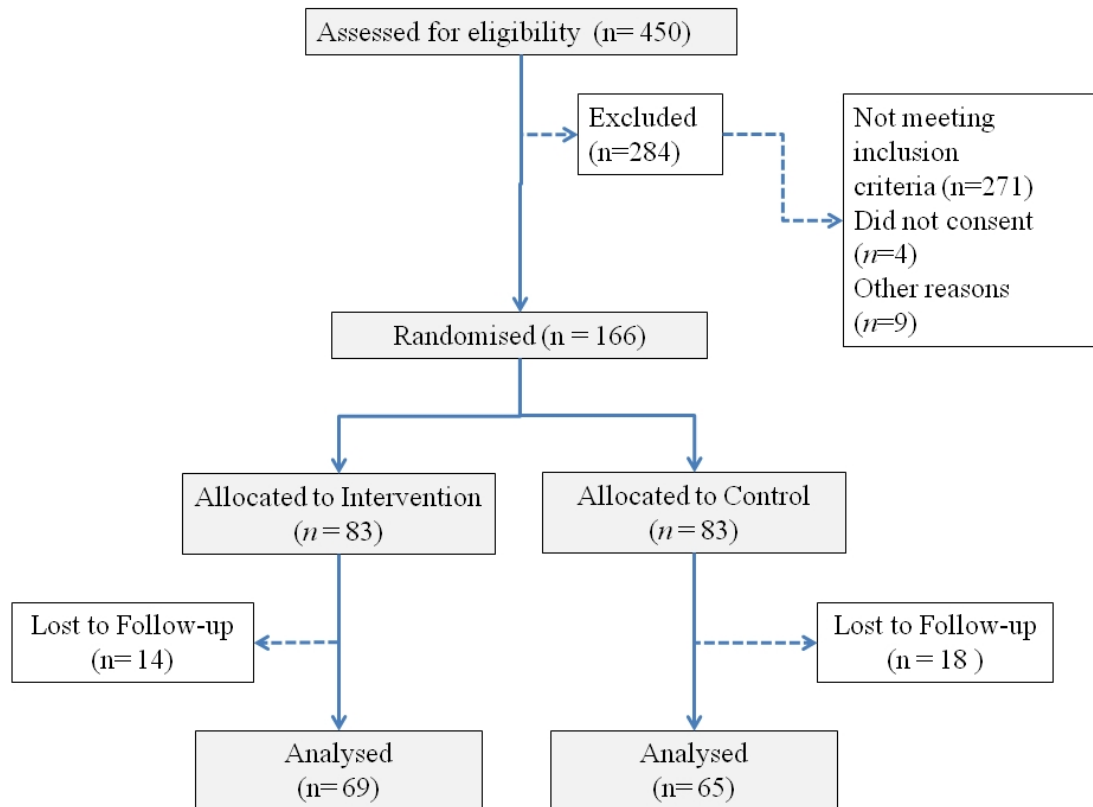
Figure 4.1. The CONSORT flow diagram used for recruitment and allocation of participants.

4.2.3. Delivery of intervention.

In the process of developing gait retraining correcting exercise to enhance both distal and proximal component each facet of the exercise was reasoned on a knowledge of lumbo-pelvic to distal muscle dysfunction found in abnormal gait participants (Ireland et al., 2003; DePalma, 2004; Willson et al., 2006; Janda et al., 2007; Franettovich et al., 2010; Chuter et al., 2012; Schmid et al., 2013). Several decisions had to be made to design the most suitable exercise programme. These include the type of muscle contraction (such as concentric, eccentric and isometric), the body positions, the level of resistance, the number of repetitions and methods of progression (Prentice, 2004).

These decisions were based on combined clinical experience working in various organisations including the Army as well as evidence in the literature to address several components of potential musculoskeletal deficiency; including exercises to increase strength, flexibility and neuromuscular control (Hibbs et al., 2011; Coppack et al., 2011). The regions targeted were the foot, leg and, in contrast to previous studies, the lumbo-pelvic complex. Since these muscle group of the foot, leg and core regions are essential to maintain the shape of the functional foot, provide stability and balance (Low et al., 1996; Fiolkowski et al., 2003; Headlee et al., 2008; Lewit et al., 2012) whilst during locomotion they generate a large moment during propulsion (Bandholm et al., 2008). In addition a system for providing bio-feedback using the plantar pressure system described previously was developed. Specifically, participants were encouraged to walk with their head and chest up, a slight anterior tilt of the pelvis and with only moderate movements of the centre of mass in the vertical direction (Norris, 1998; Comerford, 2007). Plantar pressures were then visualised immediately after the trial thus providing bio-feedback on the heel rotation variable (i.e. the risk factor for MTSS). Each bio-feedback session lasted approximately 30 minutes and was conducted once per week in which visual bio-feedback was provided 3-4 times per session.

The retraining program consisted of several exercises based on the existing literature (Table Appendix E) and was designed to target musculoskeletal deficiencies reported to be risk factors associated with lower limb overuse injuries. Since the origins of training injury are clearly complex and multifactorial (Hreljac et al., 2000), a

multifaceted training strategy was used (Hubscher et al., 2010). Certain muscle groups are pre-disposed to tightness or weakness based on their function and control by the central nervous system and serve different functions and movement patterns (Janda, 1987; Janda et al., 2007; Page et al., 2010). Postural muscles would respond to dysfunction with increased tightness, while the ''phasic'' muscles would respond with weakness, creating characteristic muscle imbalance syndromes and classified as ''upper crossed'', ''lower crossed'', and ''layer'' syndrome (Janda, 1987). Such muscle imbalances led to movement impairments and ultimately changed the motor programming within the central nervous system (Janda et al., 2007).

Muscles have the ability to produce the range of motion at joints, postural control and decelerate motion by controlling excessive range of motion (McGinnis, 1999). Muscles with multi-joint attachments, primarily have a mobility role and are biomechanically very efficient in producing movement during concentric shortening, however, they are not efficient during eccentric lengthening. On the other hand, stability role muscles are biomechanically very efficient during eccentric lengthening to limit excessive movement to prevent against overstrain (Comerford, 2007). In addition, muscles also provide afferent proprioceptive feedback to the central nervous system to coordinate and regulate muscle stiffness and tension (Janda, 1987; McGill, 2002). For normal functions it is important to train both groups of muscles as they all contribute to safe and efficient performance and in order to prevent muscular imbalance and development of compensatory movement patterns which are less efficient (Cook, 2003; Cook et al., 2006a; Cook et al., 2006b; Kiesel et al., 2007).

Biomechanically coordinated muscle actions are able to withstand more load whilst poorly coordinated muscle actions are biomechanically vulnerable and develop injury (Foreman et al., 2006).

A multifaceted exercise programme was developed (Hubscher et al., 2010) to address all the possible multifactorial risks (Hreljac et al., 2000) and causes of injury. The stretching exercises were as follows; hip flexor stretch (Coppack et al., 2011), hamstring stretch (Hartig et al.,1999; Sharma et al., 2004b) and calf stretch (Pope et al., 2000). The exercises to target neuromuscular control/strength were as follows; birddog (Brandon, 2006; Hibbs et al., 2011), gluteal medius (Coppack et al., 2011), small knee bent progressing to single leg squats (Comerford et al., 2001; Comerford, 2007), calf raise (Kulig et al., 2009), tibialis posterior control (Kulig et al., 2004), intrinsic foot muscle control (Jam, 2004; Sauer et al., 2011) and a double leg jump (Stephens et al., 2007). The balance/neuromuscular control exercises were the star excursion stability exercise (Chaiwanichsiri et al., 2005), single limb hops to stabilization (McKeon et al., 2008a) and unanticipated hop to stabilization (McKeon et al., 2009a; McKeon et al., 2009b). The training sessions were scheduled 3 times per week and the load was gradually increased by increasing the number of repetitions. The program consisted of 10 exercises performed in sets of 10 in week 1 and 14 in week 26 (e.g. Coppack et al., 2011). Each session lasted for approximately 30 minutes. The learning of a new gait pattern was performed using instructions administered by a physiotherapist who carried out all the baseline measurements and conducted the intervention. The physiotherapist has more than 10 years clinical

experience, works for the army and is also the principle researcher. Supervision was gradually reduced over the training period. In weeks 1-4, 5-6, 7-10 and 11-24, supervised sessions were conducted 3, 2, 1 and 0.5 times (i.e. fortnightly), respectively.

4.2.4. Data analysis.

The independent variables were group (intervention, control) and test (pretest, posttest). The dependent variables were foot balance, regional peak pressures (on the medial and lateral heel, metatarsal 1-5 and big toe), time to peak heel rotation and injury and non-injury. For each of the biomechanical measures, the entire gait cycle was considered. In order to determine potentially meaningful differences, the means and associated 95% confidence intervals for each variables were calculated across the entire gait cycle for both groups on both occasions (pre-test, post-test). MANOVA were used to examine the effectiveness of the intervention programme on the biomechanical variables between-groups and pre-test to post-test within- group. MANOVA was used instead of conducting a series of ANOVA or t-test separately to prevent type 1 error (Tabachnick et al., 2001). Proportion of injury were analysed using KM survival plot and proportion overall injury at the end of 26 week training was compared using the log rank test. The data were also analysed with respect to risk reduction and number of recruit needed to treat analysis (Bowers, 2008, Franklyn-Miller et al., 2011).

4.3. Results

Assumption tests were performed to check for normality, linearity, homogeneity of variance-covariance matrix and multi-colinearity, there were no violations noted. There were significant differences for the intervention and control group on the combined biomechanical variables, $F_{(20,109,)} = 8.05$, $p = 0.001$; Wilks Lambda = 0.40; partial eta squared = 0.98. Post hoc t-test showed that there were no significant changes in pre-test to post-test for the control group ($P > 0.39$) but there were changes on intervention group pre-test to post-test on the biomechanical variables of interest: foot balance, pressures on the medial and lateral heel and time to reach peak heel rotation (TPHR) (Table 4.4). The mean scores and 95% CI are presented in Table 4.4. The post-test values indicated that the intervention group had better biomechanics than the control group and significantly improved biomechanics in pre and post were seen in the intervention group but not the control group. Once the results for the dependent variables were considered separately the only difference to reach statistical significance were foot balance $F_{(1,128)} = 132.74$, $p = 0.001$, partial eta squared 0.51 and time to reach peak heel rotation $F_{(1,128)} = 0.30$, $p = 0.01$ partial eta squared 0.11. However, there were no significant differences between the pre-test and post-test measures in the control group or the pre-test measures for the both groups ($P > 0.05$). Overall 15% pressure decreased in the intervention group compared to the control group.

Table 4.3. Mean and 95% Confidence Interval (CI) for plantar pressure variables. The 95% CI are shown in brackets

Variables	Intervention group		Control group		Pairwise	
	Pretest	Posttest	Pretest	Posttest	Group effect	p
FB (N/cm^2)	19.83 (16.99-22.66)	6.274 (2.93-8.62)	18.98 (16.15-21.81)	20.144 (17.79-22.49)	15.870 (12.55-19.19)	0.001
MH (N/cm^2)	429.513 (391.62-467.41)	395.623 (362.48-428.77)	434.192 (396.30-472.08)	451.636 (418.49-484.78)	56.013 (9.14-102.88)	0.020
LH (N/cm^2)	331.91 (301.77-362.04)	305.04 (279.09-330.98)	321.65 (291.51-351.79)	343.36 (317.42-369.31)	38.323 (1.64-75.01)	0.04
M1 (N/cm^2)	180.28 (159.13-201.44)	181.32 (161.43-201.22)	173.82 (152.67-194.98)	175.74 (155.85-195.64)	-6.459 (-36.38-23.46)	0.69
M2 (N/cm^2)	216.25 (192.43-240.07)	231.03 (203.40-258.66)	218.54 (194.71-242.36)	236.86 (209.23-264.48)	5.827 (-33.24-44.89)	0.76
M3 (N/cm^2)	186.44 (161.67-211.27)	187.65 (162.83-212.46)	186.77 (161.94-211.59)	184.19 159.37-208.99)	-3.460 (-38.55-31.63)	0.85
M4 (N/cm^2)	134.69 (117.09-152.29)	131.69 (116.62-146.76)	134.02 (116.41-151.62)	124.58 (109.52-139.65)	-7.107 (-28.41-14.20)	0.51
M5 (N/cm^2)	74.18 (63.36-85.01)	80.23 (68.50-91.94)	77.85 (67.03-88.68)	81.74 (70.02-93.46)	1.512 (-15.07-18.09)	0.86
T1 (N/cm^2)	207.62 (180.24-235.01)	216.09 (185.68-246.51)	199.772 (172.39-227.16)	209.206 178.79-239.62	-6.890 (-49.89-36.12)	0.75
TPHR (%gait cycle)	15.12 (14.27-15.98)	17.00 (16.11-7.89)	15.46 (14.61-16.31)	14.72 (13.83-15.62)	-2.277 (-3.54--1.02)	0.001

FB=Foot balance, MH=Medial heel, LM=Lateral heel, M1-M5 = metatarsal head, T1 bigtoe and TPHR= time to reach peak heel rotation, Group effect were calculated mean difference from control to intervention group from posttest score.

Kaplan-Meier hazard function analysis was made to check any difference on MTSS and non-MTSS arm and overall MSK injury and non-injury over the course of 26 weeks training (Figure 4.2).
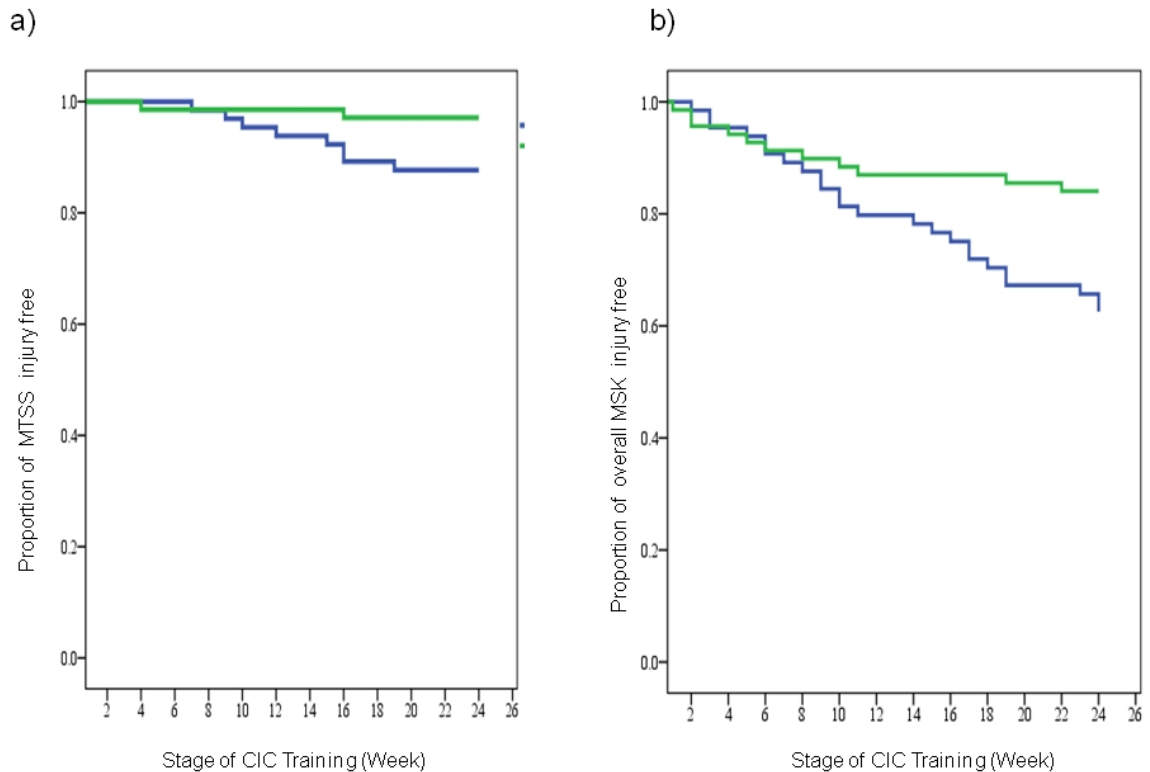
Figure 4.2. Kaplan-Meier survival curve (a) MTSS and non-MTSS (b) overall MSK injury and non-Injury between the control and intervention groups over 26 week CIC training period. Blue line Control group and Green intervention group.

There was evidence for an overall difference survival function between MTSS and non-MTSS groups (log rank test, $\chi2=6.12$, $p=0\cdot013$). The intervention group had a greater proportion of recruits who remain free from injury compared to the control group. Of 134 participants, 10 (7.46%; 95% (CI), 5.3-9.1) were diagnosed with MTSS.

There were 8 new cases of MTSS in the control group (cumulative incidence: 12.3%; 95% CI, 9.95 -15.75) and 2 in the intervention group (cumulative incidence: 2.82%; 95% CI, 1.05-3.95). Results demonstrated that an absolute risk reduction of 0.60 (60%) (CI 1.82-2.92) suggested a protective effect of the intervention group compared to the control group. However, once analysed subgroup as an overall MSK injury the absolute risk reduction is only 0.38 (38%) (CI 1.33 - 2.76) (Table 4.4).

A number needed to-treat analysis (Bowers, 2008) was performed and the results showed that two patients are needed to prevent one MTSS injury while four patients are required to prevent one MSK lower limb injury. Thus, the findings indicate that gait retraining is more effective in the prevention of MTSS compared to overall injury (Table 4.4).

Table 4.4. The number of recruits in each group sustaining injury (p values and number needed to treat analysis)			
	Control (n= 65)	Intervention (n= 69)	p
MTSS	8	2	0.001
ARR MTSS	ARR= CER – IER (0.80-.20) = 0.60		
NNT MTSS	NNT = 1/ARR, 1/0.60 = 1.66		
Overall injury	24	11	0.002
ARR overall injury	ARR = CER-IER (0.69 - 0.31) = 0.38		
NNT overall injury	NNT = 1/0.38 = 3.33		
CER = Control event rate, IER = Intervention event rate, ARR=Absolute risk reduction, NNT=Number needed to treat			

4.4. Discussion

The purpose of this study was to investigate the effect of a combined exercise and gait retraining programme on plantar pressures and the risk of developing MTSS as well as overall injury in a recruit population. It was hypothesised that this combined programme would contribute significant positive benefits in plantar pressure gait biomechanics (foot balance, time to reach heel rotation (TPHR) and overall pressure and reduce MTSS as well as overuse MSK injury in the intervention group when compared to a control group. With regard to the first aim, significant positive alterations in gait biomechanics (foot balance, time reach maximum heel rotation and overall pressure) were achieved and with regard to the second aim, incidence of MTSS and overall injury was also reduced due to the intervention.

Participants who had medial directed pressure away from one standard deviation were identified as a risk factor model group taking part in this study. Medial directed pressure in foot balance during heel strike had been significantly reduced in the intervention group. Similarly, time to reach peak heel rotation (TPHR) took longer and 15% of overall pressure was also reduced in the intervention group. This higher medial directed pressure is represented in overpronation and TPHR represented as a velocity loading rate represented fast and prolonged pronation. Previous studies found higher medial directed pressure in heel strike especially in the first 20% of stance phase of gait cycle and faster TPHR were a risk factor to develop MTSS (Sharma et al., 2011a). Over-pronation causes an increase in the magnitude and

velocity of internal tibial rotation which contributes to muscular overuse (Hunter et al., 1995; Willems et al., 2006).

Poor gait pattern may occur due to muscle imbalance among the foot's dynamic components (Halbach, 1981: Fiolkowski et al., 2003; Wong, 2007; Headlee et al., 2008; Kelly et al., 2012; Lewit et al., 2012) as well as the lumbo-pelvic-hip complex (Kibler et al., 2006). The intervention group received a combined exercise and gait retraining programme. This study targeted both distal and proximal components which contribute to correcting muscle imbalance both proximal and distal in the kinetic chain which may contribute to a positive outcome on gait parameters (Chuter et al., 2012). The present study shows that stabilisation exercises (Halbach et al., 1981) and gait retraining are promising in altering adverse gait pattern. The loading rate, especially related to time to reach heel rotation, was also reduced due to the intervention. This study also demonstrated that individuals can control poor gait pattern utilising both exercises and biofeedback, producing similar findings to a previous study (Noehren et al., 2011). Several researchers also demonstrated that subjects can alter their gait biomechanics utilising real-time feedback (Messier et al., 1989; White et al., 2005; Crowell, 2010; Crowell et al., 2011). However, a study by McKeon et al., (2009b) examined balance training on gait parameters in patients with chronic ankle instability and found no significant alterations in kinematics during walking and jogging.

Previous history of MTSS and previous orthoses use are the primary risk factor for developing future MTSS (Hubbard et al., 2009; Plisky et al., 2007). This may be due to underlying suboptimal gait biomechanics which have not been addressed and gait patterns considered as a non-modifiers. However, this study has produced clinically significant results which suggest that adverse gait patterns can be altered and thereby reduce the risk of recurrence of MTSS, or even reduce the risk of initially developing MTSS in the first place.

A second aim of this study was to explore whether combined exercise and gait retraining would reduce the incidence of MTSS and overall MSK injury. This study demonstrated a significantly reduced rate of MTSS (60%) and overall training related lower limb injuries (38%) over a 26 week training period for those subjects who participated in the intervention programme. Overuse injury is developed either by overall tissue tolerance levels being low or increasing load due to altered biomechanics (McGinnis, 1999). An analogy that may be useful is that of a horse pulling a cart that has a damaged wheel. Strengthening the horse can improve the situation but it is more efficient to repair the wheel, or even better both strengthen the horse and repair the wheel. This is the first study to deal with both underlying components (neuromuscular control/strength and gait retraining) in an injury prevention model. Dysfunction in one component has the ability to adapt or compensate function until the system has exhausted its limit of adaptations due to a series or chain of dysfunction, leading to symptoms manifesting. One of the aims of this study was to establish whether gait pattern can be normalised and thus reduce

injury. Military training includes numerous activities (eg running, marching, jumping and sports) to prepare recruits for functional efficiency. It is often necessary to address all the important parameters including strengthening, stretching, neuromuscular control and gait retraining as a holistic approach to the exercise programme. Strength exercises increase MSK system tolerance levels and good gait patterns reduce biomechanical load on the tissue. Increase tissue resilience by strengthening and neuromuscular control (Prentice, 2004). Secondly, reduce load by altering suboptimal biomechanics to optimal/efficiency which may reduce load/stress to the tissue (Norris, 1998; Whiting et al., 1998; McGinnis, 1999; Abboud, 2002). Injury can occur when the MSK system is subjected to forces of normal magnitude applied to the body incorrectly eg overpronation (Cavanagh et al., 1980) or altered neuromuscular control (Franettovich et al., 2010).

This study shows a reduction of 15% in overall heel pressure for the intervention group but not for the control group. Due to the nature of military training even a 15% reduction has a large cumulative reduction in relative terms. For example during running, impacts occur about every half to three quarters of a second (Cavanagh, 1990) equating to 4,000 impacts between the lower limb and ground in 5km route running (Shorten, et al., 1992). Military recruits cover about 11km per day (Mason et al., 1996), equivalent to some 9,000 impact (Jones et al., 2001). The attenuation of the magnitude of force applied to the limbs reduces the probability of chronic overuse injury (Nigg, 1985) and the impact vertical loading that is associated with development of stress fracture (Milner et al., 2006). This reduction of MTSS and

overall MSK injury in the intervention group in this study could be due to a decrease in overall load to the tissue (Cavanagh et al., 1980; Whiting et al., 1998).

This combined approach has both clinical and military significance when implemented in a training environment as a holistic approach to significantly reduce injury. Military personnel require fitness as well as an ideal gait pattern to avoid overuse injury. Finch (2006) advocates that prevention models need to be accepted by organisations and individuals in order that they be implemented in the organisation successfully. Multi-component exercise programmes were designed to be implemented in a military environment since none of the military personnel are doing only stretching exercises, instead they do all components of fitness.

This research shows that the intervention group had an increased heel rotation time but the control group did not change. This demonstrates that the rate of loading in the foot may be a contributing factor to more injury in the control group. The control group had a faster rate of heel rotation/prolonged pronation during the stance phase of the gait cycle.

A previous study found there was no reduction of injury using stretching (Pope et al., 2000) in Australian recruits. Another study by Bruishoj et al., (2008) into prevention of overuse injury in 1020 Royal Danish Life Guards found no difference between the groups. The exercises used were strengthening, coordination and flexibility. However, a possible reason for failure to show any efficacy was that those studies targeted only one component, since the origins of training injury are multifactorial (Meeuwisse,

1994; Hreljac et al., 2000) and adverse gait biomechanics is a critical risk factor (Yates et al., 2004; Wills et al., 2004; Willems et al., 2007; Sharma et al., 2011a). Multifaceted training might be effective in preventing injury (Hubscher et al., 2010). Pre-habilitation is a cost effective approach in the prevention and management of overuse injury, especially MTSS; however, as pre-habilitation cannot prevent all injuries, the development of an evidence-based management of MTSS injury is vital to reduce attrition.

The benefits of gait-retraining on MTSS are similar to those found for hip and knee disorders (Crowell et al., 2010; Noehren et al., 2011). To reiterate, in this study the intervention incorporated bio-feedback on gait and exercises which were chosen in order to improve strength, stability and control of the muscles around the foot and ankle, leg and lumbopelvic area. Such exercises are expected to increase strength or activation and improve gait biomechanics kinetic coupling chains (Hunter et al., 1995; Jam, 2004, Janda et al., 2007) and thus normalised gait pattern. Since there were no adverse effects encountered by the participants, the positive nature of the results would lend support to the argument for gait-retraining as an intervention to reduce the burden of MTSS in the British Army.

The reduction of injury with gait education has found a more positive effects on MTSS than overall injury. It suggested that controlling overpronation has more impact on reducing MTSS injury compare to overall injury. The number needed for treatment analysis (Peat et al., 2005; Bowers, 2008) reveals that approximately two recruits are

needed for treatment to reduce one MTSS; however, an overall reduction of four recruits needing treatment is necessary to reduce one MSK injury indicating MTSS has more protective effects than reducing overall injury impact and normalise gait patterns (Noehren et al., 2011).

Research showed that there are 26 sports and recreational musculoskeletal injury episodes per 1000 persons per year in the US (Conn et al., 2003). In addition, due to sports injuries, 20% of school children and 28% of working adults are absent at least one day a year from school or work respectively. Consequently, musculoskeletal injuries are a significant cause for concern for athletes, sports, military and society (Conn et al., 2003). Even though this study was conducted with homogeneous with highly motivated population and relatively control environment. It can be transfer to other population such as population with obese which is a major public health issue. These people may found difficult to high level of impact activities and consequence developed MSK injury and decrease motivation and compliance (Melegati et al., 2002). This will lead to de-conditions and vicious cycle continue. The exercise programme designed in this study can be used to correcting neuromuscular/strength and enhance good gait pattern without oblivious impact activities. This will ultimate increase load tolerance as well as minimises the load with optimise gait biomechanics (White et al., 2005; van Gent et al., 2007; Whittle, 2007). Once people found tolerable exercise, it will increase motivation and compliance to be involved activity hence improve public health (Melegati et al., 2002).

It is worth noting that this experiment was performed in an environment in which there were no opportunities to fine-tune the intervention using exploratory trials which would normally be done in order to isolate the active ingredients of the intervention. Instead, a randomised control trial on a reasonably large sample was used and it was recognised that such an approach is not ideal (MRC, 2000). Furthermore, corrective orthotic insoles were not included in this study yet successful interventions have been undertaken using orthotic insoles (Franklyn-Miller et al., 2011). Ideally, the benefits of gait retraining would be compared with the best alternative even though it is considered an unfeasible alternative from the perspective of the military. With regards to the latter, the battery of exercises prescribed in this intervention, are highly excessive and it is not expected that all components of the intervention contributed equally, if at all. For example, there is currently debate regarding the effectiveness of core training in improving performance in athletes.

Recent reviews (Hibbs et al., 2008; Reed et al., 2012) have revealed that despite the widespread practice of core exercises, the actual benefits in terms of sports performance and injury avoidance are unclear. Similarly, stretching of soft-tissue structures have been shown to reduce pain and increase flexibility in anterior knee pain sufferers, but it is not known whether it is beneficial in the prevention of MTSS. For example, two studies (Pope, 2002a; Brushoj et al., 2008) demonstrated no positive effects of stretching on the reduction of injury in recruit populations. In addition, it is unclear whether neuromuscular control is a modifiable parameter using the exercises in this study.

A recent prospective trial showed no alteration in reflex response times of quadriceps muscles when performed in closed kinetic chain exercises as performed in this study (McGill, 2002; Santana, 2003). Taken together, although the experimental design was robust in terms of addressing the stated aims, it was not designed to establish a causal relationship and cannot be used to determine which aspects of the intervention contributed the most. Rather, it was designed to highlight whether or not individuals within a healthy recruit population can alter their gait mechanics, and whether gait retraining is worth pursuing in terms of reducing injury. The answer appears to be yes, but with the caveat that the active ingredient of the intervention is not known and the benefits achieved have not been compared with all other possible alternatives, such as the use of prescribed orthotics.

4.5. Conclusions

It was shown in the previous chapter that MTSS could be predicted in a non-injured population using plantar pressure variables. The results of this randomised control trial take these findings a step further and indicate that these are modifiable risk factors, and hence reduce the likelihood of MTSS in an at risk group. Although it is recognised that the exercise program presented is certainly not optimal, it does include some active ingredients which help to prevent MTSS. Taken together it is argued that gait re-education could be an effective preventative strategy for the management of MTSS and this programme is easy transferable to military physical training programme. However, due the nature of the recruit training it is not possible

to predict and prevent all cases, therefore, next step is to evaluate the effective rehabilitation programme to reduce attrition.

4.6. Implications for practice and research

Gait retraining can alter adverse gait risk factors as well as reduce incidence of MTSS.

Chapter 5.The Effect of a Combined Gait Retraining and Cortico-Steroid Injection

Programme on Rehabilitation Times for Chronic MTSS: Introduction and Evaluation of

a Rehabilitation Measure (Study 4).

5.1. Introduction

Medial tibial stress syndrome is a common injury at the Infantry Training Centre, Catterick (Sharma, 2008; Sharma et al., 2009; Sharma et al., 2011a). The current treatment approach for the MTSS at ITC is in line with the available evidence of treatments. These conservative interventions which can be administered include soft tissue mobilisation, exercises, ultrasound, acupuncture, and a gradual return to training (Andrish et al., 1974; Clement, 1974; Clanton et al., 1994; Yates et al., 2004; Craig, 2008a; Galbraith et al., 2009). If this approach fails the Infantry Training Centre usually adopts a protocol similar to the tibial stress fracture treatment which includes a four-week relative rest period with partial weight bearing using crutches, and activity modifications until the pain subsides. Once recruits return from four weeks sick leave they commence rehabilitation in three phases: pre-recovery, recovery and mainstream before returning to training. The problem with the current conservative intervention approach to MTSS is prolonged periods out of training which leads to decreased recruit motivation and difficulties in re-adjusting to army life following return from sick leave. As a consequence, many recruits decide that they do not want to continue with their Army career (Dixon et al., 2003) and others are medically discharged (Sharma, 2008). Secondly, this conservative approach has poor response to treatment. Patient failure to respond to this conservative treatment at 4, 6, and 8 weeks of treatment are 50, 35 and 25% respectively (Sharma et al., 2012). Therefore, treatment of MTSS can be difficult and expensive (Parkkari et al., 2001) and some recruits can take over six months for full rehabilitation (Yates et al., 2004; Hubbard et

al., 2009). In cases where conservative treatment fails, surgical intervention in the form of fasciotomy is a possiblity (Abramowitz et al., 1994; Holen, et al., 1995). The results from fasciotomy report good success rates ranging from 29% to 90% (Detmer, 1986; Abramowitz et al., 1994; Yates et al., 2003). However, less than satisfactory are the results that despite up to twelve months post-operative rehabilitation only 41% of subjects return to pre-injury levels of activity (Yates et al., 2003). Thus, the impacts of this injury are loss of training time, a reduction of population size, delay to complete basic training and decrease operational readiness (Jones et al., 2010a); a scenario which is familiar to British military as well as other military forces (Heir et al., 1996; Brushoj et al., 2008). In order to develop an alternative new intervention to evaluate the efficacy it is advisable that a methodologically rigorous RCT to the treatment of MTSS is developed. Exercise and gait-visualisation, collectively termed gait re-education, were shown to be effective strategies for the prevention of MTSS in a group of non-injured participants. Unfortunately, however, the debilitating pain suffered by MTSS patients currently restricts the use of an exercise-based intervention for the rehabilitation of MTSS patients.

Local corticosteroid injection has been in use for MSK disorder for 60 years (Wrenn et al., 1954; Ines et al., 2005). The rationale for using corticosteroid injection in MSK injury is to reduce inflammation, pain, stiffness, swelling, promote rehabilitation and return to normal activities sooner (Saunders et al., 2011) and is used extensively for back pain, plantar fasciitis, ITBS, bursitis, tendonitis, synovitis pain, tennis elbow and other overuse MSK conditions (Cardone et al., 2002; Cole et al., 2005; Saunders et

al., 2011) and have been shown to be an effective treatment (Cardone, 2002; Cole et al., 2005; Ines et al., 2005; Skedros et al., 2007; Gaujoux Viala et al., 2009; Brinks et al., 2010; Saunders et al., 2011). However, the research findings have contradictory outcomes (Skedros et al., 2007; Gaujoux Viala et al., 2009) and adverse effects of steroid injections are also reported (Wang, et al., 2003b; Nichols., 2005; Brinks et al., 2010). There is no research on the use of steroid injections for MTSS, even though a subgroup of MTSS has an inflammatory origin (Bouche, et al., 2007; Moen et al., 2009). Despite the popularity of corticosteroid injection intervention used for a wide spectrum of MSK disorders (Saunders et al., 2012) and is recommended for MSK disorders in national and international guidelines (New Zealand Guidelines Group, 2004; NICE Guideline, 2008), the effectiveness of combined local steroid injection and rehabilitation on MTSS has not yet been evaluated in a randomised control trial.

Aim: The aim of this study was to examine the effects of a combined corticosteroid-exercise intervention on plantar pressure variables, pain intensity, time spent in rehabilitation and occupational outcome from MTSS.

5.2. Methods

5.2.1. Participants.

The study design was a prospective randomised trial. Recruits' randomisation was stratified according to each recruits' training regiments using a 4 block size randomisation process to assign the participants in intervention (I) and control group (C).The order of randomisation was CCII, CICI, IICC, ICIC. All recruits, who were

diagnosed with MTSS and were currently under rehabilitation at the medical centre at

ITC Catterick were potential participants. 66 recruits met the inclusion criteria outlined

in Table 5.1. Participants volunteering for the study were randomly allocated to an

intervention and control group in accordance with CONSORT statement shown in

Figure 5.1. The intervention group received a treatment protocol combining

corticosteroid injection with the gait retraining programme described in Chapter 4.

Outcome measures were monitored over a 26 week post-injection period. Participants

who signed a consent form were invited to participate in the study and the local army

organisation (ITC) approval was gained prior to conducting the study. The study was

approved by the Ethics Committee of School of Social Sciences and Law at Teesside

University, UK.

Table 5.1. Inclusion and exclusion criteria for rehabilitation study	
Inclusion criteria	Exclusion criteria
Diagnosis of MTSS Pain on the postero-medial border of shin Area of symptoms <7 cm to infiltrate the drugs No tibial stress fracture confirmed on MRI scan Had a minimum of 6 weeks first line conservative treatment and podiatrist assessment and intervention if required Signed informed consent form	Shin pain due to tibial stress fracture or due to acute trauma, compartment syndrome. Other lower limb injury and symptoms Not having 6 weeks conservative treatment Contraindication for steroid injection Withdraw consent form.

5.2.2. Data collection

Pain intensity was measured with the Visual Analogue Scale (VAS) which is a validated tool for measuring pain levels (Paice et al., 1997). This assessment involves testing for tenderness and pain along the posteromedial tibial border on palpation. Pain intensity was obtained in a 0-10 verbal report (zero indicates no pain and ten indicates the worst pain). Plantar pressure variables were also collected as were other outcome measures such as time spent in rehabilitation and training occupational outcome (Table 5.3).
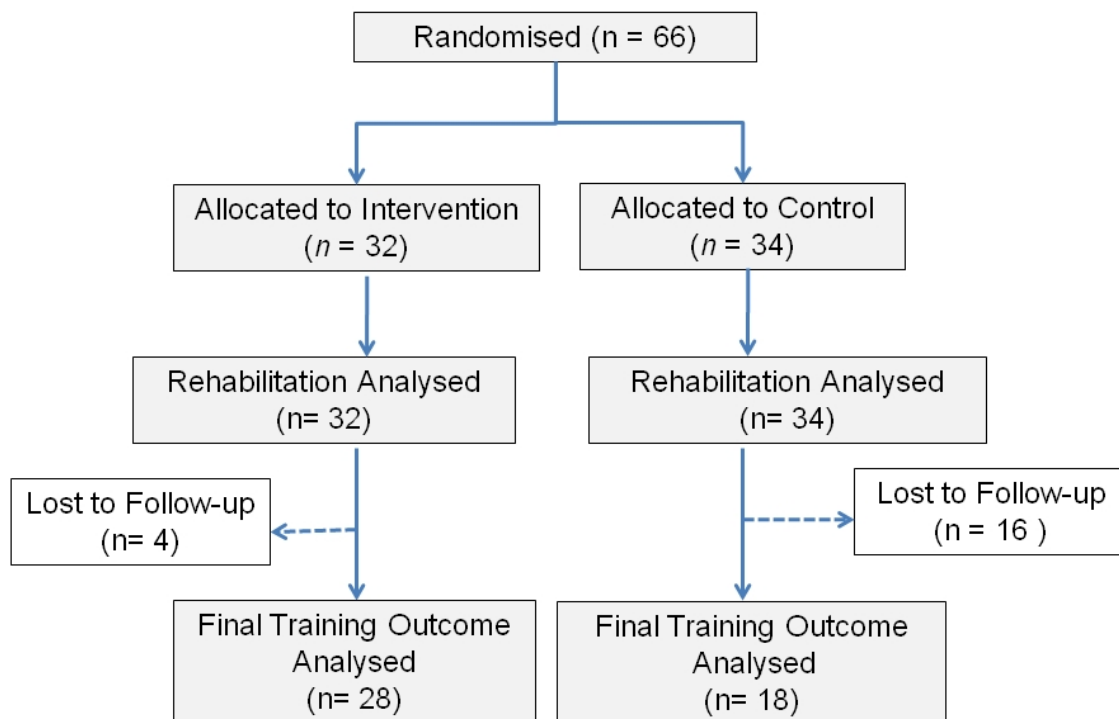
Figure 5.1. The CONSORT flow diagram used for recruitment and allocation of MTSS patients.

5.2.3. Delivery of the intervention.

The intervention group was administered 20 milligrams of Kenalog (Triamcinolone acetonide) and 1% of 1millilitre lidocaine. The dosage was selected based on use in other MSK conditions (Cardone et al., 2002; Ines et al., 2005; Tsai et al., 2006; Saunders et al., 2011). The two medicines were mixed to maximise effectiveness (McColl et al., 2000). The drugs were administered into the posteromedial aspect of the tibia by either a general practitioner (GP) or a physiotherapist qualified for injection therapy. With the patient in a supine position, palpation identified the most tender point which was then marked. The needle was inserted into the mid-point of the marked area. Once the needle touched the bone, the needle was withdrawn slightly and after safety aspiration, a total volume of 1.5ml medicine was injected around the most tender point of the periosteum/fascia/tendon interference of tibia by using a peppering technique (Kesson et al., 1998; Saunders et al., 2011). The recommended guidelines for the safety of the patient and practitioner were always followed during the injection and care was taken to avoid injecting directly into the tendons or muscles. After injection, any adverse reactions were recorded both immediately and during the 26 week follow up period. Recruits were advised to take two weeks of relative rest in order to allow the infiltrations of drugs (Kesson et al., 1998). During the two week rest period, the intrinsic foot muscle exercises, extrinsic muscles dissociation exercise and gait re-education protocol of Chapter 4 were administered. After two weeks of relative rest, the intervention group joined the standard rehabilitation programme with control group. The intervention group also

had one-to-one physiotherapy sessions approximately 8-10 times over the experimental period during which gait analysis bio-feedback was provided (as in Chapter 4). Recruits were encouraged to continue practicing their exercises and gait pattern at least 3 times a week during the course of the standard rehabilitation programme.

The standard rehabilitation programme is divided into three phases: pre-recovery, recovery and mainstream. All sessions are supervised by a Remedial Instructor. Pre-recovery is a phase of non-impact activities which mainly focus on maintaining cardio-respiratory fitness through upper body exercises such as swimming, balance, stretching and strengthening. Once recruits successfully pass assessment they advance to the recovery phase, which involves progressively longer and more challenging balance and proprioception exercises, as well as progressive strengthening exercises with involved and non-involved limbs. After jogging for 30-50 minutes one to three times per week, if the patient remains pain free after the two-week recovery phase they progress to the mainstream phase. The mainstream phase requires a higher-level of fitness and the return to a pre-injury level of activities including running, loaded march and military specific activities in order to prepare recruits for return to training. Once recruits are able to complete an eight mile loaded march carrying 35 pounds in two hours, two to three times per week, they are invited to return to training.

5.2.4. Data analysis.

A power analysis was conducted to determine sample size. To obtain a clinically relevant difference of 40% in the VAS scale between the two groups, 27 participants were required per group given 80% power with beta = 0.20 and alpha 0.05 (Cohen, 1988). To account for a 10% rate loss during follow-up, it was estimated that the total number of participants needed per group was 30, which amounted to a total of 60 participants for the study (Cohen, 1988). Pain intensity in VAS scores across the four testing sessions (baseline, 2 week, 4 week and final) were analysed using a 2 (Group) X 4 (Time) 2-way ANOVA with repeated measures on one factor (time). In order to determine whether there were any differences in plantar pressure variables between groups, the peak heel pressure and TPHR variables were analysed using a 2 (Group) X 2 (Time) 2-way ANOVA with repeated measures on one factor (time) and an independent t-test for time spent in rehabilitation. A Chi square test was used to test both rehabilitation and final training outcomes. Descriptive statistics as a mean and standard deviation for continuous variables and categorical variables were expressed by percentage. Alpha was set at 0.05.

5.3. Results

The baseline mean, standard deviation and test of relevant variables data are presented in Table 5.2 which shows that the two groups were similar with no significant difference with respect to age, height, weight, body mass index and symptom duration.

Table 5.2. Baseline demographic group characteristics for the rehabilitation study					
Variable	Intervention (n = 32)		Control (n = 34)		P
	Mean	SD	Mean	SD	
Age (years)	21.19	2.17	20.59	2.39	0.29
Height (cm)	180.06	6.32	179.62	5.80	0.77
Weight (kg)	73.28	6.92	72.85	8.42	0.82
BMI (km/m$^{2)}$	22.60	1.73	22.57	2.00	0.91
Symptom duration (month)	4.55	1.7	4.17	1.80	0.61

Of the 66 recruits (32 intervention and 34 control) who were enrolled on the study, 20 left ITC during rehabilitation. From these 20, 4 recruits were from the experimental group and 16 from the control group. Only data from the remaining 46 subjects were used for the final training outcome analysis; however, all participants were analysed for rehabilitation outcome. There was non-significance (p >0.05) on Levene's test of equality and Box's test of equality of covariance matrix, indicating that it is appropriate for a parametric test.

For biomechanical variables (Figure 5.2 (a) and (b), results showed a significant interaction between intervention type and time (group X time), {Wilks Lamda =F (F1,64 = 0.812, p <0.001)}. A post hoc t-test revealed significant differences between the groups at final measurement (p= 0.022) but no significant difference at baseline measurement (P = 0.19) between the group. The magnitude of the TPHR differences at 26 weeks in mean difference (% gait cycle) was 3.88, (95% CI: 1.57 to 7.19); the

intervention group took longer than the control group which suggests that the loading rate (high velocity) and uncontrolled movements were greater in the control group than the intervention group (Figure 5.2b).

Results on pain intensity in VAS across the occasions revealed a significant interaction between intervention type and time (time X group), {WilksLamda =F (F3,62 = 0.56), p <0.001} difference in main effects time {F=0.21(3,62), p <0.001}, Group (F 62.81, p < 0.001). The post hoc t-test revealed significant differences between the groups at 2 weeks (p= 0.039), 4 weeks (p< 0.001) and final VAS measurement (p < 0.001). Both groups showed improvement; however, the experimental group had consistently lower VAS value at every time point (Figure 5.2c). It was noteworthy that the timing of the final VAS measurement differed between recruits because they returned to training at different weeks of training. Number of days in rehabilitation variable, result showed significant differences in days for intervention (x^2 = 38.53 ± 10.03 days) and control {x^2 = 86.38 ± 20.15 days; t (64) = - 12.10, p < 0.001}. The magnitude of mean difference was -47.85, (95% CI: -55.76 to -39.94) (Figure 5.2d). The intervention group spent only half the time in rehabilitation compared to the control group which suggests that recovery time was accelerated in the intervention group.
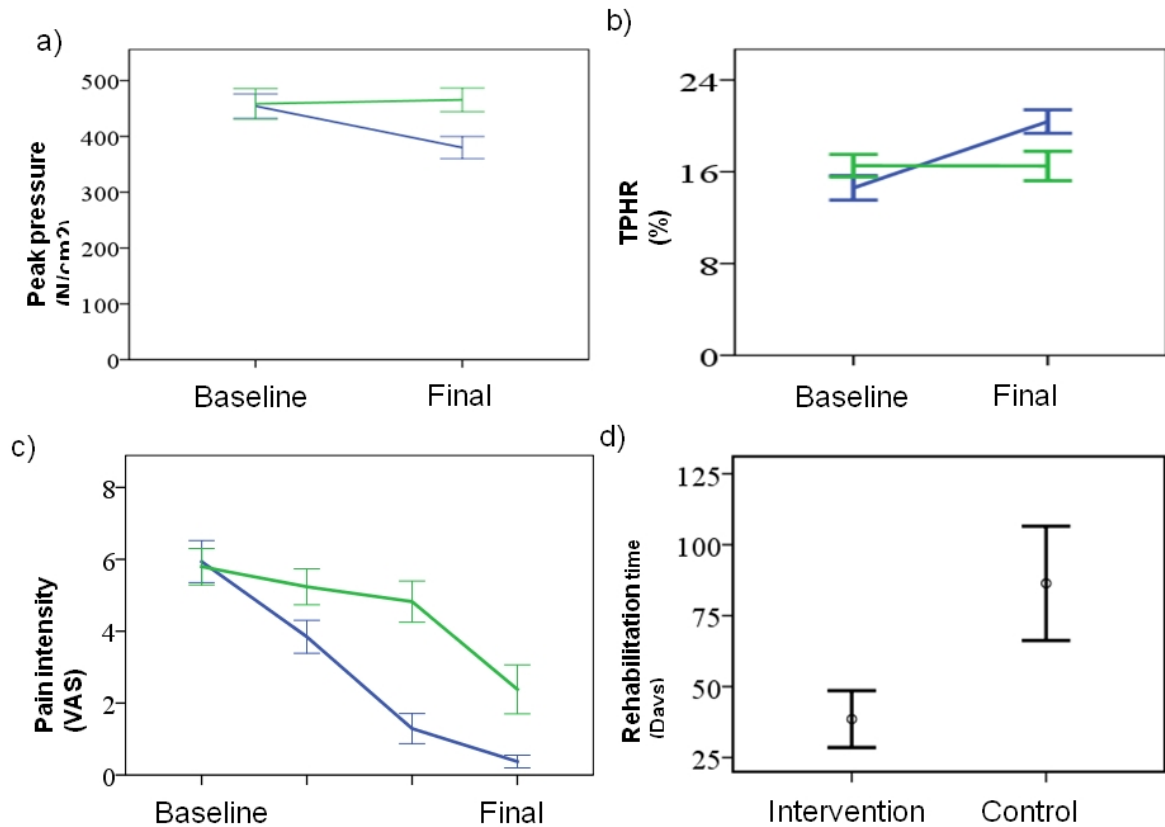
Figure 5.2. The effect of the combined gait re-training and corticosteroid injection programme on a) Peak pressure at heel b) Time to reach peak heel rotation (TPHR) expressed as percentage of stance phase of gait cycle (%) and c) Pain intensity in VAS scores, d)Rehabilitation time (days). Blue line intervention group and Green Control group and the 95% confidence intervals are shown.

Measurements of occupational outcome in rehabilitation and final training outcome are presented in Table 5.3. Results show a significant difference in both rehabilitation outcome $\{x^2 (3) = 9.37, p = 0.025\}$ and final training outcomes $\{x^2 (3) = 9.89, p = 0.019\}$ due to the intervention. In the intervention group 87.5% (n = 28) were returned to training compared to 52.9% (n = 18) in the control group. Two recruits (6.3%) from the intervention group were discharged as of right compared to seven recruits

(20.6%) from the control group. Medical discharge rates were higher in the control

group 14.7% (n = 5). For the final training outcome the intervention group was better

on all outcome measures. In terms of successfully completed training, the intervention

group had a 87.7% (n = 24) success rate compared to 44.4% (n = 8) for the control

group. Backsquadded (setback) and discharge rates were also higher in the control

group.

Table 5.3. Occupational training outcome by groups			
Rehabilitation outcome	Intervention (n=32)	Control (n= 34)	Total
RTT	28 (87.5)	18 (52.9)	46 (69.7)
DAOR/Discharge	2 (6.3)	7 (20.6)	9 (13.6)
Transfer	1 (3.1)	4 (11.8)	5 (7.6)
MD	1 (3.1)	5 (14.7)	6 (9.1)
Final training outcome			
SCT	24 (85.7)	8 (44.4)	32 (69.6)
Discharge	0 (0)	2 (11.1)	2 (4.3)
Back-squadded	3 (10.7)	7 (38.9)	10 (21.7)
Transfer	1 (3.6)	1 (5.6)	2 (4.3)
RTT = return to training, DAOR = discharge as of right, MD = medical discharge, SCT = successfully completing training			

5.4. Discussion

The aim of this study was to evaluate the effectiveness of a new management

protocol for chronic MTSS. This study has demonstrated significant improvements in

the intervention group in all outcome variables including pain intensity, gait pattern

and rehabilitation time. In addition, more recruits in this group returned to training and

completed training successfully compared to the control group. On the basis of these results it would appear that the new treatment protocol combining gait-retraining and corticosteroid injection for the treatment of MTSS was successful.

Such findings mirror those of other interventions designed to improve the treatment of MSK injuries (Mens et al., 1998; Cardone et al., 2002; Brinks et al., 2010; Saunders, 2011). Shin pain significantly decreased at 2 weeks, 4 weeks and at the final measurement in the intervention group. These results are comparable with results from other research which focused on pain reduction in MSK conditions (Wolgin et al., 1994; Crawford et al., 1999; Wang et al., 2003b; Gunter 2004; Tsai et al., 2006; Kalaci, et al., 2009). Crawford et al., (1999) found that steroid injections reduced heel pain at one month, but not at three months. In contrast, other studies found that there were significant decreases in heel pain and other MSK conditions up to six months (Wolgin et al., 1994; Genc et al. 2005; Tsai et al., 2006). The pathology of MTSS as a result of the soft-tissue inflammation origin suggested by a number of authors (Johnell et al., 1982; Mubarak et al., 1982; Bouche et al., 2007; Moen et al., 2009) may support this hypothesis since steroid injection may lessen or eliminate the low grade inflammatory cycle hence decreased pain (Kesson et al., 1998). This study has found that pain continues to decrease following injection and thus recruits are able to continue training with high impact activities. These findings reflect the positive long-term effects of the new management approach which combines local steroid injection, neuromuscular training and gait re-education.

All MSK injuries require active rehabilitation and if the rehabilitation is not complete the recruits may be susceptible to reinjuring the affected area, as well as being predisposed   injuring another part of the body and, thus, being unable to perform tasks at pre-injury level (Kinch et al., 2007). The new MTSS management protocol accelerates recruits returning to training to pre-injury level function. The control group spent on average twice as long in rehabilitation. The primary aim of injury rehabilitation is to enable recruits to return to training with full function in the shortest possible time (Kinch et al., 2007). This intervention model has all the essential rehabilitation components such as injection, individualised neuromuscular control, gait retraining and participation in a strengthening exercise programme and also improved compliance with treatment (Melegati et al., 2002) which are the keys for the effectiveness of this approach. Indeed, pain and inflammation can impede osteoblastic activity and continue the inflammatory damage-repair-damage vicious cycle (Cole et al., 2005; Bouche et al., 2007; Saunders et al., 2011) which may delay restorative functions. Although both groups demonstrate pain reduction over time the effect of the combined corticosteroid-exercise programmes expedited rehabilitation, and significantly, reduced the loss of training days as well as attrition.

Analysis of the few studies that have investigated the effects of steroid injection on plantar fasciitis have found the benefits to be mainly short-term (Crawford et al., 1999). In our study, significant improvements in VAS and occupational outcome at 26 weeks follow-ups were observed. There were no recurrence of the injuries at the 26 week follow-up in the intervention group but there was high recurrence in the control

group. High recurrence may be due to pain which inhibits and impairs muscle strength and functional control. This leads to impaired subtalar and mid tarsal joint pronation control which further increases mechanical stress on the shin and continues irritation as well as inability to shock absorb during walking, running, or climbing (Kim et al., 1995; Tsai et al., 2006; Stephen et al., 2007). This function may be adversely altered by strain on the extrinsic deep flexor muscle and by the weakening of the intrinsic muscle which causes pain and chronic inflammation. Thus reducing pain earlier by injection enhances the correction of neuromuscular function and gait pattern which shortens rehabilitation time in recruits with MTSS.

Occupational outcome in terms of rehabilitation and final training outcome show significant positive results in the intervention group. Twenty four recruits out of 32 successfully completed training in the intervention group but only eight recruits out of 34 completed training in the control group. The number of recruits lost in rehabilitation and final outcome was disappointing in the control group but not surprising. Nearly half of the recruits in the control group (n = 16) were unable to return to training after a long period spent in rehabilitation. Inability to complete training is dependent on many factors. A large number of recruits (n = 7) had recurrent injuries and those recruits were backsquadded due to their inability to continue training once completed rehabilitation. As previous research shows, once pain subsides bone mineral density also increases by approximately 19% at the MTSS site (Magnusson et al., 2003) and bone and muscle become stronger and, thus, a large number of (28/32) recruits successfully completed training after return from rehabilitation in the intervention

group. Swanik et al., (1999) highlight that altered muscle recruitment can persist upto 66 months after injury and suggests that without targeted interventions altered muscle recruitment may continue and may be related to recurrence (Plisky et al., 2007; Franettovich et al., 2010). Similar findings by Blond et al., (1998) on patellofemoral pain syndrome patients showed that 80% of patients who were involved in strengthening exercises alone, failed to experience a subsidence in pain even after a 5 year follow up period and 75% of patients had to reduce their physical activity due to pain. This may explain the disparity of training outcomes in this study since the control group had not received targeted intervention and the underlying pain and gait mechanics had not been addressed. Combined with previous studies and this study, a unique clinical approach was used to address all of the components within a holistic approach.

Research has reported the risk of complications including post injection pain, loss of skin pigmentation, atrophy of subcutaneous tissue, minor burning sensation, rupture of the tendon and plantar fascia rupture, septic bursitis, disturbance in menstruation, and flushes following corticosteroid injection (Mens et al., 1998). In a retrospective study, it was reported that as high as 10% of plantar fasciitis cases later developed a rupture following corticosteroid injection with an average time of rupture, following injection, of 3 months (Acevedo et al., 1998). Complications were not observed immediately or within a 26 week post injection follow up period in this study. Similarly other studies also reported that there were no complications following corticosteroid injection in various MSK conditions (Crawford et al., 1999; Gunter et al., 2004;Genc et

al., 2005; Baumgarten et al., 2007; Jianmongkol et al., 2007; Gurcay et al., 2009; Kalaci et al., 2009).

There are some limitations to this study. Firstly, the follow up review of 26 weeks was relatively short; therefore, the long-term benefits are not known. Thus, benefits after this time could not be discerned. Another limitation of this study was that it was not designed to isolate and discriminate the active ingredients of the intervention. Thus, it remains unclear to what extent the various intervention components (injection, neuromuscular training and gait training exercises) may have contributed to the observed efficacy. However, if only the injection modality or gait retraining had been performed, the same improvement may have been observed, thus begging the question of which modality brought about improvement.

5.5. Conclusions

Substantial benefits in terms of reducing the impact of MTSS were found due to the intervention. This rehabilitation approach is a cost-effective method that can be instantly integrated into any rehabilitation programme with the aim of accelerating rehabilitation in military populations.

5.6. Implications for practice and research

A combined corticosteroid-exercise intervention is beneficial in normalising plantar pressure, reducing rehabilitation times, pain intensity and occupational outcome for cases of MTSS.

Chapter 6. Conclusions and Future Directions

6.1. Introduction

The overall aim of this thesis was to develop and evaluate a management strategy for MSK training injury during CIC training. The underlying question posed at the beginning of this thesis is how can the problem of MSK injury and attrition in this rather unique recruit population be managed effectively? In order to answer this question, a proactive interventionalist-style of research was adopted. Van Mechelen et al., (1992) proposed a four-stage model to describe a sequence of injury prevention which has been widely adopted in the sports medicine literature (Pope, 2002b; Hootman, 2007). While stages of the model have previously been considered in isolation (Chalmers, 2002; Willems, 2004), this is the first study to conduct all of the different stages within a single research project. Furthermore, given that injuries to recruits are almost inevitable, the model was extended to incorporate a stage of rehabilitation (Figure 6.1). It is anticipated that this modified framework of injury management could be adopted easily and further developed by both the medical and training staff in order to improve the efficacy of MSK injury management in the British Army and Armed forces globally.

In order to demonstrate how this thesis has evolved the four stages of van Mechelen et al., (1992) model, shown in Figure I.I is again shown in Figure 6.1, but with additional information depicting the route taken. Due to practical constraints this thesis has been unable to cover all of these possibilities. Thus, in Figure 6.1 the ticked sub-stages are components investigated in this thesis and the bullet-pointed

sub-stages are not covered but nonetheless considered potentially important. Furthermore, it is also recognised that the model is cyclical, and ideally, following implementation of the four steps, the information needs to be repeated. Again, due to time constraints only a single cycle was represented in this thesis. On reflection, it is evident how complex this model could become and how difficult it may be to deliver a fully effective management strategy for MTSS let alone for the management of other MSK injuries. Nonetheless, it is suggested that the systematic approach taken in this thesis may be a step in the right direction.
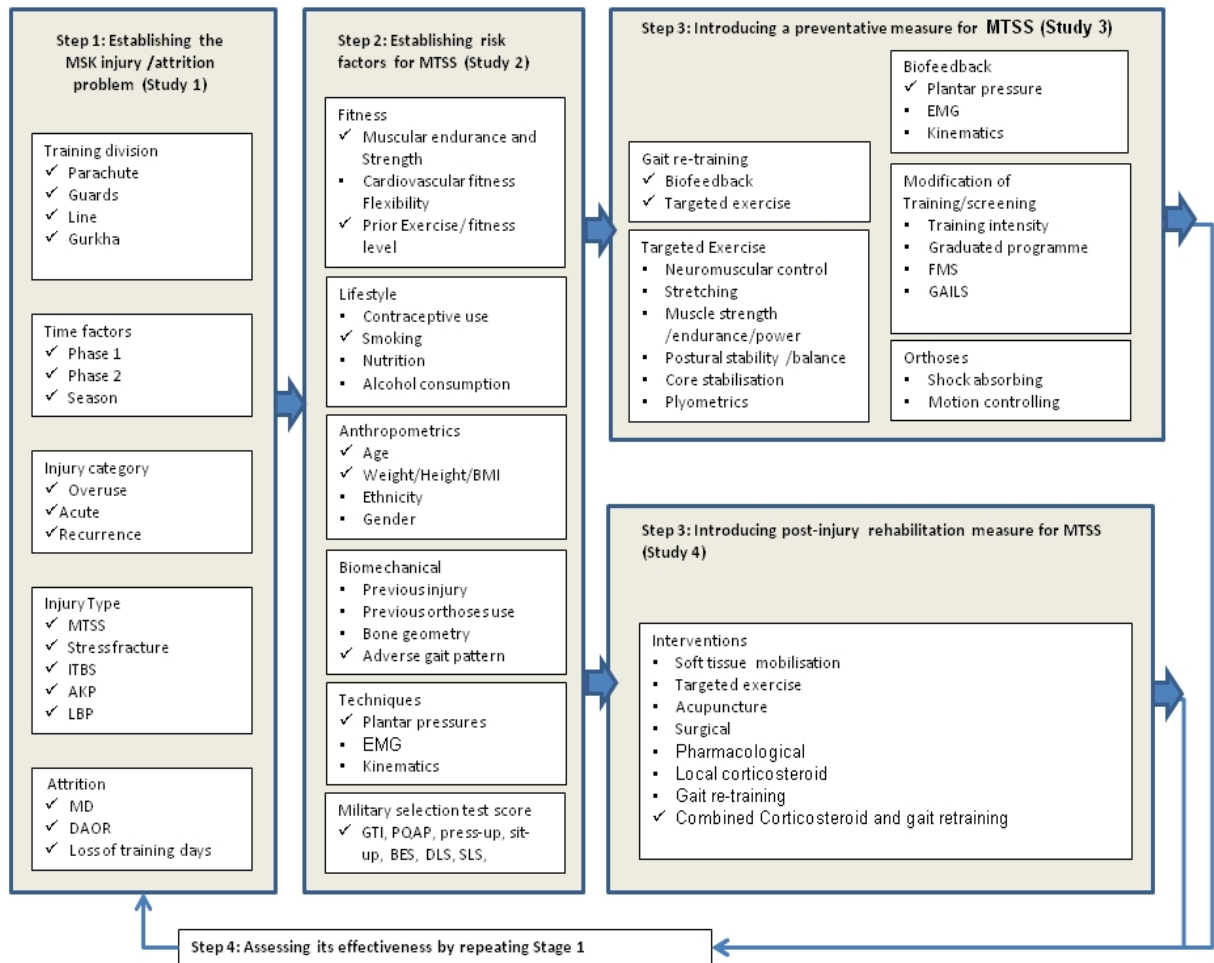
Figure 6.1. The framework used to demonstrate the approach to MSK management during CIC training (see Appendix B). Ticks represent the sub-stages covered in this thesis and bullet points represent the sub-stages which are not. The stages are modified from the sequence of prevention framework of van Mechelen et al., (1992) shown in Figure I.I. MD= medical discharge, DAOR= discharged as of right, GTI= general trainability index, PQAP = personal qualities assessment profile, BES= back extension strength, SLS= static leg strength, DLS = dynamic leg strength, FMS = functional movement screen, GALS = gait arm leg and spine

135

6.2. Original contributions to knowledge

Despite the incomplete sequence of prevention model there are nonetheless some important findings with regard to the management of injury highlighted in this thesis. Most notably this thesis is the first to utilise this modern approach to injury management for the British Army and in doing so lays the foundations for a proactive approach to injury management. The key achievements of this study were as follows:

- The establishment of the MSK injury and attrition problem in CIC training at ITC Catterick

- The determination of intrinsic risk factors for MTSS

- The development and evaluation of an effective prehabilitation programme for MTSS

- The development and evaluation of an effective rehabilitation programme for MTSS

6.2.1. The establishment of the MSK injury and attrition problem in CIC training.

There were several aspects of this study which contribute to the current evidence-base with regards to the management of MSK injury. In Chapter 2, a prospective epidemiological study was conducted to establish the magnitude of the problem of CIC training injury in terms of the injury rate, pattern of injury, most significant type of

injury, regiment and timing of the injury. It is noteworthy that training injuries are very unique to a given population and thus this type of population-specific study is necessary in order to establish the problem (Caine et al., 1996). A large sample of 6,608 CIC trainees were used and nearly half of these (48.65%) sustained at least one MSK injury during CIC training. It was found that 33% of recruits were discharged from the army and 15% of recruits were completely removed from their training company for further rehabilitation. A total of 155,403 days were lost due to injury. Training days lost are classified as minor, moderate and major (Ekstrand et al., 1983; Pasanen et al., 2008) and vary from injury to injury. Based on these classifications, MTSS and stress fractures were both categorised as major injuries while others, including ITBS, AKP and ankle injury were minor to moderate. MTSS has a high impact in terms of frequency of injury and training time lost (Yates et al., 2004; Franklyn-Miller et al., 2011). Whatever the cause, be it biomechanical, psychological or physiological, the high rates of attrition during CIC training are unacceptable. Partly due to the findings of this epidemiological study, the British Army are currently attempting to find ways to improve MSK injury management, and this chapter laid the foundations for the subsequent stages of enquiry (Chapter 3, 4 and 5).

Due to time constraints, available resources and organisational requirements, evidence-based inquiry for all MSK injuries was impossible. Therefore some difficult decisions had to be made with regard to which injuries should be considered a priority for this study. It was demonstrated that knee injury (Chapter 2) was the most common injury sustained during CIC training. However, there is already substantial evidence

for risk factors and prevention of these injuries (Hoffman et al., 1999; Wills et al., 2004; De Carlo et al., 2010; Coppack et al., 2011). In contrast the second most common injury, MTSS, has received considerably less attention in the scientific literature, yet is frequently reported to be one of the biggest causes of attrition in military recruits (Yates et al., 2004; Franklyn-Miller et al., 2011). Therefore, it was chosen to focus on MTSS for the remainder of this study.

6.2.2. The determination of intrinsic risk factors for MTSS.

Chapter 3 is the first prospective study to examine risk factors associated with MTSS. Indeed, this is one of only a few studies to combine biomechanical analyses with lifestyle factors to create a multivariable risk factor model. The lifestyle factors included were smoking habit, fitness and military selection test variables. The resulting risk factor model was able to predict 68% of MTSS cases which is a noticeable improvement on other risk factors models (Hubbard et al., 2009). These findings were published in Sharma et al., (2011a) and review published by international partners (Yuksel et al., 2011; Chuter et al., 2012; Gallo et al. 2012; Griebert, 2012; Massimiliano et al., 2012) and magazines (Lune, 2013). Although the predictive capabilities of the model should be viewed positively, it should, however, be noted that the model is not without limitations. Most notably, a third of all cases of MTSS could not be explained by the model and thus it is recognised that further improvements could be made. Taken together, it is argued that the model in its current form lacks the precision to be used as a screening tool at recruit selection, but

is sufficient for use in prehabilitation planning as demonstrated in the subsequent chapter.

6.2.3. The development and evaluation of an effective prehabilitation programme for MTSS.

In Chapter 4, a prehabilitation programme was developed for those with identifiable risk factors for MTSS as judged by the model. The intervention consisted of gait-retraining and targeted exercises and was evaluated using a prospective randomised controlled trial. Substantial improvements in plantar pressures (i.e. reduced pronation) and a reduction of MTSS (60%) and overall MSK training injuries (38%) were due to the intervention. Importantly, the study highlights that risk factor modification is a feasible approach to reducing injury rate and attrition during CIC training. Specifically, corrective exercises and gait-retraining have beneficial effects on plantar pressures leading to substantial improvements in injury and attrition rates. The benefits are considered to be greater than other prehabilitation interventions which have evaluated the effects of general conditioning (Brushoj et al., 2008) and orthotic insoles (Franklyn-Miller et al., 2011).

6.2.4. The development and evaluation of an effective rehabilitation programme for MTSS.

Using the approaches described in Chapters 3 and 4, it was not possible to prevent all cases of MTSS. Thus, in Chapter 5 a combined gait re-training and corticosteroid

injection programme was introduced as a rehabilitation treatment for MTSS. The approach was evaluated using a prospective randomised control trial. This new intervention incorporated the gait-retraining used in Chapter 4 combined with corticosteroid injection therapy. The intervention is found to be highly beneficial in terms of altering the risk factors and also in terms of reducing the impact of MTSS. It is suggested that gait re-training combined with corticosteroid therapy is an effective programme for managing MSK injury and on the basis of these results, the Medical and Rehabilitation department (Catterick) has begun to utilise the new MTSS treatment approach. Furthermore, ARTD policy regarding corticosteroid injection and gait re-training is undergoing review to enable implementation to a wider ATR and other military community.

6.3. Strengths and limitations of the studies

This study has several strengths mainly from the perspective of statistical power and study design. However, not only does it use a relatively large sample size when compared to previous MSK research, it is based primarily on objective measures (i.e. plantar pressure analysis). Furthermore, the studies conducted at each stage of the management framework are prospective and based on randomised controlled trials. Moreover, being based in a military training setting, it has excellent participant compliance and the criteria for the diagnosis of MSK injury were very consistent. However, on a more negative note, given the practical setting, it was imperative that

data collection should be time-efficient as possible. In doing so, we had to make several compromises with regards to the quality of the data being collected.

The first limitation with regard to the quality of the data was in the development of the risk factor model. It was apparent that 33% of MTSS group membership could not be predicted and it is suggested that this weakness was due to the quality of the data being collected. With more time and resources, it would have been possible to include additional biomechanical data such as lower limb 3-dimensional motion or neuromuscular activity using EMG during walking. In addition, V0^{2}Max (e.g. breath-by-breath analysis) or free oxygen radical analysis using blood sample to further improve the quality of the data could have been conducted. Furthermore, other potentially discriminating variables include bone density, inflammatory markers and nutritional status, all of which are shown to be potential risk factors for MTSS, (Bennell et al., 1996; Franklyn et al., 2008; Craig, 2009) could be included in the model.

A second limitation of the study was with regards to the specific nature of the gait-retaining intervention. Although, the findings were generally positive, the experiments were not designed to isolate and discriminate the active ingredient(s) of the intervention or target other non-MTSS injuries. Other injuries, such as stress fractures, anterior knee pain, iliotibal band syndrome and lower back pain are also important conditions occurring during CIC training. However, it should be noted that our approach followed that of Noerhen et al., (2011) who also found a targeted

approach to MSK injury enables greater specificity of the exercise progamme, and therefore greater success of the intervention.

The third limitation was the homogeneous nature of the cohort. Different populations may be required to undergo an increase in physical activity for a variety of reasons, for example those with sedentary lifestyles trying to increase their daily physical activity or athletic populations moving from sub-elite/amateur to elite/professional level. Unfortunately, the homogeneous nature of our cohort makes it difficult to predict how these other populations would respond to the interventions developed in this thesis.

6.4. Future recommendations

Based on the preceding chapters, several recommendations regarding how the management of MSK injuries could be imporved at ITC during the CIC training and potentially for the general population. These are listed according to the strength of the recommendations which is largely based on my own opionion:

1. It is very highly recommended that the British Army adopts a proactive and holistic approach towards identification and management of potential injury such as that shown in Figure 6.1. This study demonstrates substantial benefits of two interventions designed to improve prehabilitation and rehabilitation but it is expected that there are many more benefits to be accrued from this approach.

2. It is highly recommended that clinical staff should be proactively involved in the injury prevention and management by educating instructors and recruits on the risk factors for the more impactful overuse injuries encountered during training.

3. It is recommended that the British Army considers gait retraining as a viable option for reducing the impact of injury during CIC training. Further research should be carried out towards finding the active ingredients of the interventions in Chapters 3 and 4 and also into how these active ingredients could be embedded more effectively/efficiently into CIC training.

4. It is recommended that gait retraining is considered for reducing the impact of other MSK injuries during CIC training such as stress fracture, lower back pain and other such injuries (Appendix D). Further research should be carried out towards finding risk factors and strategies to reduce these injuries presented in Appendix D.

5. It is recommended that a 4-stage database, similar in structure to Figure 6.1, should be established for continual monitoring and evaluation of injury and workload at the ITC. This database could be developed iteratively to improve the management of MSK injury.

6. It is recommended that the quality of the input data for the risk factor model should be improved. In addition, it is also recommended that other variables

such as bone geometry, nutritional status and psychosocial factors should be included.

7. It is recommended that the replication of rehabilitation protocol (gait re-training and corticosteroid injection) in a wider setting is warranted in order to confirm or reject the efficacy of this protocol.

8. It is recommended that current interventions be implemented in different regiments, particularly those having female recruits and in other non-mililtary populations in order to examine their effects on the wider population. Overuse injuries are hugely de-motivating irrespective of occupation, age, gender and performance level and an effective injury prevention strategy to work across these different population groups would be desirable.

9. It is tentatively recommended that the current CIC training programme during the early weeks should be reconsidered. It is recognised, however, that the combat-readiness of trainees on completion of CIC training should not be compromised.

6.5. Overall Implications

In this study it was found that gait retraining can reduce risk factors, reduce incidence and can also be used as an effective treatment against an impactful injury, namely MTSS. While further research is clearly needed, if such findings can be extrapolated across different populations and for different injuries the implications could be very exciting. It is noteworthy that overuse injuries affect not only elite athletes or military personnel but also the general public undergoing abrupt increases in physical activity and they are hugely de-motivating for the participant irrespective of occupation, age, gender and level of performance. For example, the benefits of regular physical activity contribute to the reduced risk of many conditions such as premature mortality in general, coronary heart disease, hypertension, colon cancer, obesity and diabetes mellitus (Pate et al., 1995). Consequently, physical activity is promoted for its health benefits and is widely precribed to those with sedentary lifestyles (Pate et al., 1995). However, even though the increasing promotion of physically active lifestyles contributes towards a positive physical and mental health effect, if inappropriate loading is present this brings along the possible problem of increasing the risk of musculoskeletal injuries, which may in some cases lead to long term problems (Bahr et al., 2003). An effective injury managment strategy for a wide range of populations would therefore be highly desirable. On the basis of the results of these exploratory trials, gait retraining clearly has potential to be used as part of this strategy and thus further research is very much warranted.

Appendices

Appendix A: Combat Infantryman's Courses (CIC training)

Approximately 15,000 applicants each year succeed in passing a series of selection tests and reach the appropriate regimental standards to commence training in the British Army (Bilzon, 2003). Once prospective recruits are selected for training, non-infantry recruits in standard entry undertake Common Military Syllabus for Recruits training courses. These are done at one of the Army Training Regiments (ATR) based at Lichfield, Pirbright or Winchester. The Phase 1 training is a 14-week training course attended by all standard entry recruits except the infantry. The course teaches military skills through classroom and practical lessons and is designed to improve recruits' physical fitness through a progressive and structured physical training programme (Blacker et al., 2005; Blacker et al., 2008). For these non-infantry recruits, once Phase 1 is finished, trainees undergo further trade-specific training in various establishments. This second phase for non-infantry recruits involves more trade-specific training and has less physical intensity. ITC Catterick, where this research was conducted, is the only centre within the British Army which provides both Phase 1 and Phase 2 of the Combat Infantryman's Courses (CIC) training. CIC is the framework upon which all regular infantry recruit training is based and is the entry point for the British Army Infantry Regiments (Bilzon, 2003).

All infantry recruits embark on a CIC Phase 1 and 2 together at the infantry training centre (ITC) at Catterick. The CIC course is designed to develop soldiering skills, army values and lifestyle and turn the civilian recruit into a fully qualified infantry

soldier prepared for combat operations. The CIC course is both physically and mentally demanding, arduous and stressful in order to prepare the recruits to work effectively in various situations (Bilzon, 2003). The training programme is divided into Phase 1, which covers the first 13 weeks of the course, and Phase 2 which covers weeks 14 to 26. Once Phase 1 is completed successfully, there are normally 2 weeks leave before Phase 2 begins. Among the 15,000 applicants, 3,000-4,000 recruits commence infantry training at ITC Catterick each year and training is provided based on respective regiments standard. The summary of the content of the CIC physical training programme is given in Table 1.1.

At the time of this research the ITC was sub-divided into two infantry training battalions (1 ITB and 2 ITB). Five divisional training companies (Prince of Wales, Queens, Rifles, Scottish and Kings) which are referred to as "Line Infantry" undertake training under 1 ITB, whilst a further three training companies (Parachute Regiment, Guard Regiment and Gurkha Regiment) commence training under 2 ITB (Figure 1.2). Each divisional company consists of 5 to 9 training platoons undergoing training at any one time, with start dates at 2 to 3 week intervals. The CIC training programme is designed and validated by the Army Recruiting and Training Division, UK and meets the needs of their respective regiments. The completion of CIC training is mandatory for all infantry recruits.

Table A.1. The summary description of training activities during CIC training at ITC	
Activity	Description
Route Marching	Marching at speeds of 4mile/ hr over specified routes of up to 8 (PARA 20mile) mile carrying a 15 kg backpack and rifle.
Running	Running distances of 4 to 8 mile over specified routes
Obstacles	Running, jumping, scaling walls, vaulting and negotiating other obstacles
Circuit Training	Running, sit-ups, push-ups, weights
Swim/ Swim circuit	Swimming, pool entry and exit, poolside sit ups/ push ups
Battle training	Wrestling, log lifts, fireman's carry training, shoulder rolls, Battle physical training
Military ex/range/navigation	Field craft, firing, section attack/ map reading/navigation, drill, marching
Drill/marching	Foot drill and march

At the time of this research, the CIC training for the Line Regiment was 26 weeks compared to 28 weeks for the Guards and Parachute Regiments. The CIC training for the Gurkha Regiment is carried out for 39 weeks including 8 weeks for language education. CIC training is necessarily arduous, and infantry recruits are expected to operate at a higher intensity than other non-infantry recruits. For example, infantry soldiers carry heavy loads for a longer distance and at a faster pace.
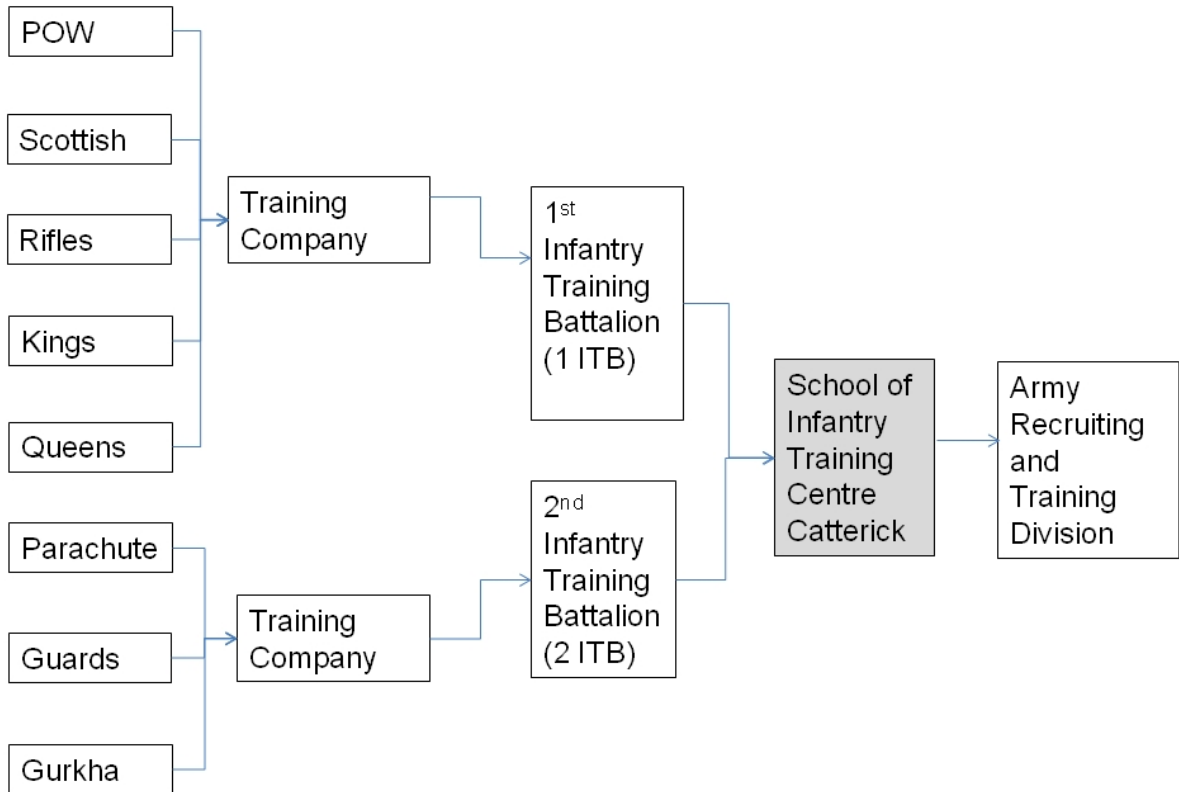
Figure A.1. The training divisional companies organisational structure at ITC Catterick where this study was undertaken, (POW = Prince of Wales)

The physical demands during the 26 weeks initial CIC training can be ranked according to intensity: Parachute, Gurkha, Guard and Line Regiments respectively. CIC Parachute recruits have the most physically and mentally demanding training in the British armed forces (Wilkinson et al., 2008). Physical fitness is the ability to function efficiently and effectively in response to the demands of training and performance. The most frequent training activities for recruits are strenuous running, loaded marching, jumping cutting manoeuvres, field exercises and cross county running (Almeida, 1999a; Pope, 2002a). Marching with loaded packs, repetitive lifting

and carrying are the tasks which are common to all military personnel (Rayson et al., 1994; Rayson et al., 1997; Rayson et al., 2002) and being able to perform such tasks effectively requires a combination of muscle strength, muscle endurance, aerobic and anaerobic fitness, all of which are equally important in order to cope with physical demands during training (Greeves, 2001). Training involves physically and mentally robustness, as well as regiment-specific training to effectively prepare them for their duty within a field army unit. Recruits cannot progress until CIC training has been completed successfully. Due to the nature of training, both injury and attrition which are common to all soldiers, takes a heavy toll on these recruit populations during this period (Billings, 2002; Sharma, 2008; Knapik et al., 2013b). Injury is described as damage to a biological organism which can be classified by cause, location or activity.

Appendix B: Commissioning letters

From Dr J L J Bilzon BSc MSc PhD BASES

Headquarters
Army Training and Recruiting Agency
Trenchard Lines
Upavon
Pewsey
Wiltshire SN9 6BE

Telephone: 01980 618193
Facsimile: 01980 615718
Mobile: 07766 697895
e-mail: hso-occmed@hqatra.mod.uk

Senior Scientific Adviser

D/ATRA/5/22/7/12

fao: Trisha
Finance Department
University of Teesside
Middlesborough
TS1 3BA   17 March 2006

UNIVERSITY TUITION FEES: MR JAGANNATH SHARMA

Reference:

A.   Telecon TEESSIDE/HQ ATRA dated 15 March 2006.

1.   Further to the Reference, I write to confirm that Mr Jagannath Sharma is conducting ATRA directed research under the supervision of Teesside University.
2.   This Headquarters will meet the costs of Mr Sharma's part-time PhD University Tuition fees.
3.   Please address all invoices and correspondence to this address (see above).

Yours sincerely,

Headquarters
Army Recruiting and Training Division
Occupational Medicine
Building 370
Trenchard Lines
Upavon
Wiltshire
SN9 6BE

Telephone:	01980 618193
Facsimile:	01980 615718
E-mail:	Julie.Greeves715@mod.uk
Website:	

School of Social Science and Law   Our Reference: ARTD/4/5/6/1
Sports and Exercise Group
Teesside University   Date 23 July 2013
Middlesbrough Tees Valley
TS1 3BA

DOCTORAL RESEARCH PROGRAMME: MR JAGANNATH SHARMA

1.   Please accept this letter as confirmation that Headquarters Army Recruiting and Training Division (HQ ARTD) has sponsored the Doctoral programme of Mr Jagannath Sharma, titled *The Development and Evaluation of a Management Plan for Musculoskeletal Injuries in British Army Recruits: A Series of Exploratory Trials on Medial Tibial Stress Syndrome.*

2.   This research was conducted at the Infantry Training Centre Catterick under the academic supervision of Teesside University. The output of this research will be delivered in the form of PowerPoint presentations, manuscripts and technical progress reports. All manuscripts emerging from this research programme must be approved for publication by HQ ARTD according to the Joint Service Publication 101.

Signed on original

J P Greeves PhD

SSO OM/ For DG ART

Appendix C: Publications

Sharma, J., Golby, J., Greeves, J. & Spears, I.R. 2011, "Biomechanical and lifestyle risk factors for medial tibia stress syndrome in army recruits: A prospective study", Gait & Posture, vol. 33, pp. 361-365.It forms part of the identification of intrinsic risk factors for developing MTSS injury.

Sharma, J., Spears, I.R., Golby, J. &Rennie, P.E.J. 2009, "Medial tibial stress syndrome", International Musculoskeletal Medicine, vol. 31, no. 1, pp. 45-46.

Sharma, J. 2008, Training related musculoskeletal overuse injury risk factors: Research summary., Director General Army Medical Services annual report on the health of the army, UK 2007, UK. It forms part of the combined Epidemiology study and identification of intrinsic risk factors for developing MTSS injury.

Internal/conference papers

RSscan international 2006 Planter Pressure Biomechanics to Predict overuse Injury: a methodology in the Prospective Study in Infantry Recruits.

Sharma, J. 2008, Risk Model Asssociated with predicting medial tibial stress syndromw; A prospective study with infantry recruits. ARTD Rehabiliation Forum Occupational health May 2008.

RISK MODEL ASSOCIATED WITH PREDICTING MEDIAL TIBIAL STRESS SYNDROME: A PROSPECTIVE STUDY WITH INFANTRY RECRUITS.

J Sharma*, J Golby, IR Spears and PEJ Rennie

1. Background/Purpose:

Infantry Training Centre Catterick (ITC(C)) is a Phase 1 and 2 combined training establishment. 3,000 to 4,500 recruits commence training at ITC(C) annually and spend 26-28 weeks on the Combat Infantry Course. 72% of Medical Discharges are related to lower limb overuse injury. Nearly 33% of those diagnosed with overuse-injury are also back termed (Wills et al., 2003).

Medial tibial stress syndrome (MTSS) is a common overuse shin injury in both military and running populations with incidence rates of up to 35% (Yates and White, 2004). In more serious cases it progresses to tibial stress fracture (Matin, 1988). The most effective management of MTSS is often prolonged relative rest followed by a graduated return to fitness. This leads to a loss of training days, increased cost of medical support, reduction in operational readiness. MTSS has been suggested to be result of biomechanical and physiological factors but the exact mechanism causing injury are not known (Murphy et al., 2003). The aim of this study is to determine prospectively whether gait biomechanics and physiological factors can be used as a predictor of MTSS development over a 24 week military training period.

2. Methods

❖ **Subjects**
❖ 468 infantry recruits with mean age (18.9 ±2.3 years), weight (70.4±9.7 kg) height (176.5 ±6.8 cm) and body mass index (22.5 ±2.5) at ITC(C) participated in this study. They had no known injury at the time of testing and all signed an informed consent form. The study was approved by the Ethics Committee at the University of Teesside.

❖ **Data collection**
❖ Fitness levels were assessed in terms of a 1.5 mile run time and smoking status established.
❖ A footscan pressure plate was hidden in the middle of a 10 meter long purpose-built walkway. Following weight calibration, the subjects walked unshod across the hidden plate at their natural walking speed. Six left and six right plantar pressure distributions during stance phase were recorded. The plantar pressure analysis software was configured to detect the left and the right foot and other relevant gait parameters (Figs 1-2).

Fig1. Plantar pressure measurement.

❖ Injury data was collected over 24 weeks in order to ascertain the rate of training-related MTSS injury within the sample (Fig2).
❖ **Variables**
❖ Independent: MTSS and non-injury.
❖ Dependent: Age, weight, height, BMI, 1.5mile run time, smoking and gait biomechanical parameters: Peak; pressure, time to get maximum heel rotation and foot balance (Medial to Lateral ratio) % gait cycle.
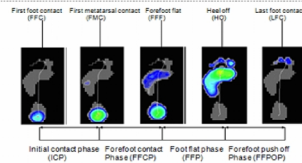
Fig 3. Five distinct instants & phases of foot-ground contact

Data analysis
2 (Group) X Time(100) 2-way ANOVA with repeated measure on 1 factor (time) with appropriate post-hoc analysis. X² test for relevant categorical data and logistic regression analysis using membership of group category.

3. Results

The overall incidence rate of the development of MTSS was 7.9 % (n=37). Higher medial peak pressure, rapid heel rotation during weight acceptance and generally higher plantar pressures were the most significant biomechanical risk factors (Fig 4-6). Slow 1.5mile running times and smoking habit were also important risk factors. Logistic regression analysis of the two groups as dependent variables and biomechanical and physiological as predictors revealed that the full model to predict MTSS significantly (P=0.002). This model is capable of predicting 96.9% of the non-injured and 67.5% MTSS. Overall the model is 87.7% accurate.
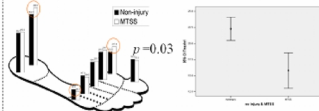
Fig4. Peak pressure (N/cm2) by group.
Fig5. Time to max heel rotation
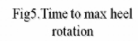
	Time	Interaction (T*G)	Group
df	93,18 4	93,184	1, 276
F	4.83	1.62	7.293
P	0.005	0.003	0.007
η2	0.71	0.450	0.026
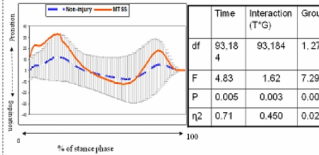
Fig6. ANOVA with repeated measure on Foot balance

4. Discussion

This study created a risk model for the development of MTSS and highlighted the potential importance of biomechanics & physiology as shown in Fig6. The results are inter-related at the tissue-level. The adverse biomechanics increase load to the tissue. Fatigue would be accelerated by poor biomechanics, poor fitness and smoking. As such the tissues ability to repair is reduced, thus, minor trauma to the tissue, is not repaired and subsequently leads on to more prolonged damaged.

Study design, relatively large sample size, external variables relatively control and clinical relevant are the strength of this study. Barefoot walking at self-selected speeds was analysed was the limitation of this study.
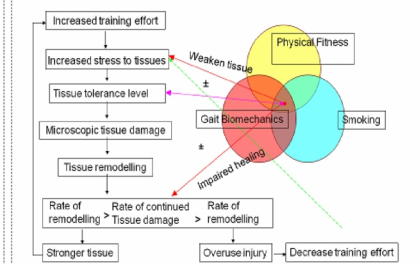
Fig 6. Risk model for developing MTSS

5. Conclusion

- Effective strategies for reducing the risk of MTSS might involve reducing smoking behaviour, improving physical fitness and correcting undesirable gait patterns prior to the intensive training programme.

- Future developments will include these interventions with the aim being to reduce injury rates.

6. References

Matin, P. (1988). Basic principles of nuclear medicine techniques for detection and evaluation of trauma and sport medicine injuries. Seminar Nuclear Medicine 18: 90-112.
Murphy, D. F., Connolly, D. A. J., and Beynnon, B. D. (2003). Risk factors for lower extremity injury: a review of the literature. British Journal of sport medicine 37: 13-29.
Yates, B. and White, S. (2004). The incidence and risk factors in the development of medial tibial stress syndrome among naval recruits. American Journal of Sports Medicine 32: 772-780.
Wills A.K, Ramasamy A, Ewins D, Carter N & Etherington, J. (2003). A prospective study into the epidemiology and dynamic biomechanical risk factors of overuse anterior knee pain. DMRC Headley Court Report.

*Contact : Jagannath Sharma Principal Physiotherapist, ITC(C). Email: J.sharma@tees.ac.uk , Tel. +44 01748 872619

Sharma J., Spears, I.R Golby, J. Musculoskeletal Injury during British Infantry Recruit training: A prospective study. ARTD Rehabiliation Forum Occupational health 24th May 2011.

Musculoskeletal injury during British Infantry Recruits training: a prospective study.

J Sharma*, J Golby, J. Greeves and IR Spears

UNIVERSITY OF TEESSIDE

ARMY

1. Background/Purpose:

Infantry Training Centre (ITC) Catterick is a Phase 1 and 2 combined training establishment. Between 3,000 to 4,500 recruits annually commence training at ITC and spend 26 weeks on the Combat Infantry Course. Improving physical fitness is a major component of recruit training. Such training leads to musculoskeletal (MSK) injuries and attrition with incidence rates of up to 85% (Yates and White, 2004) and 82% of Medical Discharges (MD) are also related to lower limb MSK injury at ITC (Sharma et al 2007). However, there are no published studies to quantify the magnitude of the problem at ITC. The most effective management of MSK injury is often prolonged relative rest followed by a graduated return to training. This leads to a significant problems in both personal cost to recruits and financial burden to the army.

MSK injury has been suggested to be the result of training error, and/or biomechanical and physiological factors but the exact mechanism causing injury are not known (Murphy et al, 2003). The aim of this study was to quantify incidence rates, injury patterns and their impact on British army recruits undergoing recruit training over a 26 week period.

2. Methods

❖ **Participants**
- Study periods: 1st April 2006 to 30th March 2008, 7726 recruits arrived at ITC invited to take part in the study.
- 1118 out of 7726 (14%) left prior to completing training.
- Remaining number totalled 6608 subjects based on four regimental training company. These regiments comprise:
  - Line n = 4372 (69.7%), Guards n=1044 (15.8%), parachute (PARA) n = 734 (11.1%) and Gurkha n= 458 (6.9%) were taking part in this study.
❖ **Training programme:**
- Standardised and validated for regiment specific task. Recruit training is divided into phase 1 (1-13 weeks) and phase 2 (14-26 weeks) and had 2 weeks leave once finished phase 1 training.
❖ **Demographic characteristic:**
- Mean age (18.9 ±2.3 years), weight (70.4±9.7 kg), height (176.5 ±6.8 cm) and body mass index (22.5 ±2.5)
- All signed an informed consent form. The study was approved by the Ethics Committee at the University of Teesside.
❖ **Data collection:**
- All injured recruits reported to medical centre for assessment & treatment.
- MSK injury was defined prior to collection data & diagnosis was made by medical staff.

Injury data was collected prospectively over 26 weeks based on: Injury onset, injury based on regimental cap badge (PARA, Guards, Line and Gurkha) training company, anatomical body part of injury, and week of training when injury occurred.

Variables Analysed:

Independent: MSK injury and non-injury.
Dependent: Age, weight, height, BMI, training regiments, phase of training
Occupational outcome- first time completed training and attrition.

Data analysis

Kaplan-Meier (KM) survival function curves were plotted among 4 training regiment arms and log rank test was used to examine the differences of survival probability of MSK injury. X^2 test for other relevant categorical data and also analysed descriptively on training outcome and attrition.

3. Results

The overall incidence rate of the development of MSK injury was 48.65% (n=3232). Of these, 82.34% injuries were found in the lower extremity.

The KM survival curve (Figure 1) and log rank test was used to answer the research question, what is the probability of recruit surviving from MSK injury among training regiments? Result show significant difference (p<0.001) with the probability of being free from MSK injury were for the PARA (14%), the Guards (54.4%), the Line (52.4%) and the Gurkha regiment (90%).

To answer the research question- "is there any difference in MSK injury between 1st and 2nd phase of training"? X^2 test showed statistically significance difference (p<0.01), most of the injury reported in the first phase of training.

Results also showed there was significant difference (P=0.02) in injury types. This pattern was; overuse (43%), followed by acute (32.8%) and recurrence (24.16) . Table 1 shows the overall pattern was similar for the four training regiment but the PARA had higher proportion of (54.7%) of overuse injury.

Occupational outcome (number passing out first time) and attrition was also analysed. Results showed significant difference (P=0.02) among regiments. Order of first time completed training were; PARA, Guards, Line and Gurkha 38%,51%,56% and 98%. 33% of the total sample left prior to complete training. 991 (15%) recruits have taken completely out of training for further rehabilitation. Mean rehabilitation time was 58 days (SD 15) and this ranged between 21 to 168 days depending on the injury type. Over a period of 26 weeks a total of 155403 training days were lost due to injury. These lost days are equivalent to 853 (12%) recruits' training time.

Table 1 Onset of injury pattern among four regiments

Training Regiment		Acute	Recurrent	Overuse	Total
Line (n=4372)	Count	706	530	843	2079
	% within cap badge	33.9%	25.5%	40.5%	100.0%
PARA (n=734)	Count	189	118	345	831
	% within cap badge	30.6%	19.7%	54.7%	100.0%
Guards (n=1044)	Count	182	131	163	476
	% within cap badge	34.5%	25.4%	40.3%	100.0%
Gurkha (n=458)	Count	5	9	20	46
	% within cap badge	39.1%	17.4%	43.5%	100.0%
Total (n=6608)	Count	1082	777	1403	3232
	% within cap badge	32.5%	24.0%	43.4%	100.0%

Fig. 1. The kaplan-Meier survival curve

Log rank test: X^2 =792.5, p<0.001

4. Conclusion

This study demonstrates that MSK injury is a big problem during recruit training. The proportion of those surviving MSK injury varied amongst the different training regiments ranging from 14% for the PARAS to 90% for the Gurkha. Such disparities in MSK injury could be due to differences in the training programme. Most notably, there appears to be a 8 times greater risk of sustaining MSK injury whilst undergoing training in the parachute regiment compared with the Gurkha regiment.

Recruits are more likely to develop injuries during the first phase of training . Majority of injury were overuse.

Future research should persue injury reduction strategies and predicive validity fitness background in recruits.

6. References

Matin, P. (1988). Basic principles of nuclear medicine techniques for detection and evaluation of trauma and sports medicine injuries. *Seminar Nuclear Medicine* 18: 90-112.

Murphy, D. F., Connolly, D. A. J., and Beynnon, B. D. (2003). Risk factors for lower extremity injury: a review of the literature *British Journal of sport medicine* 37: 13-29.

Sharma, J. (2007). Training Related Musculoskeletal Overuse-Injury Risk Factors: Research Summary. Annual Report on the Health of the Army. Director General Army Medical Service, Camberley, UK.

Yates, B. and White, S. (2004). The incidence and risk factors in the development of medial tibial stress syndrome among naval recruits. *American Journal of Sports Medicine* 32: 772-780.

Wills AK, Ramasamy A, Ewins D, Carter N & Etherington, J. (2003). A prospective study into the epidemiology and dynamic biomechanical risk factors of overuse anterior knee pain. DMRC Headley Court Report.

Sharma J., Spears, I.R, Golby, J. Efficacy of a new rehabilitation protocol on Medial Tibial Stress Syndrome in Recruits.ARTD Rehabiliation Forum Occupational health 31 May 2012.

Appendix D: Types of musculoskeletal overuse injuries in a military training setting

   D.1. Lower back pain.

Low back pain is the most common disability in those under the age of 45 (Hutson, 1993). It can be either acute, subacute or chronic in duration (Holz et al., 2009). With conservative measures, the symptoms of low back pain typically show significant improvement within a few weeks from onset. Low back pain is a common symptom in the general, military and sports populations (Brukner et al., 2012). Back pain affects up to 85% of the populations at some time in their lives, with 14% having an episode that lasts more than 2 weeks (Deyo et al., 1992). Back pain cannot be given a definitive diagnosis due to weak associations among symptoms, pathological changes and imaging results (Shiqing et al., 1987). However, back pain is a leading contributor to time absent from work. The vast majority improve over a three month periods, however, nearly 50% will have recurrent episodes and the estimated annual cost of low back pain in the United States is over US$40 billion (Brukner et al., 2012). Causes of lower back pain are varied and in most cases are due to a sprain or strain in the muscles and soft tissues of the back. Injury can occur to the intervertebral discs, sacroiliac joint dysfunction, osteoarthritis, rheumatoid arthritis, degeneration of the discs,spinal disc herniation, a vertebral fracture (Hutson, 1993). In the vast majority of cases, no serious cause is ever identified. If the pain resolves after a few weeks, further investigation is not indicated. Over-activity of the muscles or excessive rotation or torsion stress may damage the facet joint, the disc or both (Norris, 1998).

The symptoms are pain described as mild to severe across the lower part of the back. Pain sometimes travels into the buttocks, the groin area or down into the back of the thigh and pain is usually aggravated by movement. Other symptoms may be stiffness and muscle spasm. Range of motion may be restricted and posture may change due to severe pain and spasm in the muscles surrounding the spine (Hooker et al., 2004). There may on occasion be a tingling sensation or a feeling of numbness in the back, buttocks or down one or both legs. Considerable research has been published on risk factors for low back pain: these are age, gender, obesity, height, posture, smoking, physical work, sedentary occupation, abrupt increased fitness, psychological factors (Brukner et al., 2007) and excessive pronation (Harradine et al., 2006).

D.2. Iliotibial band syndrome.

The ilio-tibial band (ITB) plays a role in stability around the hip along with hip adduction and flexion which increase the pressure around the greater trochanter. This pressure is further increased by knee flexion (Brukner et al., 2012). On the other hand, the same pressure is reduced with hip abduction and knee extension. Biomechanical studies have found no difference in sagittal knee movements which suggest other planes of motion may contribute. For example; internal tibial rotation can increase compressive force by moving the ITB more medially (Noehren et al., 2011). The hip adduction is likely to create loading and lengthening of the ITB causing significantly greater lateral displacement of the patella, than when the hip is abducted and the ITB unloaded (Herrington et al., 2012). Biomechanically, the proposed

aetiology is distally increased rearfoot eversion and subsequent internal tibial rotation while proximally increased hip adduction due to weakness of the hip abductor and increased knee internal rotation contribute to the development of ITB syndrome (Willson et al., 2006).

ITB syndrome is an overuse injury presenting as lateral knee pain and it is commonly seen in runners and recruit populations (Gooch, et al., 1993; Almeida, 1999a; Fredericson et al., 2000). Incidence rates range from 1.6 to 12% and 1 to 5.5% in runner and military populations respectively (Ellis et al., 2007). The ITB is a thick band of fibrous tissue which reinforces the tensor fascia lata muscle (Myers, 2009). It originates on the anterolateral iliac tubercle of the iliac crest and inserts into Gerdy's tubercle on the lateral condyle of the proximal tibia (Kendall et al., 1993). The ITB moves with knee position, for example anterior to the femoral condyle in knee extended position; lateral in knee flexed position and beyond 30-40 degree of knee flexion it moves to the posterior of the femoral condyle (Williams et al., 1989; Saladin, 2012).

The location of pain is mainly over the lateral femoral condyle, approximately 2 cm above the knee joint line (Brukner et al., 2012). The symptoms are aggravated by running downhill or any activity which places the knee in a weight bearing position with 30 degrees of knee flexion (Gunter et al., 2004; Fredericson et al., 2005). The pain is insidious in onset and unrelated to any traumatic events and Nobles

compression test is positive (Brukner et al., 2012). If the ITB is excessively tight it causes friction and inflammation (Gunter et al., 2004; Ellis et al., 2007).

D.3. Anterior knee pain.

Anterior knee pain (AKP) is a syndrome that encompasses various condition including patellofemoral pain and jumpers knee which is frequently associated with pain in the front of the knee (Tumia et al., 2002; De Carlo et al., 2010). However, patellofemoral pain syndrome describes pain in and around the patella and mostly occurs with an overuse injury (Wills et al., 2004). Patellofemoral pain syndrome is insidious in onset unrelated to any traumatic event and the pain is aggravated by prolonged sitting, squatting, stair climbing, running or hopping and the pain is reproduced on palpation of the patella facet and squeezing the patello-femoral joint (PFJ) (Crossley et al., 2002).

An incidence of 8.7% has been reported in British Army recruits during phase 1 training (Wills et al., 2004) and 5 to 15% in other country's recruits with anterior knee pain accounting for 25 to 40% of all knee problems (Jones et al., 1993a; Cowan et al., 1996; Fagan et al., 2008). Regarding the etiology of the patellafemoral pain two theories have emerged. One invokes patellar malalignment relative to the femoral trochlea causing unevenly loading articular cartilage (Kesson et al., 1998). A second theory proposes that AKP is due to a supra physiological mechanical loading and chemical irritation of the nerve endings (Brukner et al., 2007; Comfort et al., 2010).

Once it is inflamed it is continuously aggravated by the activity of daily living resulting in prolonged symptoms.

The risk factors of patellafemoral pain are; hyperpronation, with a secondary increase in transverse plane motion of the tibia which often leads to eccentric loading of the patella including overuse of vastus lateralis and under use of vastus medialis (Tiberio, 1987). Anterior knee pain (AKP) is a common injury (Brushoj et al., 2008; Coppack et al., 2011) and as such the risk factors and intervention of AKP has been researched extensively in the past (Wills et al., 2004; De Carlo et al., 2010; Coppack et al., 2011). Hoffmann (1998) investigated 80 participants to find out whether there was any relationship with anterior knee pain and plantar pressure distribution. They compared the static pressure under the metatarsal head (M1 and M5) and found that the pressure under M5 was higher than under M1. The dynamic pressure distributed under the forefoot equated to 49% of the pressure at M1 and M2 while there was 51% under M3-M5. This result showed high pressure on both static and dynamic distribution of the lateral foot. The author considered that the high pressure on the lateral foot was attributed to the development of anterior knee pain. The normal physiological forces transfer sequence reported medial forefoot-talus-tibia, the lateral pressure caused an unphysiological impulse through the lateral forefoot and calcaneus. The possible cause of knee pain was attributed to a continued rotation at the knee which can cause a change to the angle of the patellar tendon. One problem of this study was its small number of subjects using only 15 subjects who had anterior

knee pain, pain might compensate for the pressure distribution pattern (Schmid et al., 2013).

D.4. Lower leg pain.

Lower leg pain is a combination of conditions such as medial tibia stress syndrome (MTSS), compartment syndromes and bone stress spectrum which may co-exist (Clement, 1974; Detmer, 1986; Rudzki et al., 2012). However, the most common of these lower limb overuse injuries is MTSS (Rudzki et al., 2012). MTSS refers to the specific overuse injury which results in an inflammatory soft-tissue reaction and pain along the posteromedial border of the tibia in the middle and distal third of the leg (Andrish, 1974; Story, et al., 2006; Carr et al., 2008). MTSS is the second most common overuse injury (Gooch et al., 1993) with a high incidence rate ranging from 4-35% in athletic and military populations (Almeida, 1999a; Almeida et al., 1999b; Yates et al., 2004; Willems et al., 2006). On examination there is a diffused area of tenderness along the posteromedial border of the tibia. Stress fractures, may result from MTSS if ignored (Beck, 1998). Stress fractures have a much more focal area of severe tenderness and greatly increased radionuclide uptake on a bone scan (Couture et al., 2002). Two or more of these conditions may exist simultaneously and differential diagnosis can be confirmed from a combination of injury history records, physical examination and magnetic resonance imaging (MRI) (Young et al., 2006; Craig, 2009; Brukner et al., 2012). MRI has the sensitivity to elevate bony lesions, marrow changes and soft tissue injuries. Stress fracture and MTSS can be

differentiated using MRI and one aspect would be more focal periosteal swelling (edema) in stress fracture cases (Fredericson et al., 1995).

Medial tibial stress syndromes (MTSS) has a substantial impact on the loss of individual health and training days in military populations (Yates et al., 2004; Franklyn-Miller et al., 2011; Sharma et al., 2011b). The patho-mechanics of this injury are not known but two theories have been proposed. The first is that MTSS is due to tibial bending (Lanyon, 1975; Michael et al., 1985; Beck, 1998; Couture et al., 2002) and the second is that MTSS is due to soft-tissue traction due to excessive eccentric loading (Detmer, 1986; Saxena et al., 1990; Beck et al., 1994; Kortebein, et al., 2000; Bouche et al., 2007). The latter theory relates to the sequence of events during walking and running. For example, the soleus muscle eccentrically contracts to resist pronation (Galbraith et al., 2009). Excessive and longer pronation due to adverse foot function or overload combined with repetitive impact loading leads to chronic traction over its insertion onto the periosteum (Willems et al., 2007; Craig, 2008c; Craig, 2009; Brukner et al., 2012). Soft tissue traction may lead to the development of chronic pain due to inflammation (Bouche et al., 2007) which the body may not be able to abolish (Bennett et al., 2001). Furthermore, Magnusson et al., (2001) found abnormal decreased bone mineral density in individuals who suffered from MTSS. They stated that pain and inflammation impedes osteoblastic activity leading to the bone becoming weaker; hence, both types of MTSS may develop into stress fractures if not treated early. Research also shows that once pain subsides, bone mineral density also increases by approximately 19% at the MTSS site (Magnusson et al., 2003). This

clearly demonstrates that early optimal management of this condition is essential to prevent the further complication of developing stress fractures, the breakdown of a chronic inflammation vicious cycle, and optimum gait pattern. However, it is not yet clear which is the most effective strategy for the management of this disorder (Galbraith et al., 2009). In chapter 5, the effectiveness of new rehabilitation on this condition research is conducted and discussed more details further.

Appendix E: The exercises used on both Study 3 and Study 4

1. **Birddog:** Position hands below shoulders and knees below hips. Position back in neutral, extend one leg backwards and raise the opposite arm until level with back. Ensure back does not extend and shoulders and pelvis do not tilt sideways. 5 seconds hold in position. Bring leg and arm back to start position and swap sides (Hibbs et al., 2011).

2. **Gluteal Medius Control:** Stand against a Swiss ball that is touching the wall. Apply a force through the side of your knee and into the ball. Lift your knee up to 900 rolling the ball against the wall (Coppack et al., 2011).

3. **Small Knee Bend Progress to Single Leg Squats:** In weight bearing with correct the alignment- the line of the femur should be over and parallel to the line of the 2nd metatarsal then perform small knee bent then progress to single leg squats. Standing with back in neutral and hands on hips. Flexion left knee to 900 so foot is off floor and balancing on right leg. Keeping head looking forward and hips straight, flexion the right hip and knee. Squat as low as possible, hold and return to starting position, remain balanced on right leg and repeat 2second hip flexion (down) – 2second hold – 2second hip extension (up) (Comerford, 2007).

4. **Calf Raises:** Stand on one leg on the edge of a step with your heel down and knee straight. Raise up onto the ball of your foot. Slowly lower under control.

Stand on one leg on the edge of a step with your heel down and knee bent

Raise up onto the ball of your foot keeping your knee bent. Slowly lower under

control 2seconds raises heel up (concentric), 2 seconds heel lower (eccentric)

and 2second hold while heel down (Kulig et al., 2009).

5. **Tibialis Posterior Control:** Stand on the edge of a step with only half your

foot on the step. Slowly roll your foot into the middle (3 seconds) and then over

onto the outside edge (3 seconds). This should be a controlled, smooth

movement (Kulig et al., 2004).

6. **Intrinsic Foot Muscle (IFM) Control:** Stand in front of a wall, with the feet

shoulder width apart and knees slightly flexed. The fingertips may be lightly

placed on the wall. Then gently supinate and actively attempt to approximate

the head of the first metatarsal towards the heel, without flexing the toes and

the gluteal muscles may also need to be activated to facilitate femoral and

tibial lateral rotation, which may assist in this active supination. While actively

maintaining the medial longitudinal arch (MLA), stand on a single leg. The

knee on the weight-bearing lower extremity flexed 10-20° to help the

contraction of the quadriceps muscle and the potential facilitation of the IFM.

The fingertips should remain lightly on the wall for balance and fall prevention.

Hold the position for a count of 10 seconds and attempt to maintain the MLA

as steady as possible during the entire time without any compensatory

extrinsic foot muscle activity. Following the 10-seconds, slowly and with

eccentric control allow the foot to pronate and the MLA to lower to a relaxed state (Jam, 2004; Sauer et al., 2011).

7. **Double Leg Jump:** Stand with feet shoulder width apart. Bend at the knee while maintaining a straight back. Move hands upwards jump onto the middle of the step. Land softly while bending at the knee and maintain your balance and jump off the step (Stephens et al., 2007)

8. **Star Excursion Stability Exercise:** Reach Directions - anterior, posterior, postero-medial, and postero-lateral. Marks made in front of toes and behind heel, Position stance foot accordingly, both feet on the ground, hands on hips maximally reach and lightly tough with big toe and return to start position (Chaiwanichsiriet al., 2011).

9. **Single Limb Hops to Stabilization/ Unanticipated Hops to Stabilization:** A number sequence is displayed on a computer screen in front of the participants. Each number corresponded to a target position to which they would hop. As the progression of numbers changed, participants would hop to the new target position. The hop to stabilization rules applied for this activity, however in this case, participants were allowed to use any combination of hops they desired to accomplish the goal of getting to through the sequence error free. As a participant developed proficiency, the amount of time per move was reduced (McKeon et al., 2008a, McKeon et al., 2009a; 2009b)

10. **Hip flexor stretch:** Place stretching knee on the floor, other leg foot placement forward and lean forward toward not stretching leg keep your back straight and chest up. Move forward until you feel stretching leg front of the thigh feel stretch (Coppack et al., 2011).

11. **Hamstrings stretch:** Lying supine, keeping your head and shoulders on the floor slowly raise your leg and grasp the limb above or below the knee, to extend the stretch pull the toes towards the head. A towel can be placed onto the foot as a variation of the stretch (Hartig et al., 1999; Sharma et al., 2004b).

12. **Calf stretch:** Standing one leg back and other front, keeping knee straight and heel on the floor leaning forward and front knee bent bring knee toward the wall and swap the leg (Pope et al., 2000).

Appendix F: Examples of published intervention programmes for preventing MSK injuries in athlete and military populations.

Table F.1. Examples of published intervention programmes for preventing MSK injuries in athlete and military populations.			
Study Design	Participants	Interventions and duration	Outcomes
Andrish et al., 1974 RCT	2777 Navel USA	Four intervention groups: Use of heel pad Stretching exercises use of heel pad and stretching Graduated running programme Control group normal physical education programme	Incidence of shin splints during training Compliance
Brushoj et al., 2008 RCT	1020 male Royal Danish life guards Age range :19-26 years	Intervention group: lower-limb muscle strength, coordination and flexibility (5 exercises performed in 3 sets of 5-25 repetitions, 3 times per week. The load was progressed every 2 weeks) Control group: exercise programme for arms and upper body (placebo training) Duration of intervention in weeks: 12	Overuse knee injuries, MTSS, muscle strains and other overuse injuries of the lower limb. Compliance
Buist et al., 2008 RCT	532 Novice runners Age range:18-65 years.	Intervention group: graded training programme for 13 weeks, based on the 10% training rule, refers to an increase in training volume of no more than 10% per week) Control group: standard training programmeme for 8 weeks	Incidence of running related injury (self reported)
Finestone et al., 2004 RCT	451 Israel male Age mean: 18.74	Intervention group : soft custom-made orthoses Control group: soft prefabricated orthoses Duration of intervention in weeks: 14 basic training	Stress fracture, ankle sprains and foot problems Compliance
Gardner et al., 1988 CCT Cluster randomised by platoon.	3025 USA male marine recruits Age range: 18 to 41	Intervention group:Sorbothane shock absorbent viscoelastic polymer insoles in standard marine boots Control group: standard mesh insoles Duration of intervention in weeks: 12	Incidence of lower extremity injuries
Hartig et al., 1999 RCT Cluster randomised by company	298 USA male Army recruits Age mean: 20 years	Intervention group: routine stretching before training plus 3 hamstring stretching sessions daily (before lunch, dinner and bedtime). Stretching routine: 5 x 30 seconds Control group: routine stretching before training Duration of intervention in weeks: 13	Incidence of lower-limb overuse injuries.

Table F.1 (Cont.). Examples of published intervention programmes for preventing MSK injuries in athlete and military populations.

Study Design	Participants	Interventions and duration	Outcomes
Knapik et al., 2009 CCT Individually randomised	3952 Army recruits (32% female) undergoing 9 weeks of training Age mean ± SD: men 23 ± 5, women 23 ± 6	Intervention group (N = 1346 male and 633 female): participants were prescribed a type of running shoes (stability, cushion or motion control) based on the plantar shape Control group (N = 1343 male and 630 female): standard stability shoes Duration of intervention : 9 weeks	Lower extremity overuse injuries
Knapik et al., 2010 CCT Individually randomised	3021 USA Air Force recruits (28% female) undergoing 6 weeks training	Intervention group (N = 1417; 26% female): prescribed a type of running shoes (stability, cushion or motion control) based on the plantar shape Control group (N = 1259; 27% female): standard stability shoes Duration of intervention in weeks: 6	Lower extremity overuse injuries (using the Training Injury Index)
Larsen et al., 2002 RCT Individually randomised	146 Denmark Army recruits (1 female) undergoing 3-month training Age range: 18-24	Intervention group: military boots + custom-made biomechanics shoe orthoses Control group: military boots and no inserts Duration of intervention in weeks: 12	Self-reported back and lower-limb injuries with at least one day off from duty compliance
Liu et al., 2008 RCT Individually randomised	122 Chinese male army recruits undergoing 12 weeks of training Age range :17-19	Intervention group: routine daily morning gastrocnemius stretches plus three more sessions of stretching before lunch, supper and sleep. Control group: routine daily morning gastrocnemius stretching exercises. Stretching routine: 5 x 30 seconds static stretches bilateral limbs Duration of intervention in weeks: 12	Lower-limb overuse injuries (include patellofemoral joint pain syndrome, tendinopathy, muscle injuries, shin splints, foot injuries and stress fracture).
van Tiggelen et al., 2004 RCT Individually randomised	200 Belgium officer cadets undergoing 6 weeks basic military training Age range: 17 to 26	Intervention group (N = 61; 20% female in the analysis): dynamic patello-femoral knee brace. Control group (N = 139; 17% female in the analysis): no brace Duration of intervention in weeks: 6	Incidence of anterior knee pain diagnosed by the military physician

T Table F.1 (Cont). Examples of published intervention programmes for preventing MSK injuries in athlete and military populations.

Study Design	Participants	Interventions and duration	Outcomes
Van Tiggelen et al., 2009 RCT Cluster randomised by platoon	189 male and female officers cadets Belgian Royal Military Academy, Brussels, undergoing 6 weeks of basic military training	Intervention group : padded polyester socks (88% polyester, 11% polyamide and 1% elastane). 2. Intervention group : wore a thin inner sock (45% polyester, 45% viscose, 8% polyamide, and 2% elastane) under a thick cotton-wool stock (40% cotton, 40% wool, 18% polyamide, and 2% elastane) Control group: regular Army socks (70% combing wool and 30% polyamide). Duration of intervention in weeks: 6	Overuse injuries of the knee ,ankle, achilles tendinopathy, shin splints and tibial stress reactions. Participants kept a diary of their injuries during the training
Withnall et al., 2006 RCT Individually randomised	1300 Royal Air Force recruits (22% female) RAF Halton, UK, undergoing 9-week basic training Age range: 16 to 35	Intervention group (N = 421, 22% female): Sorbothane shock-absorbing insoles Intervention group (N = 383, 22% female): Poron shock-absorbing insoles Control group (N = 401, 23% female): Saran non shock-absorbing insoles Duration of intervention in weeks: 9	Serious lower-limb injuries necessitating withdrawal from training. Overall and by location (thigh, knee, shin and calf, ankle, foot and achilles tendon). Diagnosed by the Medical Centre doctors, nurses or physiotherapists
Coppack et al., 2011 RCT Clustered by platoon	1502 British Army recruits, Pirbright Age range: 19 to 20	Intervention group: strength :isometric hip abduction, forward lunges, single leg step down, single leg squats, Stretches: quardriceps, iliotibial band, hamstring, calf Duration of intervention: 14 week	Incidence of anterior knee pain and occupational endpoint: DAOR, MD, successful completion training
Pope et al., 2000 CCT Cluster randomised by platoon	1538 Australian male Army recruits undergoing 11weeks of training Age: 17-35 years	Intervention group: stretches to gastrocnemius, soleus, hamstrings, quadriceps, hip adductor and hip flexor muscle groups, interspersed with 4 minute warm up activities before training. Stretching routine: 1 x 20 seconds stretch for each muscle group Control group: only warm up activities but no stretching exercises	Lower-limb injuries by area and by type: joint injury, ligament sprain, muscle strain, tendinitis, periostitis compartment syndrome.

References

Abboud, R.J. 2002, "Relevant foot biomechanics", Current Orthopaedics, vol. 16, pp. 165-179.

Abramowitz, A., Schepsis, A. & McArthur, C. 1994, "The medial tibial syndrome: the role of surgery", Orthopedic Review, vol. 24, pp. 875-881.

Acevedo, J.I. & Beskin, J.L. 1998, "Complications of plantar fascia rupture associated with corticosteroid injection", Foot Ankle International, vol. 19, no. 2, pp. 91-97.

Akesson, K.A. & Woolf, A.D. 2007, "How to develop strategies for improving musculoskeletal health", Best Practice & Research Clinical Rheumatology, vol. 21, no. 1, pp. 5-25.

Alexander, I.J., Chao, E.Y.S. & Johnson, K.A. 1990, "The assessment of dynamic foot-to-ground contact forces and planter pressure distribution: a review of the evolution of current techniques and clinical applications", Foot and Ankle, vol. 11, pp. 152-167.

Allsopp, A.J., Scarpello, E.G., Andrews, S. & Pethybridge, R.J. 2003, "Survival of the fittest? The scientific basis for the Royal Navy pre-joining fitness test", Journal of Royal Navy Medical Services, vol. 89, pp. 11-18.

Almeida, S., Trone, D., Leone, D. & Shaffer, R. 1999b, "Gender differences in musculoskeletal injury rates: a function of symptom reporting?", Medicine and Science in Sports and Exercise, vol. 31, no. 12, pp. 1807-1812.

Almeida, S.A. 1999a, "Epidemiological patterns of musculoskeletal injuries and physical training", Medicine & Science in Sports & Exercise, vol. 31, no. 8, pp. 1176-1182.

Andrish, J.T., Bergfeld, J.A. & Walheim, J. 1974, "A prospective study on the management of shin splints", Journal of Bone and Joint Surgery, vol. 56, pp. 1697-1700.

Angioi, M., Metsios, G.S., Koutedakis, Y., Tiwtchett, E. & Wyon, M. 2009, "Physical fitness and severity of injuries in contemporary dance", Medical Problems of Performing Artists, vol. 24, no. 1, pp. 26-29.

Arthritis research UK, 2008, Arthritis in the UK - key facts, Arthritis in the UK. Available from: http://www.arthritisresearchuk.org/pdf/arthritis%20key%20facts.pdf

Ascenzi, A. & Bonucci, E. 1976, "Mechanical similarities between alternate osteons and cross-ply laminates", Journal of Biomechanics, vol. 9, no. 2, pp. 65-72.

Atkinson, G. & Nevilla, A. 2001, "Selected issues in the design and analysis of sport performance research", Journal of Sports Sciences, vol. 19, no. 10, pp. 811-827.

Bahr, R. & Holme, I. 2003, "Risk factors for sports injuries - a methodological approach", British Journal of Sports Medicine, vol. 37, pp. 384-392.

Bandholm, T., Boysen, L., Haugaard, S., Zebis, M.K. & Bencke, J. 2008, "Foot medial longitudinal-arch deformation during quiet standing and gait in subjects with medial tibial stress syndrome", Journal of Foot & Ankle Surgery, vol. 47, no. 2, pp. 89-95.

Baoge, L., Van Den Steen, E., Rimbaut, S., Philips, N., Witvrouw, E., Almqvist, K.F., Vanderstraeten, G. & Vanden Bossche, L.C. 2012, "Treatment of skeletal muscle injury: a Review", ISRN Orthopedics, [Online], pp. 7. Available from: doi:10.5402/2012/689012.

Barnes, A., Wheat, J. & Milner, C. 2008, "Association between foot type and tibial stress injuries: a systematic review", British Journal of Sports Medicine, vol. 42, no. 2, pp. 93-98.

Barrios, J.A., Crossley, K.M. & Davis, I.S. 2010, "Gait retraining to reduce the knee adduction moment through real-time visual feedback of dynamic knee alignment", Journal of Biomechanics, vol. 43, no. 11, pp. 2208-2213.

Barter, P. 2010, "Injury prevention and screening" In Sports Rehabilitation and Injury Prevention, eds. P. Comfort & E. Abrahamson, pp. 15-37.

Baumgarten, K.M., Gerlach, D. & Boyer, M.I. 2007, "Corticosteroid injection in diabetic patients with trigger finger. A prospective, randomized, controlled double-blinded study", Journal of Bone Joint Surgery, vol. 89, no. 12, pp. 2604-2611.

Beattie, K.A., Bobba, R., Bayoumi, I., Chan, D., Schabort, I., Boulos, P., Kean, W., Obeid, J., McCallum, R., Ioannidis, G., Papaioannou, A. & Cividino, A. 2008, "Validation of the GALS musculoskeletal screening exam for use in primary care: a pilot study", BMC Musculoskeletal Disorders, [Online] vol. 9, pp. 115. Available from: http://www.biomedcentral.com/1471-2474/9/115/.

Beck, B.R. & Osternig, L.R. 1994, "Medial tibial stress syndrome. The location of muscles in the leg in relation to symptoms", Journal of Bone and Joint Surgery, vol. 76, no. 7, pp. 1057-1061.

Beck, B.R. 1998, "Tibial stress injuries: an aetiological review for the purposes of guiding management", Sports Medicine, vol. 26, no. 4, pp. 265-279.

Belechri, M., Petridou, E., Kedikoglou, S. & Trichopoulos, D. 2001, "Sports injuries European Union Group. Sports injuries among children in six European union countries", European Journal of Epidemiology, vol. 17, no. 11, pp. 1005-1012.

Bellchamber, T.L. & van den Bogert, A.J. 2000, "Contributions of proximal and distal moments to axial tibial rotation during walking and running", Journal of Biomechanics, vol. 33, no. 11, pp. 1397-403.

Bennell, K., Crossley, K., Jayarajan, J., Walton, E., Warden, S., Kiss, Z.S. & Wrigley, T. 2004, "Ground reaction forces and bone parameters in females with tibial stress fracture", Medicine and Science in Sports and Exercise, vol. 36, pp. 397-404.

Bennell, K., Matheson, G., Meeuwisse, W., Brukner, P. 1999, "Risk factors for stress fractures", Sports Medicine, vol. 28, no. 2, pp.91-122.

Bennell, K.L., Malcolm, S.A. & Thomas, S.A. 1996, "Risk factors for stress fractures in track and field athltes: a 12-month prospective study", American Journal of Sports Medicine, vol. 24, pp. 810-818.

Bennett, J.E., Reinking, M.F., Pluemer, B., Pentel, A., Seaton, M. & Killian, C. 2001, "Factors contributing to the development of medial tibial stress syndrome in high school runners", Journal of Orthopaedic and Sports Physical Therapy, vol. 31, no. 9, pp. 504-510.

Bensel, C. & Kaplan, D.B. 1986, "Wear test of boot inserts": memorandum for the record, US Army Natick Research & Development Laboratories Central , STRNC-ICH. Natick (MA) USA.

Bergman, B.P. & Miller, S.A. 2001, "Equal opportunities, equal risks? Overuse injuries in female military recruits", Journal of Public Health Medicine, vol. 23, pp. 35-39.

Bettcher, S. & Asplund, C. 2008, "Exertional Leg Pain", Athletic Therapy Today, vol. 13, no. 6, pp. 20-24.

Beynnon, B.D., Murphy, D.F. & Alosa, D.M. 2002, "Predictive factors for lateral ankle sprains: a literature review", Journal of Athletic Training, vol. 37, pp. 376-380.

Beynnon, B.D., Renström, P.A., Alosa, D.M., Baumhauer, J.F. & Vacek, P.M. 2001, "Ankle ligament injury risk factors: a prospective study of college athletes", Journal of Orthopaedic Research, vol. 19, pp. 213-220.

Billings, C.E. 2002, "Epidemiology of injuries and illnesses during the United States Air Force Academy 2002 Basic Cadet Training program: documenting the need for prevention", Military Medicine, vol. 169, pp. 664-670.

Bilzon, J.L.J. 2003, Streaming in British army recruit training: options for change. ATRA Report No. 2003.001, HQ ATRA, Upavon, UK.

Bird, A.R. & Payne, C.B. 1999, "Foot function and low back pain", Foot, vol. 9, no. 4, pp. 175-180.

Blacker, S.D., Wilkinson, D.M., Bilzon, J.L.J. & Rayson, M.P. 2008, "Risk factors for training injuries among British Army recruits", Military Medicine, vol. 173, no. 3, pp. 278.

Blanc, Y., Balmer, C., Landis, T. & Vingerhoets, F. 1999, "Temporal parameters and patterns of the foot roll over during walking: normative data for healthy adults", Gait & Posture, vol. 10, pp. 97-108.

Blond, L. & Hansen, L. 1998, "Patellofemoral pain syndrome in athletes: a 5.7-year retrospective follow-up study of 250 athletes", Acta Orthopædica Belgica, vol. 64, pp. 393-400.

Boakes, J.L. & Rab, G.T. 2006, "Muscle activity during walking" In Human Walking, eds. J. Rose & J.G. Gamble, 3rd edn, Lippincott Williams and Wilkins, USA, pp. 103-118.

Bonci, C.M. 1999, "Assessment and evaluation of predisposing factors to anterior cruciate ligament injury ", Journal of Athletic Training, vol. 34, no. 2, pp. 155-164.

Bouche, R.T. & Johnson, C.H. 2007, "Medial tibial stress syndrome (tibial fasciitis): A proposed pathomechanical model involving fascial traction", Journal of the American Podiatric Medical Association, vol. 97, no. 1, pp. 31-36.

Bouche, R.T. 1999, "Exercise-Induced Leg Pain", . In Sports Medicine of the Lower Extremity Ed. by St. Subotnick 2nd edn,Churchill Livingstone

Bowers, D. 2008, "Medical Statistics from Scratch: An introduction for health professionals" 2nd edn, John Wiley & Sons, Chichester.

Brandon, R. 2006, "Core Training Menus, in Core Stability: Injury Free Performance", J. Taylor, Editor. Pye, J.A.: London. pp. 57-90.

Bressel, E. & Cronin, J. 2005, "The landing phase of a jump: strategies to minimize injuries", Journal of Physical Education, Recreation & Dance, vol. 76, no. 2, pp. 31-47.

Brinks, A., Koes, B.W., Volkers, A.C.W., Verhaar, J.A.N. & Bierma-Zeinstra, S.M.A. 2010, "Adverse effects of extra-articular corticosteroid injections: a systematic review", BMC Musculoskeletal Disorders, vol. 11, pp. 206.

Brukner, P. & Khan, K. 2007, Clinical Sports Medicine, 3rd edn, McGraw-Hill Australia pty Limited, North Ryde NSW.

Brukner, P., Bahar, R., Blair, S., Cook, J., Crossley, K., McColl, J., McCrory, P. & Noakes, T. 2012, "Brukner & Khan's clinical sports medicine", 4th edn, McGraw-Hill, Sydney.

Brukner, P., Bennell, K. & Matheson, G. 1999, "Stress Fracture", Blackwell Science, Australia.

Brushoj, C., Larsen, K., Albrecht-Beste, E., Nielsen, M.B., Loye, F. & Holmich, P. 2008, "Prevention of overuse injuries by a concurrent exercise program in subjects exposed to an increase in training load - A randomized controlled trial of 1020 army recruits", American Journal of Sports Medicine, vol. 36, no. 4, pp. 663-670.

Buchanan, K.R. & Davis, I. 2005, "The relationship between forefoot, midfoot, and rearfoot static alignment in pain free individuals", Journal of Orthopaedic and Sports Physical Therapy, vol. 35, pp. 559-566.

Buist, I., Bredeweg, S.W., van Mechelen, W., Lemmink, K.A., Pepping, G.J. & Diercks, R.L. 2008, "No effect of a graded training program on the number of running-related injuries in novice runners: a randomized controlled trial", American Journal of Sports Medicine, vol. 36, no. 1, pp. 33-39.

Bullock, S.H., Jones, B.H., Gilchrist, J. & Marshall, S.W. 2011, "Prevention of physical training-related injuries recommendations for the military and other active populations based on expedited systematic reviews", American Journal of Preventive Medicine, vol. 38, pp. S156-S181.

Buschbacher, R.M., Prahlow, N.D. & Dave, S.J. (eds) 2009, Sports Medicine and Rehabilitation : A Sports Specific Approach, 2nd edn, Lippincott Williams & Wilkins, Philadelphia, USA.

Caine, D.J., Caine, C.G. & Lindner, K.J. 1996, "The epidemiologic approach to sports injuries" In Epidemiology of Sports Injuries, eds. D.J. Caine, C.G. Caine & K.J. Lindner, Human Kinetics, Champaign, IL, pp. 1-13.

Campbell, A.D.K. 2002, "Army Training and Recruiting Agency Medical Discharge Statistics" Report no. FY01/02.

Cardone, D.A. & Tallia, A.F. 2002, "Joint and soft tissue injection", American Family Physician, vol. 66, no. 2, pp. 283-288.

Carr, K., Sevetson, E. & Aukerman, D. 2008, "How can you help athletes prevent and treat shin splints?", Journal of Family Practice, vol. 57, no. 6, pp. 406-408.

Carter, J.M., Izard, R.M., Blacker, S.D., Wilkinson, D.M., Rayson, M.P. & Bilzon, J.L.J. 2006, The physical demands of the combined infantryman's course for foot guards at ITC Catterick, Optimal Performance Limited and ARTD, UK.

Casey, A. & Owen, G. 2001, Nutrition, stress, and injury during army phase one training: a study of energy balance, metabolism, musculoskeletal injury and cognitive function during an army recruits training course, DERA Report No. TR010145, UK.

Cashmere, T., Smith, R. & Hunt, A. 1999, "Medial longitudinal arch of the foot: stationary versus walking measures", Foot Ankle International., vol. 20, no. 2, pp. 112-118.

Castillo, R.C., Bosse, M.J., MacKenzie, E.J. & Patterson, B.M. 2005, "Impact of smoking on fracture healing and risk of complications in limb-threatening open tibia fractures", Journal of Orthopaedic Ttrauma, vol. 19, no. 3, pp. 151-157.

Cavanagh, P.R. & Hennig, E.M. 1982, "A new device for the measurement of pressure distribution on a rigid surface", Medicine and Science in Sports and Exercise, vol. 14, no. 2, pp. 153-153.

Cavanagh, P.R. & LaFortune, M.A. 1980, "Ground reaction forces in distance running", Journal of Biomechanics, vol. 13, pp. 397-406.

Cavanagh, P.R. 1990, "Biomechanics of distance running" Human Kinetics Champaign, Illiuois, pp. 251-255

Cavanagh, P.R., Morag, E., Boulton, A.J., Young, M.J., Deffner, K.T. & Pammer, S.E. 1997, "The relationship of static foot structure to dynamic foot function", Journal of Biomechanics, vol. 30, no. 3, pp. 243-250.

Chaiwanichsiri, D., Lorprayoon, E. & Noomanoch, L. 2005, "Star excursion balance training:effects on ankle functional stability after ankle sprain", Journal of the Medical Association of Thailand, vol. 88, pp. S90-S94.

Chalmers, D.J. 2002, "Injury prevention in sport: not yet part of the game?", Injury Prevention, vol. 8, no. iv, pp. iv22-iv25.

Chen, J.H., Chao, L., Lidan, Y. & Craig, S.A. 2010, "Boning up on Wolff's law: mechanical regulation of the cells that make and maintain bone", Journal of Biomechanics, vol. 43, no. 1, pp. 108-118.

Christina, K.A., White, S.C. & Gilchrist, L.A. 2001, "Effect of localized muscle fatigue on vertical ground reaction forces and ankle joint motion during running", Human Movement Science, vol. 20, pp. 257-276.

Chuter, V.H. & Janse de Jonge, X.A.K. 2012, "Proximal and distal contributions to lower extremity injury: A review of the literature", Gait & Posture, vol. 36, no. 1, pp. 7-15.

Clanton, T.O. & Solcher, B.W. 1994, "Chronic leg pain in the athlete", Clinical Sports Medicine, vol. 13, pp. 743-759.

Clark, T.G., Bradburn, M.J., Love, S.B. & Altman, D.G. 2003, "Survival analysis part I: basic concepts and first analyses", British Journal of Cancer, vol. 89, pp. 232-238.

Clement, D.B. 1974, "Tibial stress syndrome in athletes", Journal of Sports Medicine, vol. 2, pp. 81-85.

Cohen, J. 1988, Statistical power analyses for the behavioural sciences, Hillsdale, NJ, Erlbaum.

Colclough, M. 1999, Predicting training related musculoskeletal injury in British Army recruits, MSc Thesis, University of Southampton.

Cole, B.J. & Schumacher, H.R. 2005, "Injectable corticosteroids in modern practice", Journal of American Academic Orthopaedic Surgery, vol. 13, no. 1, pp. 37-46.

Comerford, M.J. 2007, "Performance Stability: Module 1 Stability For Performance: Course 1: Core Stability Concepts", The 'Performance Matrix', Comerford & Performance Stability, UK.

Comfort, P. & Matthews, M. 2010, "Assessment and needs analysis" In Sports Rehabilitation and Injury Prevention, eds. P. Comfort & E. Abrahamson, John Wiley & Sons, Ltd, Chichester, UK, pp. 39-63.

Conn, J.M., Annest, J.L. & Gilchrist, J. 2003, "Sports and recreation related injury episodes in the US population, 1997-99", Injury Prevention., vol. 9, no. 2, pp. 117-123.

Cook, G. 2003, Athletic body in balance optimal movement skills and conditioning for performance, Humand Kinetics, Leeds UK.

Cook, G., Burton, L. & Hogenboom, B. 2006a, "Pre-participation screening: The use of fundamental movements as an assessment of function - Part 2", North American Journal of Sports Physical Therapy, vol. 1, pp. 132-139.

Cook, G., Burton, L. & Hogenboom, B. 2006b, "The use of fundamental movements as an assessment of function - Part 1 ", North American Journal of Sports Physical Therapy, vol. 1, pp. 62-72.

Coppack, R.J., Etherington, J. & Wills, A.K. 2011, "The effects of exercise for the prevention of overuse anterior knee pain: a randomized controlled trial", American Journal of Sports Medicine, vol. 39, no. 5, pp. 940-948.

Council of Europe 1989, "Sports for all sports injuries and their prevention", Osterbeek National Institute for Sport Health Care.

Cousins, S.D., Stewart C Morrison, S.C. & Drechsler, W.I. 2012, "The reliability of plantar pressure assessment during barefoot level walking in children aged 7-11 years", Journal of Foot and Ankle Research, [Online] . Available from: http://www.jfootankleres.com/content/5/1/8.

Couture, C.J. & Karlson, K.A. 2002, "Tibial stress injuries: decisive diagnosis and treatment of 'shin splints'", Physician and Sports medicine, vol. 30, no. 6, pp. 29-36.

Cowan, D.N., Jones, B.H. & Frykman, P.N. 1996, "Lower limb morphology and risk of overuse injury among male infantry trainees", Medicine & Science in Sports & Exercise, vol. 28, pp. 945-952.

Craig, D.I. 2008a, "Medial tibial stress syndrome: evidence-based prevention", Journal of Athletic Training, vol. 43, no. 3, pp. 316-318.

Craig, D.I. 2008b, "Medial tibial stress syndrome: current etiological theories part 1 - Background", Athletic Therapy Today, vol. 13, no. 1, pp. 17-20.

Craig, D.I. 2008c, "Medial tibial stress syndrome: Etiological theories, Part 2", Athletic Therapy Today, vol. 13, no. 2, pp. 34-36.

Craig, D.I. 2009, "Current developments concerning medial tibial stress syndrome", The Physician Sportsmedicine, vol. 37, no. 4, pp. 39-44.

Craik, R.L. & Oatis, C.A. 1988, "Introduction to the foot and ankle", Physical Therapy, vol. 68, pp. 1801.

Crawford, F., Atkins, D., Young, P. & Edwards, J. 1999, "Steroid injection for heel pain: evidence of short-term effectiveness. A randomized controlled trial", Rheumatology (Oxford), vol. 38, no. 10, pp. 974-977.

Crossley, K., Bennell, K., Green, S., Cowan, S. & McConnell, J. 2002, "Physical therapy for patellofemoral pain: a randomized, double-blinded, placebo-controlled trial", American Journal of Sports Medicine, vol. 30, pp. 857-865.

Crowell, H.P. & Davis, I.S. 2011, "Gait retraining to reduce lower extremity loading in runners", Clinical Biomechanics, vol. 26, no. 1, pp. 78-83.

Crowell, H.P. 2010, "Reducing impact loading during running with the use of real-time visual feedback", Journal of Orthopaedic & Sports Physical Therapy, vol. 40, no. 4, pp. 206-213.

Dahle, L.K., Mueller, M.J., Delitto, A. & Diamond, J.E. 1991, "Visual assessment of foot type and relationship of foot type to lower extremity injury", Journal of Orthopaedic Sports Physical Therapy, vol. 14, no. 2, pp. 70-74.

Davidson, P., Chalmers, D., Wilson, B. & McBride, D. 2008, "Lower limb injuries in New Zealand Defence Force personnel: descriptive epidemiology", Australian and New Zealand Journal of Public Health, vol. 32, no. 2, pp. 167-173.

Davis, I., Milner, C., Hamill, J. 2004, "Does increased loading during running lead to tibial stress fractures? A prospective study", Medicine and Science in Sports and Exercise, vol.35, pp. S58.

Dawson, A.P., Steele, E.J., Hodges, P.W. & Stewart, S. 2009, "Development and test-retest reliability of an extended version of the Nordic Musculoskeletal Questionnaire (NMQ-E): a screening instrument for musculoskeletal pain", The Journal of Pain, vol. 10, no. 5, pp. 517-526.

De Carlo, M. & Armstrong, B. 2010, "Rehabilitation of the knee following sports injury", Clinics in Sports Medicine, vol. 29, no. 1, pp. 81-106.

De Cock, A., De Clercq, D., Willems, T. & Witvrouw, E. 2005, "Temporal characteristics of foot roll-over during barefoot jogging: reference data for young adults", Gait Posture, vol. 21, pp. 432-439.

De Cock, A., Willems, T., Witvrouw, E., Vanrenterghem, J. & De Clercq, D. 2006, "A functional foot type classification with cluster analysis based on plantar pressure distribution during jogging", Gait & Posture, vol. 23, pp. 339-347.

DePalma, B. 2004, "Rehabilitation of groin, hip and thigh injuries" In Rehabilitation Techniques for Sports Medicine and Athletic Training, ed. W.E. Prentice, 4th edn, McGraw-Hill, New York, pp. 485-525.

Detmer, D.E. 1986, "Chronic shin splints: classification and management of medial tibial stress syndrome", Sports Medicine, vol. 3, no. 6, pp. 436-446.

Deyo, R.A., Rainville, J. & Kent, D.L. 1992, "What can the history and physical examination tell us about low back pain?", Journal of the American Medical Association, vol. 268, pp. 760-765.

DGAMS 1998, Annual Report on the Health of the Army (1996-1997).

Dixon, G.G., Pugh, L., Duda, J.L., Ntoumanis, N., Lemmon, A. & Rayson, M.P. 2003, "Optimising investment and retention in recruits", Optimal Performance Ltd., Bristol, UK.

Dominguez, R.H. 1982, Total body training, East Dundee edn, Moving Force System, East Dundee, IL.

Donatelli, R. 1990, "The Biomechanics of the Foot and Ankle" in normal anatomy and biomechanics, ed. R. Donatelli, FA Davis Company, Philadelphia, pp. 3-31.

Dugan, S.A. & Bhat, K.P. 2005, "Biomechanics and analysis of running gait", Physical Medicine and Rehabilitation Clinics of North America, vol. 16, no. 3, pp. 603-621.

Dvorak, J., & Junge, A. 2000, "Football injuries and physical symptoms. A review of the literature", American Journal of Sports Medicine, vol. 28, pp. S3-S9.

Edwards, W.B., Gillette, J.C., Thomas, J.M. & Derrick, T.R. 2008, "Internal femoral forces and moments during running: implications for stress fracture development", Clinical Biomechanics, vol. 23, pp. 1269-1278.

Ekstrand, J. & Gillquist, J. 1983, "The avoidability of soccer injuries", International Journal of Sports Medicine, vol. 4, pp. 124-128.

Ekstrand, J. & Tropp, H. 1990, "The incidence of ankle sprains in soccer", Foot and Ankle, vol. 11, pp. 41-44.

Ellis, R., Hing, W. & Reid, D. 2007, "Iliotibial band friction syndrome - a systematic review", Manual Therapy, vol. 12, no. 3, pp. 200-208.

El-Zawawy, H.B., Gill, C.S. & Wright, R.W. 2006, "Smoking delays chondrogeneis in a mouse model of closed tibial fracture healing ", Journal of Orthopaedic Research, vol. 21, pp. 50-58.

Emery, C.A., Cassidy, J.D., Klassen, T.P., Rosychuk, R.J. & Rowe, B.H. 2005,"Effectiveness of a home-based balance-training program in reducing sports-related injuries among healthy adolescents: a cluster randomized controlled trial", Canadian Medical Association Journal, vol. 172, no. 6, pp. 749-754.

Emery, C.A., Rose, M.S., McAllister, J.R. & Meeuwisse, W.H. 2007, "A prevention strategy to reduce the incidence of injury in high school basketball: a cluster randomized controlled trial", Clinical Journal of Sport Medicine, vol. 17, no. 1, pp. 17-24.

Esterman, A. & Pilotto, L. 2005, "Foot shape and its effect on functioning in Royal Australian Air Force recruits part 2:pilot, randomized controlled trial of orthotics in recruits with flat feet", Military Medicine, vol. 170, pp. 629-633.

Etherington, J. & Owen, G. 2002, Prediction of musculoskeletal injuries in army recruits using artificial neural networks, Defence services medical rehabilitation centre (Headley Court) report.

Fagan, V. & Delahunt, E. 2008, "Patellofemoral pain syndrome: a review on the associated neuromuscular deficits and current treatment options", British Journal of Sports Medicine, vol. 42, pp. 789-795.

Fauno, P., Kalund, S., Andreasen, I. & Jorgensen, U. 1993, "Soreness in lower extremities and back is reduced by use of shock absorbing heel inserts", International Journal of Sports Medicine, vol. 14, no. 5, pp. 288-290.

Finch, C. 2006, "A new framework for research leading to sports injury prevention", Journal of Science and Medicine in Sport, vol. 9, pp. 3-9.

Finestone, A., Novack, V., Farfel, A., Berg, A., Amir, H. & Milgrom, C. 2004, "A prospective study of the effect of foot orthoses composition and fabrication on comfort and the incidence of overuse injuries", Foot & Ankle International, vol. 25, no. 7, pp. 462-466.

Finestone, A.,Giladi,M., Flad,H.& Salmon, A. 1999 "Prevention of stress fracture using custom biomechanical shoe orthoses" Clinical Orthopaedics and Related Research, vol.360,pp.182-190.

Fiolkowski, P., Brunt, D., Bishop, M., Woo, R. & Horodyski, M. 2003, "Intrinsic pedal musculature support of the medial longitudinal arch: an electromyography study", Journal of Foot and Ankle Surgery, vol. 42, no. 6, pp. 327-333.

Fletcher, R.H., Fletcher, S.W. & Wagner, E.H. 1996, Clinical Epidemiology: the Essentials, Williams and Wilkins, Baltimore, USA.

Folkes, F. 2004, ATRA Training Injury Symposium presentation. ARTD report, UK.

Foreman, T.K., Addy, t., Baker, S., Burns, J., Hill, N. & Madden, T., 2006, "Prospective studies into the causation of hamstring injuries in sport: A systematic review", Physical Therapy in Sport, vol. 7, no. 2, pp. 101-109.

Franettovich, M., Chapman, A.R., Blanch, P. & Vicenzino, B. 2010, "Altered neuromuscular control in individuals with exercise-related leg pain", Medicine & Science in Sports & Exercise, vol. 42, no. 3, pp. 546-555.

Franklyn, M., Oakes, B., Field, B., Wells, P. & Morgan, D. 2008, "Section modulus is the optimum geometric predictor for stress fractures and medial tibial stress syndrome in both male and female athletes", American Journal of Sports Medicine, vol. 36, no. 6, pp. 1179-1189.

Franklyn-Miller, A., Wilson, C., Bilzon, J. & McCrory, P. 2011, "Foot orthoses in the prevention of injury in initial military training a randomized controlled trial", American Journal of Sports Medicine, vol. 39, no. 1, pp. 30-37.

Fredericson, M. & Wolf, C. 2005, "Iliotibial band syndrome in runners: innovations in treatment", Sports Medicine, vol. 35, pp. 451-459.

Fredericson, M. & Wun, C. 2003, "Differential diagnosis of leg pain in the athlete", Journal of the American Podiatric Medical Association, vol. 93, no. 4, pp. 321-324.

Fredericson, M., Bergman, A.G., Hoffman, K.L. & Dillingham, M.S. 1995, "Tibial stress reaction in runners correlation of clinical symptoms and scintigraphy with a new magnetic resonance imaging grading system", American Journal of Sports Medicine, vol. 23, no. 4, pp. 472-481.

Fredericson, M., Cookingham, C.L., Chaudhari, A.M., Dowdell, B.C., Oestreicher, N. & Sahrmann, S.A. 2000, "Hip abductor weakness in distance runners with iliotibial band syndrome", Clinical Journal of Sport Medicine, vol. 10, no. 3, pp. 169-175.

Frost, H.M. 1994, "Wolff's Law and bone's structural adaptations to mechanical usage: an overview for clinicians", The Angle Orthodontist, vol. 64, no. 3, pp. 175-188.

Fuchs, R.K., Bauer, J.J. & Snow, C.M. 2001, "Jumping improves hip and lumbar spine bone mass in prepubescent children: a randomized controlled trial", Journal of Bone & Mineral Research, vol. 16, no. 1, pp. 148-156.

Gabbe, B.J., Bennell, K.L., Wajswelner, B.H. & Finch, C.F. 2004b, "Reliability of common lower extremity musculoskeletal screening tests", Physical Therapy in Sport, vol. 5, pp. 90-97.

Gabbe, B.J., Finch, C.F., Wajswelner, H. & Bennell, K.L. 2004a, "Predictors of lower extremity injuries at the community level of Australian football", Clinical Journal of Sport Medicine, vol. 14, no. 2, pp. 56-63.

Galbraith, R.M. & Lavallee, M.E. 2009, "Medial tibial stress syndrome: conservative treatment options", Current Review Musculoskeletal Medicine, vol. 2, pp. 127-133.

Gallo, R. A., Plakke, M., Silvis,M.L. 2012,"Common leg injuries of long-distance runners anatomical and biomechanical approach" Sports Health: A Multidisciplinary Approach vol. 4, pp. 485-495

Gamboa, J.M., Roberts, L.A., Maring, J. & Fergus, A. 2008, "Injury patterns in elite preprofessional ballet dancers and the utility of screening programs to identify risk characteristics", Journal of Orthopaedic and Sports Physical Therapy, vol. 38, no. 3, pp. 126-136.

Gardner, L.I., Dziados, J.E. & Jones, B.H. 1988, "Prevention of lower extremity stress fractures:a controlled trial of a shock absorbent insole", American Journal of Public Health, vol. 78, no. 12, pp. 256-260.

Gardner, L.I., Dziados, J.E., Jones, B.H., Brundage, J.F., Harris, J.M., Sullivan, R. & Gill, P. 1988, "Prevention of lower extremity stress fractures: a controlled trial of a shock absorbent insole", American Journal of Public Health, vol. 78, no. 12, pp. 1563-1567.

Garrick, J.G. & Lewis, S.L. 2001, "Career hazards for the dancer", Occupational Medicine (Philadelphia, Pa.), vol. 16, no. 4, pp. 609-618.

Garrick, J.G. & Requa, R.K. 1993, "Ballet injuries. An analysis of epidemiology and financial outcome", American Journal of Sports Medicine, vol. 21, no. 4, pp. 586-590.

Gaujoux Viala, C., Dougados, M. & Gossec, L. 2009, "Efficacy and safety of steroid injections for shoulder and elbow tendonitis: a meta-analysis of randomised controlled trials", Annals of the Rheumatic Diseases, vol. 68, no. 12, pp. 1843-9.

Gemmell, I.M. 2002, "Injuries among female army recruits: a conflict of legislation", Journal of the Royal Society of Medicine, vol. 95, no. 1, pp. 23-27.

Genc, H., Saracoglu, M., Nacir, B., Erdem, H.R. & Kacar, M. 2005, "Long-term ultrasonographic follow-up of plantar fasciitis patients treated with steroid injection ", Joint Bone Spine, vol. 72, pp. 61-65.

Gilchrist J, M., B.R., Melancon, H., Ryan, G.W., Silvers, H.J., Griffin, L.Y., Watanabe, D.S., Dick, R.W. & Dvorak, J. 2008, "A randomized controlled trial to prevent noncontact anterior cruciate ligament injury in female collegiate soccer players", American Journal of Sports Medicine, vol. 36, no. 8, pp. 1476-1483.

Gilchrist, J., Jones, B., Sleet, D. & Kimsey, C. 2000, "Exercise-related injuries among women: strategies for prevention from civilian and military studies", Morbidity and Mortality weekly report. Recommendations and Reports, vol. 49, no. RR-2, pp. 15.

Gill, C.S., Sandell, L.J. & El-Zawawy, H.B. 2006, "Effects of cigarette smoking in early medial collateral ligament healing in a mouse model", Journal of Orthopaedic Research, vol. 24, pp. 2141-2149.

Gooch, J., Geiringer, S. & Akau, C. 1993, "Lower Extremity injuries", Archives of Physical Medicine and Rehabilitation, vol. 74, no. 3 suppl, pp. s438-s442.

Greeves, J. 2001, "Physical training of women in the military", Journal of Defence Science, vol. 6, no. 3, pp. 228-238.

Greeves, J.P. 2002, Prevention of musculoskeletal injuries, risk factors for injury in female military recruits. QinetiQ Report.

Gregg, R.L., Banderet, L.E., Reynolds, K.L., Creedon, J.F. & Rice, V.J. 2002, "Psychological factors that influence traumatic injury occurrence and physical performance", Work, vol. 18, no. 2, pp. 133-139.

Griebert, M. C. 2012, Lower-leg kinesio® tape application reduces rate of loading in subjects with medial tibial stress syndrome (Doctoral dissertation, University of Delaware).

Gruhn, J., Leggat, P. & Muller, R. 1999, "Injuries presenting to army physiotherapy in North Queensland, Australia", Military Medicine, vol. 164, no. 2, pp. 145.

Gunter, P. & Schwellnus, M.P. 2004, "Local corticosteroid injection in iliotibial band friction syndrome in runners: a randomised controlled trial", British Journal Sport Medicine, vol. 38, no. 3, pp. 269-272.

Gurcay, E., Unlu, E., Gurcay, A.G., Tuncay, R. & Cakci, A. 2009, "Evaluation of the effect of local corticosteroid injection and anti-inflammatory medication in carpal tunnel syndrome", Scottish Medical Journal, vol. 54, no. 1, pp. 4-6.

Hahn, F., Maiwald, C., Horstmann, T. & Vienne, P. 2008, "Changes in plantar pressure distribution after achilles tendon augmentation with flexor hallucis longus transfer", Clinical Biomechanics, vol. 23, pp. 109-116.

Halbach, J. 1981, "Pronated foot disorders", Athletic Training, vol. 16, pp. 53-55.

Harradine, P., Bevan, L. & Carter, N. 2006, "An overview of podiatric biomechanics theory and its relation to selected gait dysfunction", Physiotherapy, vol. 92, pp. 122-127.

Harrast, M.A. & Colonno, D. 2010, "Stress fractures in runners", Clinical Sports Medicine, vol. 29, pp. 399-416.

Harrison, M., Casey, A., Weller, A. & Richardson, S. 2000, "Military applications of ergogenic aids", Journal of Defence Science, vol. 5, pp. 235.

Hartig, D.E. & Henderson, J.M. 1999, "Increasing hamstring flexibility decreases lower extremity overuse injuries in military basic trainees", American Journal of Sports Medicine, vol. 27, no. 2, pp. 173-176.

Harwood, A.G., Box, C.J. & Freeland, W.A. 1989, A survey of overuse lower limb injuries in Army recruits, MOD Memorandum 89M503, UK.

Harwood, G.E., Rayson, M.P. & evill, A.M. 1999, "Fitness, performance and risk of injury in British Army Officer Cadets", Military Medicine, vol. 164, no. 6, pp. 428-434.

Hauret, K.G., Jones, B.H., Bullock, S.H., Canham-Chervak, M. & Canada, S. 2010, "Musculoskeletal injuries description of an under-recognized injury problem among military personnel", American Journal of Preventive Medicine, vol. 38, no. 1 Suppl.

Headlee, D.L., Leonard, J.L., Hart, J.M., Ingersoll, C.D. & Hertel, J. 2008, "Fatigue of the plantar intrinsic foot muscles increases navicular drop", Journal of Electromyography and Kinesiology, vol. 18, no. 3, pp. 420-425.

Health and Safety Executive 2008a, Musculoskeletal disorders – Why tackle them?, Available at : http://www.hse.gov.uk/ healthservices/msd/whytackle.htm [Date accessed: 1-7-2008].

Health and Safety Executive, 2008b, Estimated days (full-day equivalent) off work and associated average days lost per (full-time equivalent) worker and per case due to a self-reported work-related illness or workplace injury. Health and Safety Executive, UK. Available at : http://www.hse.gov.uk/statistics/tables/0607/swit1.htm [Date accessed: 13-5-2008].

Heir, T. & Eide, G. 1997, "Injury proneness in infantry conscripts undergoing a physical training programme: smokeless tobacco use, higher age, and low levels of physical fitness are risk factors", Scandinavian Journal Of Medicine & Science In Sports, vol. 7, pp. 304-311.

Heir, T. & Glomsaker, P. 1996, "Epidemiology of musculoskeletal injuries among Norwegian conscripts undergoing basic military training", Scandinavian Journal of Medicine & Science in Sports, vol. 6, no. 3, pp. 186.

Heir, T. 1998, "Musculoskeletal injuries in officer training: one-year follow-up", Military Medicine, vol. 163, pp. 229-233.

Henderson, N.E., Knapik, J.J., Shaffer, S.W., McKenzie, T.H. & Schneider, G.M. 2000, "Injuries and injury risk factors among men and women in U.S. Army Combat Medic Advanced individual training", Military Medicine, vol. 165, pp. 647-652.

Herrington, L. & Law, J. 2012, "The effect of hip adduction angle on patellar position measured using real time ultrasound scanning", The Knee, vol. 19, no. 5, pp. 709-712.

Hesar, N.G.Z., Van Ginckel, A., Cools, A., Peersman, W., Roosen, P., De Clercq, D. & Witvrouw, E. 2009, "A prospective study on gait-related intrinsic risk factors for lower leg overuse injuries", British Journal of Sports Medicine, vol. 43, no. 13, pp. 1057-1061.

Hibbs, A.,Thompson, K.G., French, D., Spears, I. 2008, "Optimising performance by improving core stability and core strength" Sports Medicine vol. 38, no.12 pp. 995-1008.

Hibbs, A.E., Thompson, K.G., French, D.,N., Hodgson, D. & Spears, I.R. 2011, "Peak and average rectified EMG measures: Which method of data reduction should be used for assessing core training exercises?", Journal of Electromyography and Kinesiology, vol. 21, no. 1, pp. 102-111.

Hincapie, C.A., Morton, E.J. & Cassidy, J.D. 2008, "Musculoskeletal injuries and pain in dancers: a systematic review", Archives of Physical Medicine and Rehabilitation, vol. 89, no. 9, pp. 1819-1829.

Hintermann, B. & Nigg, B.M. 1998, "Pronation in runners. Implications for injuries", Sports Medicine, vol. 26, no. 3, pp. 169-176.

Hodge, M.C., Bach, T.M. & Carter, G.M. 1999, "Orthotic management of plantar pressure and pain in rheumatoid arthritis", Clinical Biomechanics, vol. 14, pp. 567-575.

Hodgson P.L. 2000, "Sports injury incidence", British Journal of Sports Medicine, vol. 34, pp. 133-136.

Hoffman, J.R., Chapnik, L., Shamis, A., Givon, U. & Davidson, B. 1999, "The effect of leg strength on the incidence of lower extremity overuse injuries during military training", Military Medicine, vol. 164, pp. 153-156.

Holen, K.J., Engebretsen, L., Grontvedt, T., Rossvoll, I., Hammer, S. & Stoltz, V. 1995, "Surgical treatment of medial tibial stress syndrome (shin splint) by fasciotomy of the superficial posterior compartment of the leg", Scandinavian Journal of Medicine & Science in Sports, vol. 5, no. 0905-7188; 1, pp. 40-43.

Holz, S.C. & Smuck, M. 2009, "Tissue injury and healing" In Sports medicine and rehabilitation: A sports-specific approach, eds. R.M. Buschbacher, N.D. Prahlow & S.J. Dave, 2nd edn, Lippincott Williams & Wilkins, Philadelphia, pp. 17-22.

Hooker, D.N. & Prentice, W.E. 2004, "Rehabilitation of injuries to the spine" In Rehabilitation Techniques for Sports Medicine and Athletic Training, ed. W.E. Prentice, 4th edn, Mcgraw-Hill, New York USA, pp. 649-691.

Hootman, J.M. 2007, "Is it possible to prevent sports and recreational injuries? A systematic review of randomized controlled trials, with recommendations for future work" In Evidence-based Sports Medicine, eds. D. MacAuley & T.M. Best, 2nd edn, Blackwell, Singapore, pp. 3-17.

Hopper , D.M., Hopper, J.L., Elliott, B.C. 1995, "Do selected kinanthropometric and performance variables predict injuries in female netball players?", Journal of Sports Sciences, vol. 13, pp. 213-222.

Hosea, T.M., Carey, C.C. & Harrer, M.F. 2000, "The gender issue: epidemiology of ankle injuries in athletes who participate in basketball", Clinical Orthopaedics, vol. 372, pp. 45-49.

Hreljac, A., Marshall, R.N. & Hume, P.A. 2000, "Evaluation of lower extremity overuse injury potential in runners ", Medicine & Science in Sports & Exercise, vol. 32, pp. 1635-1641.

Huang, C. & Ogawa, R. 2010, "Mechanotransduction in bone repair and regeneration", The Journal of the federation of American Societies for Experimental Biology, vol. 24, no. 10, pp. 3625-3632.

Huang, M.F., Lin, W.L. & Ma, Y.C. 2005, "A study of reactive oxygen species in mainstream of cigarette", Indoor Air, vol. 15, pp. 135-140.

Hubbard, T.J., Carpenter, E.M. & Cordova, M.L. 2009, "Contributing factors to medial tibial stress syndrome: a prospective investigation", Medicine & Science in Sports & Exercise, vol. 41, no. 3, pp. 490-496.

Hubscher, M., Zech, A., Pfeifer, K., Hansel, F., Vogt, L. & Banzer, W. 2010,"Neuromuscular training for sports injury prevention: a systematic review", Medicine & Science in Sports & Exercise, vol. 42, no. 3, pp. 413-421.

Hughes, R., Rowlands, H. & McKeekin, S. 2000, "A comparison of two studies of the pressure distribution under the feet of normal subjects using different equipment", Foot and Ankle, vol. 14, pp. 514-519.

Hughes, T. 2008, "The effects of proprioceptive exercise and taping on proprioception in subjects with functional ankle instability: a review of the literature", Physical Therapy in Sport, vol. 9, no. 3, pp. 136-147.

Hunter, S. & Prentice, W.E. 2004, "Rehabilitation of ankle and foot injuries" In Rehabilitation Techniques for Sports Medicine and Athletic Training, ed. W.E. Prentice, 4th edn, McGraw-Hill Companies, New York, pp. 608-648.

Hunter, S., Dolan, M.G. & Davis, J.M. 1995, Foot Orthotics in Therapy and Sports, Human Kinetics, Champaign.

Huovinen, J., Tulppo, M., Nissila, J., Linnamo, V., Hakkinen, K. & Kyrolainen, H. 2009, "Relationship between heart rate variability and the serum testosterone-to-cortisol ratio during military service", European Journal of Sport Science, vol. 9, pp. 277-284.

Hutson, M.A. 1993, Back pain: Recognition and Management, Butterworth-Heinemann, Avon UK.

Ines, L.P. & da Silva, J.A. 2005, "Soft tissue injections", Best Practice & Research Clinical Rheumatology, vol. 19, no. 3, pp. 503-527.

Ireland, M.L., Willson, J.D., Ballantyne, B.T. & McClay Davis, I. 2003, "Hip strength in females with and without patellofemoral pain", Journal of Orthopaedic and Sports Physical Therapy, vol. 33, no. 11, pp. 671-676.

Jam, B. 2004, Evaluation and retraining of the intrinsic foot muscles for pain syndromes related to abnormal control of pronation, Available at: www.aptei.com/articles/pdf/IntrinsicMuscles.pdf.

James, S.L., Bates, B.T. & Osternig, L.R. 1978, "Injuries to runners", American Journal of Sports Medicine, vol. 6, no. 2, pp. 40-50.

Janda, V. 1987, "Muscles and motor control in low back pain: assessment and management" In Physical Therapy of the Low Back, ed. L.T. Twomey, Churchill Livingstone, New York, pp. 253-278.

Janda V, FrankC, LiebensonC.2007Evaluation of muscular imbalance. In:LiebensonC, ed. Rehabilitation of the Spine: A Practitioner's Manual, 2nd ed. Baltimore: Lippincott Williams & Wilkins

Jianmongkol, S., Kosuwon, W. & Thammaroj, T. 2007, "Intra-tendon sheath injection for trigger finger: the randomized controlled trial", Hand Surgery, vol. 12, no. 2, pp. 79-82.

Johnell, O., Rausing, A. & Westlin, N. 1982, "Morphological bone changes in shin splints", Clinical Orthopaedics and Related Ressearch, vol. 167, pp. 180-184.

Johnston, E., Flynn, T., Bean, M., Breton, M., Scherer, M., Dreitzler, G. & Thomas, D. 2006, "A randomized controlled trial of a leg orthosis versus traditional treatment for soldiers with shin splints: A pilot study", Military Medicine, vol. 171, no. 1, pp. 40-44.

Jones, B.H. & Knapik, J.J. 1999, "Physical training and exercise-related injuries. Surveillance, research and injury prevention in military populations", Sports Medicine, vol. 27, no. 2, pp. 111-125.

Jones, B.H., Bovee, M.W. & Harris, J.M. 1993b, "Intrinsic risk factors for exercise-related injuries among male and female army trainees", American Journal of Sports Medicine, vol. 21, pp. 705-710.

Jones, B.H., Bovee, M.W. & Knapik, J.J. 1992, "Associations among body composition, physical fitness, and injury in men and women army trainees" In Body Composition and Physical Performance, ed. G.J. Marriiot BM, National Academy Press, Washington.

Jones, B.H., Canham-Chervak, M. & Sleet, D.A. 2010b, "An evidence-based public health approach to injury priorities and prevention: recommendations for the U.S. military", American Journal of Preventive Medicine, vol. 38, pp. S1-S10.

Jones, B.H., Canham-Chervak, M., Canada, S., Mitchener, T.A. & Moore, S. 2010a, "Medical surveillance of injuries in the US Military descriptive epidemiology and recommendations for improvement", American Journal of Preventive Medicine, vol. 38, no. 1 Suppl.

Jones, B.H., Cowan, D.N. & Knapik, J.J. 1994, "Exercise, training and injuries", Sports Medicine, vol. 18, pp. 202-214.

Jones, B.H., Cowan, D.N., Tomlison, J.P., Robinson, J.R., Polly, D.W. & Frykman, P.N. 1993a, "Epidemiology of injuries associated with physical training among young men in the Army", Medicine & Science in Sports & Exercise, vol. 25, pp. 197-203.

Jones, B.H., Thacker, S.B., Gilchrist, J., Kimsey, C.D.,Jr. & Sosin, D.M. 2002, "Prevention of lower extremity stress fractures in athletes and soldiers: a systematic review", Epidemiologic Reviews, vol. 24, no.2, pp. 228-247.

Jones, R., Llewellyn, M. & Collins, S. 2001, "Using ground reaction forces to guide military physical training", Journal of Defence Science, vol. 6, no. 3, pp. 219-227.

Jonson, S.R. & Gross, M.T. 1997, "Intraexaminer reliability, interexaminer reliability and mean values for nine lower extremity skeletal measures in healthy naval

midshipmen", Journal of Orthopaedic Sports Physical Therapy, vol. 25, no. 4, pp. 253-263.

Jorgensen, L.N., Kallehave, N.F., Christensen, E., Siana, J.E. & Gottrup, F. 1998, "Less collagen production in smokers", Surgery, vol. 123, pp. 450-455.

Junge, A. 2000, "The influence of psychological factors on sports injuries: review of the literature", American Journal of Sports Medicine, vol. 28, pp. S10-S15.

Kalaci, A., Cakici, H., Hapa, O., Yanat, A.N., Dogramaci, Y. & Sevinc, T.T. 2009, "Treatment of plantar fasciitis using four different local injection modalities: a randomized prospective clinical trial", Journal of American Podiatric Medicine Association, vol. 99, no. 2, pp. 108-113.

Kanis, J.A., Johnell, O., Oden, A., Johansson, H., DeLaet, C., Eisman, J.A., Fujiwara, S., Kroger, H., McCloskey, E.V., Mellstrom, D., Melton, L.J., Pols, H., Reeve, J., Silman, A. & Tenenhouse, A. 2005, "Smoking and fracture risk:a meta-analysis", Osteoporosis International, vol. 16, pp. 155-162.

Karim, A., Pandit, H., Murray, J., Wandless, F. & Thomas, N.P. 2006, "Smoking and reconstruction of the anterior cruciate ligament", The Journal of Bone & Joint Surgery, vol. 88, no. 8, pp. 1027-1031.

Kaufman, K., Brodine, S. & Shaffer, R. 2000, "Military training-related injuries - Surveillance, research, and prevention", American Journal of Preventive Medicine, vol. 18, no. 3, pp. 54.

Kaufman, K.R., Brodine, S.K., Shaffer, R.A., Johnson, C.W. & Cullison, T.R. 1999, "The effect of foot structure and range of motion on musculoskeletal overuse injuries", American Journal of Sports Medicine, vol. 27, pp. 585-593.

Kelly, L.A., Kuitunen, S., Racinais, S. & Cresswell, A.G. 2012, "Recruitment of the plantar intrinsic foot muscles with increasing postural demand", Clinical Biomechanics, vol. 27, pp. 46-51.

Kendall, F.P., McCreary, E.K. & Provance, P.G. 1993, Muscles Testing and Function with Posture and Pain, 4th edn, Lippincott williams and Wilkins, Philadelphia.

Kesson, M. & Atkins, E. 1998, Orthopaedic Medicine: A Practical Approach, Butter-Heinemann, Oxford.

Kibler, W.B., Press, J., & Sciascia, A. 2006, "The role of core stability in athletic function", Sports Medicine, vol. 36, no. 3, pp. 189-198.

Kiesel, K., Plisky, P.J. & Voight, M.L. 2007, "Can serious injury in professional football be predicted by a preseason functional movement screen? ", North American Journal of Sports Physical Therapy, vol. 2, no. 3, pp. 147-158.

Kim, W., Voloshin, A., 1995, " Role of plantar fascia in the load bearing capacity of the human foot" Journal of Biomechanics vol 28, pp. 1025-1033.

Kinch, M. & Lambart, A. 2007, "Principles of rehabilitation" In Clinical Sports Medicine, eds. P. Brukner & K. Khan, 3rd edn, McGraw-Hill, Australia, pp. 174-197.

King, N., Fridlund, K.E. & Askew, E.W. 1993, "Nutrition issues of military females", Journal of American College of Nutrition, vol. 12, pp. 344.

Kirtley, C. 2006, Clinical Gait Analysis Theory & Practice, Elsevier Churchill Livingstone, London.

Kitaoka, H.B., Luo, Z.P. & An, K.N. 1997, "Effect of the posterior tibial tendon on the arch of the foot during simulated weight bearing: biomechanical analysis", Foot and Ankle International, vol. 18, no. 1, pp. 43-46.

Knapik, J.J., Brosch, L.C., Venuto, M., Swedler, D.I., Bullock, S.H., Gaines, L.S., 2010, "Effect on injuries of assigning shoes based on foot shape in air force basic training", American Journal of Preventive Medicine, vol 38, no. 1, pp.S197–211.

Knapik, J.J., Canham-Chervak, M., Hauret, K., Hoedebecke, E., Laurin, M.J. & Cuthie, J. 2001a, "Discharges during U.S. Army basic training: injury rates and risk factors", Military Medicine, vol. 166, pp. 641-647.

Knapik, J.J., Canham-Chervak, M., Hauret, K., Laurin, M.J., Hoedebecke, E., Craig, S. & Montain, S.J. 2002, "Seasonal variations in injury rates during American Army basic combat training", The Annals of Occupational Hygiene, vol. 46, no. 1, pp. 15-23.

Knapik, J.J., Graham, B., Cobbs, J., Thompson, D., Steelman, R. & Jones, B. 2013b, "A prospective investigation of injury incidence and injury risk factors among army recruits in military police training", BMC Musculiskeletal Disorders vol.,14 pp.32 [Online], . Available from: http://www.biomedcentral.com/content/pdf/1471-2474-14-32.pdf.

Knapik, J.J., Graham, B., Cobbs, J., Thompson, D., Steelman, R. & Jones, B. 2013a, "A prospective investigation of injury incidence and risk factors among army recruits in combat engineer training", [Online],. Available from: http://www.occup--med.com/content/8/1/5.

Knapik, J.J., Hauewt, K.G., Marin, R & Jones, B.H. 2011 "Association between ambulatory physical activity and injuries in United States Army Basic Training" Journal of Physical Activity and Health, vol. 8,:pp. 496-502.

Knapik, J.J., Sharp, M.A., Canham-chervak, M., Hauret, K., Patton, J. & Jones, B.H. 2001b, "Risk factors for training-related injuries among men and women in basic combat training", Medicine & Science in Sports & Exercise, vol. 33, no. 6, pp. 946-954.

Knapik,J.J., Swedler, D.I., Grier, T.L., Hauret, .G., Bullock, S.H., Williams, K.W., 2009, "Injury reduction effectiveness of selecting running shoes based on plantar shape", Journal of Strength & Conditioning Research; vol 23, no. 3, pp.685–697.

Knowles, S.B., Marshall, S.W. & Miller, T. 2007, "Cost of injuries from a prospective cohort study of North Carolina high school athletes", Injury Prevention, vol. 13, no. 6, pp. 416-421.

Knutzen, K.M. & Price, A. 1994, "Lower extremity static and dynamic relationships with rearfoot motion in gait", Journal of American Podiatric Medical Association, vol. 84, no. 4, pp. 171-180.

Koplan, J.P., Powell, K.E., Sikes, R.K., Shirley, R.W. & Campbell, C.C. 1982, "An epidemiologic study of the benefits and risks of running", The Journal of the American Medical Association, vol. 248, pp. 3118-3121.

Koplan, J.P., Siscovick, D.S. & Goldbaum, G.M. 1985, "The risks of exercise: a public health view of injuries and hazards", Public Health Rep, vol. 100, pp. 189-195.

Kortebein, P.M., Kaufman, K.R. & Basford, J.R. 2000, "Medial Tibial Stress Syndrome", Medicine & Science in Sports & Exercise, vol. 32, pp. 27.

Kowal, D.M. 1980, "Nature and causes of injuries in women resulting from an endurance training program", The American Journal of Sports Medicine, vol. 8, pp. 265-269.

Kulig K, Burnfield JM, Requejo, SM, Sperry M, Terk M.2004, Selective Activation of Tibialis Posterior: Evaluation by Magnetic Resonance Imaging. *Medicine and Science in Sports & Exercise*, vol. 36, no. 5, pp. 862-867.

Kulig K, Lederhaus ES, Reischl S, Arya S, Bashford G.2009, Effect of Eccentric Exercise Program for Early Tibialis Posterior Tendinopathy. Foot Ankle International vol.30 no. 9 pp.877-885.

Landorf, K.B. & Keenan, A.M. 2007, "Do foot orthoses prevent injury?" In Evidence-based Sports Medicine, eds. D. MacAuley & T. Best, 2nd edn, Blackwell, Singapore, pp. 73-92.

Lanyon, L.E. 1975, "Bone deformation recorded in vivo from strain gauges attached to the human tibial shaft", Acta Orthopaedica Scandinavica, vol. 46, no. 2, pp. 256.

Lappe, J.M., Stegman, M.R. & Recker, R.R. 2001, "The impact of lifestyle factors on stress fractures in female Army recruits", Osteoporosis International, vol. 12, pp. 35-42.

Larsen, K., Weidich, F. & Leboeuf-Yde, C. 2002, "Can custom-made biomechanic shoe orthoses prevent problems in the back and lower extremities? A randomized, controlled intervention trial of 146 military conscripts", Journal of Manipulative & Physiological Therapeutics, vol. 25, no. 5, pp. 326-331.

Larsson, H., Broman, L. & Harms-Ringdahl, K. 2009, "Individual risk factors associated with premature discharge from military service ", Military Medicine, vol. 174, no. 1, pp. 9-20.

Laslett, M., Oberg, B., Aprill, C.N. & McDonald, B. 2004, "Zygapophysial joint blocks in chronic low back pain: a test of Revel's model as a screening test", BMC Musculoskeletal Disorders, vol. 5, no. 43, pp. 1-6.

Lephart, S.M., Perrin, D.H., Minger, K. & Fu, F. 1991, "Functional performance test for the Anterior cruciate ligament insufficient athlete", Athletic Trainer, vol. 26, pp. 44-50.

Lewit, K. & Lepslkova, M. 2012, "The role of the feet as an important part of the stabilization system", International Musculoskeletal Medicine, vol. 34, no. 2, pp. 55-61.

Light, L.H., McLellan, G.E. & Klenerman, L. 1980, "Skeletal transients on heel strike in normal walking with different footwear", Journal of Biomechanics, vol. 13, no. 6, pp. 477-480.

Linenger, J.M. & West, L.A. 1992, "Epidemiology of soft-tissue/musculoskeletal injury among U.S. Marine recruits undergoing basic training", Military Medicine, vol. 157, no. 9.

Liu, M.S., Huang, H., Ke, J.B. & Geng, L. 2008, "Relationship between gastrocnemius flexibility and lower extremity overuse injuries in physical fitness training" Journal of Clinical Rehabilitative Tissue Engineering Research [Zhongguo Zuzhi Gongcheng Yanjiu yu Linchuang Kangfu]", vol. 12, no. 28, pp. 5541-5544.

Lord, M. 1981, "Foot pressure measurement: a review of methodology", Journal of Biomedical Engineering, vol. 3, pp. 91-99.

Low, J. & Reed, A. 1996, Basic Biomechanics Explained, Butterworth-Heinemann, Great Britain.

Luke, A.C., Kinney, S.A., D'Hemecourt, P.A., Baum, J., Owen, M. & Micheli, L.J. 2002, "Determinants of injuries in young dancers", Medical Problems of Performing Artists, vol. 17, no. 3, pp. 105-112.

Lune, L. 2013 "Why Barefoot is Best, Men's Living Magazine (Australia) by, featuring Dr. James Stoxen DC."January 19

Magnusson, H.I., Ahlborg, H.G., Karlsson, C., Nyquist, F. & Karlsson, M.K. 2003, "Low regional tibial bone density in athletes with medial tibial stress syndrome normalizes after recovery from symptoms", The American Journal of Sports Medicine, vol. 31, pp. 596-600.

Magnusson, H.I., Westlin, N.E., Nyqvist, F., Gardsell, P., Seeman, E. & Karlsson, M.K. 2001, "Abnormally decreased regional bone density in athletes with medial tibial stress syndrome", The American Journal of Sports Medicine, vol. 29, no. 0363-5465; 6, pp. 712-715.

Marieb, E.N. & Hoehn, K. 2006, Human Anatomy and Physiology, 7th edn, Benjamin Cummings.

Marshall, S.W. & Guskiewics, K.M. 2003, "Sports and recreational injury: the hidden cost of a healthy lifestyle", Injury Prevention, vol. 9, pp. 100-102.

Marti, B., Abelin, T., Minder, C.E. & Vader, J.P. 1988, "Smoking alcohol consumption and endurance capacity: an analysis of 6,500 19-year-old conscripts and 4,100 joggers", Preventive medicine, vol. 17, pp. 79-92.

Marti, B., Vader, J.P., Minder, C.E. & Abelin, T. 1984, "On the epidemiology of running injuries: the 1984 Bern Grand-Prix Study", American Journal of Sports Medicine, vol. 16, pp. 285-294.

Martin, R.B., Lau, S.T., Matthews, P.V., Gibson, V.A. & Stover, S.M. 1996, "Collagen fiber organization is related to mechanical properties and remodelling in equine bone", Journal of Biomechanics, vol. 29, no. 12, pp. 1515-1521.

Mason, M.J., N'Jie, M., Holliman, D.E. & Rayson, M.P. 1996, The physical demands of basic training in British army recruits: a pilot study., DERA Report.

Massimiliano, P., & Ciuti, C. 2012 "Stresses in the plantar region for long-and short-range throws in women basketball players" European Journal of Sport Science ahead-of-print pp. 1-7.

Matin, P. 1988, "Basic principles of nuclear medicine techniques for detection and evaluation of trauma and sports medicine injuries.", Seminar Nuclear Medicine, vol. 18, no. 2, pp. 90-112.

Matos, N.F., Winsley, R.J. & Williams, C.A. 2011, "Prevalence of nonfunctional overreaching/overtraining in young English athletes", Medicine & Science in Sports & Exercise, vol. 43, pp. 1287-1294.

McColl, G.J., Dolezal, H. & Eizenberg, N. 2000, "Common corticosteroid injections. An anatomical and evidence based review", Australian Family Physician, vol. 29, pp. 922-926.

McGill, S. 2002, "Normal and Injury Mechanics of the Lumbar Spine" In Low Back Disorders: Evidence based Prevention and Rehabilitation, Human Kinetics, Champaign, ILL, pp. 87-137.

McGill, S. 2002, Low back disorders: evidence-based prevention and rehabilitation, Human Kinetics, Chanmpaign, IL

McGinnis, P.M. 1999, Biomechanics of Sport and Exercise, Champaign, IL: Human Kinetics, Leeds.

McGuine, T.A. & Keene, J.S. 2006, "The effect of a balance training program on the risk of ankle sprains in high school athletes", Journal of Sports Medicine, vol. 34, no. 7, pp. 1103-1111.

McKeon, P. 2009a, "Cultivating functional variability: the dynamical-systems approach to rehabilitation", Athletic Therapy Today, vol. 14, no. 4, pp. 1-3.

McKeon, P.O. & Mattacola, C.G. 2008b, "Interventions for the prevention of first time and recurrent ankle sprains", Clinics in Sports Medicine, vol. 27, pp. 371-382.

McKeon, P.O., Ingersoll, C.D., Kerrigan, D.C., Saliba, E., Bnnett, B.C. & Hertel, J. 2008a, "Balance training improves function and postural control in those with chronic ankle instability.", Medicine & Science in Sports & Exercise, vol. 40, no. 10, pp. 1810-1819.

McKeon, P.O., Ingersoll, C.D., Kerrigan, D.C., Saliba, E.N., Bennett, B.C. & Hertel, J. 2009b, "Effects of balance training on gait parameters in patients with chronic ankle instability: a randomized controlled trial", Clinical Rehabilitation, vol. 23, pp. 609-621.

McNitt-Gray, J.L. 1991, "Kinematics and impulse characteristics of drop landings from three heights", International Journal of Sports Biomechanics, vol. 7, pp. 201-224.

McPoil, T.G. & Knecht, H. 1985, "Biomechanics of the foot in walking: a function approach", The Journal of Orthopaedic and Sports Physical Therapy, vol. 7, pp. 69-72.

Meehan, H.I., Bull, S.J. & James, D.V.B. 2002, "The role of non-training stress in the development of the overtraining syndrome", Journal of Sports Sciences, vol. 20, pp. 69-70.

Meeuwisse, W. & Bahar, R. 2009, "A systematic approach to sports injury prevention" In Handbook of sports medicine and science sports injury prevention, eds. R. Bahr & L. Engebretsen, Wiley-blackwell, Chichester, UK, pp. 7-16.

Meeuwisse, W.H. 1994, "Assessing causation in sport injury: a multifactorial model", Clinical Journal Sports Medicine, vol. 4, pp. 166-170.

Melegati, G., Tornese, D., Bandi, M. & Caserta, A. 2002, "The influence of local steroid injections, body weight and the length of symptoms in the treatment of painful subcalcaneal spurs with extracorporeal shock wave therapy", Clinical Rehabilitation, vol. 16, pp. 789-794.

Mens, J.M., Nico de Wolf, A., Berkhout, B.J. & Stam, H.J. 1998, "Disturbance of the menstrual pattern after local injection with triamcinolone acetonide", Annals of the Rheumatic Diseases, vol. 57, no. 11, pp. 700.

Messier, S.&Cirillo, K. 1989, "Effects of a verbal and visual feedback system on running technique, perceived exertion and running economy in female novice runners" Journal of Sports Science vol.7, pp. 113–126.

Messier, S.P. & Pittala, K.A. 1988, "Etiologic factors associated with selected running injuries", Medicine & Science in Sports & Exercise, vol. 20, no. 5, pp. 501-505.

Michael, R.H. & Holder, L.E. 1985, "The soleus syndrome. A cause of medial tibial stress (shin splints)", American Journal of Sports Medicine, vol. 13, pp. 87-94.

Milgrom, C., Finestone, A., Segev, S., Olin, C., Arndt, T. & Ekenman, I. 2003, "Are overground or treadmill runners more likely to sustain tibial stress fracture?", British Journal of Sports Medicine, vol. 37, pp. 160-163.

Milgrom, C., Radeva-Petrova, D.R., Finestone, A., Nyska, M., Mendelson, S., Benjuya, N., Simkin, A. & Burr, D. 2007, "The effect of muscle fatigue on in vivo tibial strains", Journal of Biomechanics, vol. 40, no. 4, pp. 845-850.

Milner, C.E., Ferber, R., Pollard, C.D., Hamill, J., Davis, I.S., 2006, "Biomechanical factors associated with tibial stress fracture in female runners" Medicine & Science in Sports & Exercise, vol.38, pp. 323–328.

Moen, M.H., Bongers, T., Bakker, E.W., Zimmermann, W.O., Weir, A., Tol, J.L. & Back, F.J.G. 2012, "Risk factors and prognostic indicators for medial tibial stress syndrome", Scandinavian Journal of Medicine & Science in Sports, vol. 22, no. 1, pp. 34-39.

Moen, M.H., Tol, J.L., Weir, A., Steunebrink, M. & Winter, T.C.D. 2009, "Medial tibial stress syndrome: a critical review", Sports Medicine, vol. 39, no. 7, pp. 523-546.

Moore, K.L. 1985, Clinically Oriented Anatomy, Willians & Wilkins.

MRC, 2000, A framework for the development and evaluation of RCTs for complex interventions to improve health. Medical Research Council.

Mubarak, S.J., Gould, R.N., Lee, Y.F., Schmidt, D.A. & Hargens, A.R. 1982, "The medial tibial stress syndrome. A cause of shin splints", The American Journal of Sports Medicine, vol. 10, no. 4, pp. 201-205.

Munnoch, K. & Bridger, R.S. 2007, "Smoking and injury in Royal Marines' training", Occupational Medicine, vol. 57, no. 3, pp. 214-216.

Munnoch, K., Brasher, K. & Dew, A. 2009, An audit of injuries and recovery times in Hunter company, Commando Training Centre, Royal Marines, INN, UK.

Murphy, D.F., Connolly, D.A.J. & Beynnon, B.D. 2003, "Risk factors for lower extremity injury: a review of the literature", British Journal of Sport Medicine, vol. 37, no. 1, pp. 13-29.

Myers, T.W. 2009, Anatomy Trains: Myofascial Meridians for Manual and Movement Therapists, 2nd edn, churchill Livingstone, Oxford, UK.

Nadeau, S., Gravel, D., Hébert, L.J., Arsnault, B. & Lepage, Y. 1997, "Gait study of patients with patellofemoral pain syndrome", Gait & Posture, vol. 5, pp. 21-27.

Neely, F.G. 1997, Intrinsic risk factors for lower limb injuries, DERA Reports.

Netter, F.H. 1987, Musculoskeletal System: Anatomy, Physiology and metabolic Disorders. Ciba-geigy, Summit NJ.

New Zealand Guidelines Group 2004, Diagnosis and management of soft tissue shoulder injuries and related disorders, Best practice evidence based guideline, New Zealand.

NICE Guideline 2008, National Collaborating Centre for Chronic Conditions. Osteoarthritis: national clinical guideline for care and management in adults, Royal College of Physicians, London.

Nichols, A.W. 2005, "Complications associated with the use of corticosteroids in the treatment of athletic injuries", Clinical Journal of Sport Medicine, vol. 15, no. 5, pp. 370-375.

Nigg, B.M. & Segesser, B. 1988, "The influence of playing surfaces on the load on the locomotor system and on football and tennis injuries", Sports Medicine, vol. 5, pp. 375-388.

Nigg, B.M. 1985, "Biomechanics, load analysis and sports injuries in the lower extremities", Sports Medicine, vol. 2, pp. 367.

Noehren, B., Scholz, J. & Davis, I. 2011, "The effect of real-time gait retraining on hip kinematics, pain and function in subjects with patellofemoral pain syndrome", British Journal Sport Medicine, vol. 45, pp. 691-696.

Nordin, M. & Frankel, V.H. 1989, Basic Biomechanics of the Musculoskeletal System, 2nd edn, Lea & Febiger, Philadelphia.

Norris, C.M. 1998, Sports Injuries Diagnosis, 2nd edn, Butterworth-Heinemann, Bath, UK.

Oatis, C.A. 1998, "Biomechanics of the foot and ankle under static conditions", Physical Therapy, vol. 68, pp. 1815-1821.

Olsen, O.E., Myklebust, G., Engebretsen, L., Holme, I. & Bahr, R. 2005, "Exercises to prevent lower limb injuries in youth sports: cluster randomised controlled trial", British Medical Journal, vol. 330, no. 7489, pp. 449.

Ostenberg, A. & Roos, H. 2000, "Injury risk factors in female European football. A prospective study of 123 players during one season", Scandinavian Journal of Medicine & Science in Sports, vol. 10, pp. 279-285.

Ozgurbuz, C., Yukse, O., Ergun, M., Islegen, C., Taskiran, E., Denerel, N. & Karamzrak, O. 2011, "Tibial bone density in athletes with medial tibial stress syndrome: a controlled study", Journal of Sports Science and Medicine, vol. 10, no. 4, pp. 743-747.

Paice, J.A. & Cohen, F.L. 1997, "Validity of a verbally administered numerical rating scale to measure cancer pain intensity", Cancer Nursing, vol. 20, pp. 88-93.

Page, P., Frank, C. C., Lardner, R. 2010 Assessment and Treatment of Muscle Imbalance: The Janda Approach Human kinetics Chicogo IL.

Parkkari, J., Kujala, U.M. & Kannus, P. 2001, "Is it possible to prevent sports injuries? Review of controlled clinical trials and recommendations for future work", Sports Medicine, vol. 31, pp. 985-995.

Parmar, M.K.B. & Machin, D. 1995, Survival Analysis. A Practical Approach, John Wiley & Sons, Chichester.

Pasanen, K., Parkkari, J., Pasanen, M., Hiilloskorpi, H., Makinen, T., Jarvinen, M. & Kannus, P. 2008, "Neuromuscular training and the risk of leg injuries in female floorball players: cluster randomised controlled study ", British Journal Medicine, vol. 337, no. 10, pp. a295.

Pate RP, Pratt M, Blair SN, et al. Physical activity and public health. A recommendation from the Centers for Disease Control and Prevention and the American College of Sports Medicine. JAMA. 273: 402-7, 1995.

Paul, J.P. 2005, "The history of musculoskeletal modelling in human gait", Theoretical Issues in Ergonomics Science, vol. 6, pp. 217-224.

Peat, J. & Barton, B. 2005, Medical Statistics: a guide to data analysis and critical appraisal, Blackwell, India.

Pegrum, J., Crisp, T., Padhiar, N. 2012 " Diagnosis and management of bone stress injuries of the lower limb in athletes" BMJ, 28 April 2012, vol. 344., pp. 35-40.

Petchell, A., Keenan, A.M. & Landorf, K. 1998, "National clinical guidelines for podiatric foot orthoses", Australian Journal of Podiatric medicine, vol. 32, pp. 97-103.

Petersen, E.J. & Smith, K.C. 2007, "Benefits of a musculoskeletal screening examination for initial entry training soldiers", Military Medicine, vol. 172, no. 1, pp. 92-97.

Peterson, L., Junge, A., Chomiak, J., Graf-Baumann, T. & Dvorak, J. 2000, "Incidence of football injuries and complaints in different age groups and skill-level groups", American Journal of Sports Medicine, vol. 28, pp. S51-7-57.

Plisky, M.S., Rauh, M.J., Heiderscheit, B., Underwood, F.B. & Tank, R.T. 2007, "Medial tibial stress syndrome in high school cross-country runners: incidence and risk factors", Journal of Orthopaedic and Sports Physical Therapy, vol. 37, no. 2, pp. 40-47.

Plisky, P.J., Rauh, M.J., Kaminski, T.W. & Underwood, F.B. 2006, "Star excursion balance test as a predictor of lower extremity injury in high school basketball players", Journal of Orthopaedic Sports Physical Therapy, vol. 36, no. 12, pp. 911-919.

Pocock, S.J., Clayton, T.C. & Altman, D.G. 2002, "Survival plots of time-to-event outcomes in clinical trials: good practice and pitfalls", Lancet, vol. 359, pp. 1686-1689.

Pohl, M., Mullineaux, D., Milner, C., Hamill, J. & Davis, I. 2008b, "Biomechanical predictors of retrospective tibial stress fractures in runners", Journal of Biomechanics, vol. 41, no. 6, pp. 1160.

Pohl, M.B. & Buckley, J.G. 2008a, "Changes in foot and shank coupling due to alterations in foot strike pattern during running", Clinical Biomechanics, vol. 23, no. 3, pp. 334-341.

Pollard, R. & Reep, C. 1997, "Measuring effectiveness of playing strategies at soccer", The Statistician, vol. 46, pp. 541-550.

Pope, R.P. 2002a, Prediction and preventsion of lower limb injuries and attrition in army recruits, PhD Thesis, Charles Sturt University.

Pope, R.P. 2002b, "Rubber matting on an obstacle course causes anterior cruciate ligament ruptures and its removal eliminates them", Military Medicine, vol. 167, no. 4, pp. 355-358.

Pope, R.P., Herbert, R., Kirwan, J.D. & Graham, B.J. 1999a, "Predicting attrition in basic military training", Military Medicine, vol. 164, pp. 710-714.

Pope, R.P., Herbert, R.D., Kirwan, J.D. & Graham, B.J. 2000, "A randomized trial of preexercise stretching for prevention of lower-limb injury", Medicine & Science in Sports & Exercise, vol. 32, no. 2, pp. 271-277.

Powell, K.E., Kohl, H.Ww., Caspersen, C.J. & Blair, S.N. 1986, "An epidemiologic perspective on the causes of running injuries.", Physician and Sports Medicine, vol. 14, no. 6, pp. 100-114.

Prentice, W. 3003, Arnheim's Principles of Athletic Training McGraw-Hill, St. Louis.

Prentice, W.E. (ed) 2004, Rehabilitation techniques for sports medicine and athletic training, 4th edn, McGraw-Hill, New York.

Pritchett, J.W. 1981, "Cost of high school soccer injuries" American Journal of Sports Medicine, vol. 9, pp. 64-66.

Raikin, S.M., Landsman, J.C., Alexander, V.A., Froimson, M.I. & Plaxton, N.A. 1998, "Effect of nicotine on the rate and strength of long bone fracture healing", Clinical Orthopaedics, vol. 353, pp. 231-237.

Rauh, M.J., Macera, C.A., Trone, D.W., Shaffer, R.A. & Brodine, S.K. 2006, "Epidemiology of stress fracture and lower-extremity overuse injury in female recruits", Medicine & Science in Sports & Exercise, vol. 38, no. 0195-9131; 9, pp. 1571-1577.

Rayson, M.P. & Dixon, G. 2004, Discharge as of Right in recruits: summary of qualitative findings., ARTD.

Rayson, M.P. & Harwood, G.E. 1997, The Physical Demands of the Commissioning Course: Management Report. Technical Report.

Rayson, M.P. & Wilkinson, D.M. 2003, Potential Risk Modifiers for Training Outcome and Injury in Single Entry Recruits: Body Mass, Composition and Aerobic Fitness, Optimal Performance Ltd, Farnham, Surrey.

Rayson, M.P., Bell, D.G., Holliman, D.E., Llewellyn, M., Nevola, V.R. & Bell, R.L. 1994, Physical selection standards for the British Army. Phase 1 and 2, APRE Technical Report 94R036, Farnborough.

Rayson, M.P., Wilkinson, D.M., Valk, E. & Nevill, A.M. 2002, "Physical activity and energy expenditure during army basic training.", Proceedings of the Nutrition Society, vol. 61, pp. 170.

Razeghi, M. & Batt, M.E. 2002, "Foot type classification: a critical review of current methods", Gait & posture, vol. 15, pp. 282-291.

Recker, R.R., Davies, K.M., Hinders, S.M., Heaney, R.P., Stegman, M.R. & Kimmel, D.B. 1992, "Bone gain in young adult women", Journal of the American Medical Association, vol. 268, pp. 2403-2408.

Reed, C.A., Ford, K.R., Myer, G.D. & Hewett, T.E. 2012, "The effects of isolated and integrated 'core stability' training on athletic performance measures: a systematic review", Sports Medicine, vol. 42, no. 8, pp. 697-706.

Reinking, M.F., Austin, T.M. & Hayes, A.M. 2007, "Exercise-related leg pain in collegiate cross-country athletes: extrinsic and intrinsic risk factors", Journal of Orthopaedic & Sports Physical Therapy, vol. 37, no. 11, pp. 670-678.

Reis, J.P., Trone, D.W., Macera, C.A. & Rauh, M.J. 2007, "Factors associated with discharge during marine corps basic training", Military Medicine, vol. 172, pp. 936-941.

Revel, M., Poiraudeau, S., Auleley, G.R., Payan, C., Denke, A., Nguyen, M., Chevrot, A. & Fermanian, J. 1998, "Capacity of the clinical picture to characterize low back pain relieved by facet joint anesthesia. Proposed criteria to identify patients with painful facet joints", Spine, vol. 23, pp. 1972-1977.

Rockar, P.A.J. 1995, "The subtalar joint: anatomy and motion", Journal of Orthopaedic Sports Physical Therapy, vol. 21, no. 6, pp. 361-372.

Rodgers, M.M. 1995, "Dynamic foot biomechanics" Journal of Orthopeadic Sports Physical

Rosenbaum, D. & Becker, H. 1997, "Plantar pressure distribution measurements. Technical background and clinical applications", Foot and Ankle Surgery, vol. 3, pp. 1-14.

Ross, R.A. & Allsopp, A. 2002, "Stress fractures in royal marines recruits", Military Medicine, vol. 167, pp. 560-565.

Rowlands, G., Sims, J. & Kerry, S. 2005, "A lesson learnt: the importance of modelling in randomized controlled trials for complex interventions in primary care", The Journal of Family Practice, vol. 22, pp. 132-139.

Rudzki, S., Delaney, T. & Maci, E. 2012, "Military personnel" In Brukner & Khan's Clnical sports medicine, eds. P. Brukner, R. Bahar, S. Blair, et al, 4th edn, McGraw-Hill, NSW Australia, pp. 943-959.

Ruscio, B.A., Jones, B.H., Bullock, S.H., Burnham, B.R., Canham-Chervak, M., Rennix, C.P., Wells, T.S. & Smith, J.W. 2010, "A process to identify military injury prevention priorities based on injury type and limited duty days", American Journal of Preventive Medicine, vol. 38, no. 1 suppl, pp. S19-33.

Saladin, K.S. 2012, Anatomy and Physiology: The Unity of Form and Function, 6th edn, McGraw-Hill, USA.

Saltzman, C.L., Nawoczenski, D.A. & Talbot, K.D. 1995, "Measurement of the medial longitudinal arch", Archives of Physical Medicine and Rehabilitation, vol. 76, no. 1, pp. 45-49.

Santana, J. 2003, "Sport-specific conditioning: The serape effect - a kinesiological model for core training", Strength and Conditioning Journal, vol. 25, no. 2, pp. 73-74.

Saunders, S. & Longworth, S. 2011, Injection Techniques in Musculoskeletal Medicine : A Practical Manual for Clinicians in Primary and Secondary Care, 4th edn, Churchill Livingstone.

Sauer L, Beazell J, Hertel J. 2011, Considering the Intrinsic Foot Musculature in Evaluation and Rehabilitation for Lower Extremity Injuries. Athletic Training & Sports Health Care. Vol. 3, no. 1 pp. 43-47. doi: 10.3928/19425864-20100730-02

Saxena, A., O'Brien, T. & Bunce, D. 1990, "Anatomic dissection of the tibialis posterior muscle and its correlation to medial tibial stress syndrome", The Journal of Foot Surgery, vol. 29, no. 2, pp. 105-108.

Schmid, S., Schweizer, K., Romkes, J., Lorenzetti, S. & Brunner, R. 2013, "Secondary gait deviations in patients with and without neurological involvement: a systematic review", Gait & Posture, vol. 37, no. 4, pp. 480-493.

Schneider, S., Seither, B., Tonges, S. & Schmitt, H. 2006, "Sports injuries: population based representative data on incidence, diagnosis, sequelae, and high-risk groups", British Journal of Sport Medicine, vol. 40, no. 4, pp. 334-339.

Schwellnus, P., Jordaan, G. & Noakes, T.D. 1990, "Prevention of common overuse injuries by the use of shock absorbing insoles a prospective study", American Journal of Sports Medicine, vol. 18, no. 6, pp. 636-641.

Shaffer, R., Brodine, S., Almeida, S., Williams, K. & Ronaghy, S. 1999, "Use of simple measure of physical activity to predict stress fractures in young men undergoing a rigorous physical training program", American Journal of Epidemiology, vol. 149, no. 3, pp. 236-242.

Shaffer, R.A., Rauh, M.J., Brodine, S.K., Trone, D.W. & Macera, C.A. 2006, "Predictors of stress fracture susceptibility in young female recruits", The American Journal of Sports Medicine, vol. 34, no. 1, pp. 108-115.

Sharma, J. 2008, Training related musculoskeletal overuse injury risk factors: Research summary., Director General Army Medical Services annual report on the health of the army, UK 2007, UK.

Sharma, J., Golby, J., Greeves, J. & Spears, I.R. 2011a, "Biomechanical and lifestyle risk factors for medial tibia stress syndrome in army recruits: A prospective study", Gait & Posture, vol. 33, pp. 361-365.

Sharma, J., Senjyu, H., Williams, L. & White, C. 2004a, "Intra-tester and inter-tester reliability of chest expansion measurement in clients with ankylosisng spondylitis and healthy individuals", Journal of the Japanese Physical Therapy Association, vol. 7, pp. 23-28.

Sharma, J., Spears, I.R. & Golby, J. 2011b, "Musculoskeletal injury during British Infantry Recruits training: a prospective study ", Annual Conference University of Teesside, 24 May.

Sharma, J., Spears, I.R. & Golby, J. 2012, Efficacy of a new rehabilitation protocol on medial tibial stress syndrome in recruits: a pilot study., 31 May 2012 ARTD, Occupational Medicine, Upavon UK.

Sharma, J., Spears, I.R., Golby, J. & Rennie, P.E.J. 2009, "Medial tibial stress syndrome", International Musculoskeletal Medicine, vol. 31, no. 1, pp. 45-46.

Sharma, J., White, C. & Senjyu, H. 2004b, "A description of single case design- as an example to evaluate the effect of warm-up and stretching on hamstring flexibility in a clinical setting", Journal of Physical Therapy Science, vol. 16, pp. 21-26.

Sherman, R.A., Karstetter, K.W., May, H. & Woerman, A.L. 1996, "Prevention of lower limb pain in soldiers using shock-absorbing orthotic inserts", Journal of American Podiatric Medicine Association, vol. 86, no. 3, pp. 117-122.

Shiqing, X., Quanzhi, Z. & Dehao, F. 1987, "Significance of straight-leg-raising test in the diagnosis and clinical evaluation of lower lumbar intervertebral disc protrusion", Journal of Bone and Joint Surgery American volume, vol. 69, pp. 517-522.

Shorten, M.R.& D.S. Winslow, D.S. 1992, "Spectral analysis of impact shock during running" International Journal of Sport Biomechanics vol. 8, pp. 288-304.

Shrier, I. 2007, "Does stretching help prevent injuries?" In Evidence-based Sports Medicine, eds. D. MacAuley & T. Best, 2nd edn, Blackwell BMJbooks, Singapore, pp. 36-58.

Siafaka, A., Angelopoulos, E., Kritikos, K., Poriazi, M., Basios, N., Gerovasili, V., Andreou, A., Roussos, C. & Nanas, S. 2007, "Acute effects of smoking on skeletal muscle microcirculation monitored by near-infrared spectroscopy", Chest, vol. 131, pp. 1479-1485.

Silvino, N., Evanski, P.M. & Waugh, T.R. 1980, "The Harris and beath footprinting mat: diagnostic validity and clinical use", Clinical Orthopaedics, vol. 151, pp. 265-269.

Simkin, A., Leichter, I., Giladi, M., Stein, M. & Milgrom, C. 1989, "Combined effect of foot arch structure and an orthotic device on stress fractures", Foot & Ankle, vol. 10, no. 1, pp. 25-29.

Skedros, J.G., Hunt, K.J. & Pitts, T.C. 2007, "Variations in corticosteroid/anesthetic injections for painful shoulder conditions: comparisons among orthopaedic surgeons, rheumatologists, and physical medicine and primary-care physicians", BMC Musculoskeletal Disorders, vol. 8, no. 63, pp. doi:10.1186/1471-2474-8-63.

Smith, E.L., Hill, R.L., Lehman, I.R., Lefkowitz, R.J., Handler, P. & White, A. (eds) 1983, Principles of Biochemistry: Mammalian Biochemistry., 7th edn, McGraw-hill, New York.

Soames, R.W. & Atha, J. 1981, "The role of the antigravity musculature during quite standing in man", European Journal of Applied Physiology and Occupational Physiology, vol. 47, pp. 159-167.

Souza, R.B. & Powers, C.M. 2009, "Differences in hip kinematics, muscle strength, and muscle activation between subjects with and without patellofemoral pain", Journal of Orthopaedic and Sports Physical Therapy, vol. 39, pp. 12-19.

Souza, T.R., Pinto, R.Z.A., Trede, R.G., Kirkwood, R.N. & Fonseca, S.T. 2010, "Temporal couplings between rearfoot-shank complex and hip joint during walking", Clinical Biomechanics, vol. 25, no. 7, pp. 745-748.

Stacy, R.J. & Hungerford, R.L. 1984, "A method to reduce work-related injuries during basic recruit training in the New Zealand Army", Military Medicine, vol. 149, pp. 318-320.

Steffen, K., Myklebust, G., Olsen, O.E., Holme, I. & Bahr, R. 2008, "Preventing injuries in female youth football ? A cluster-randomized controlled trial", Scandinavian Journal of Medicine & Science in Sports, vol. 18, no. 5, pp. 605-614.

Stephen, M., Pribut, D. 2007, "Current approaches to the management of plantar heel pain syndrome, including the role of injectable corticosteroids" Journal of the American Podiatric Medical Association vol.97, pp. 68-74.

Stephens,T.M. Lawson, B.R., DeVoe, D.E. Reiser, R.F.2007 "Gender and bilateral differences in single-leg countermovement jump performance with comparison to a double-leg jump" Journal of Applied Biomechanics, vol. 23 pp. 190-202.

Stolwijk, N.M., Duysens, J., Louwerens, J.W. & Keijsers, N.L. 2010, "Plantar pressure changes after long-distance walking", Medicine & Science in Sports & Exercise, vol. 42, no. 12, pp. 2264-2272.

Story, J. & Cymet, T.C. 2006, "Shin splints: painful to have and to treat", Comprehensive therapy, vol. 32, no. 0098-8243; 3, pp. 192-195.

Swanik, C.B., Lephart, S.M., Giraldo, J.L., DeMont, R.G. & Fu, F.H. 1999, "Reactive muscle firing of anterior cruciate ligament-injured females during functional activities", Journal of Athletic Training, vol. 34, no. 2, pp. 121-129.

Tabachnick, B.G. & Fidell, L.S. 2001, Using Multivariate Statistics, 4th edn, Allyn & Bacon, Boston.

Taimela, S., Kujala, U.M. & Osterman, K. 1990a, "Intrinsic risk factors and athletic injuries", Sports Medicine, vol. 9, pp. 205-215.

Taimela, S., Kujala, U.M. & Osterman, K. 1990b, "Stress injury proneness: a prospective study during a physical training program", International Journal of Sports Medicine, vol. 11, pp. 162-165.

Talcott, G.W., Haddock, C.K., Klesges, R.C., Lando, H. & Fiedler, E. 1999, "Prevalence and predictors of discharge in United States Air Force Basic Military Training", Military Medicine, vol. 164, pp. 269-274.

Taunton, J.E., Ryan, M.B., Clement, D.B., McKenzie, D.C., Lloyd-Smith, D.R. & Zumbo, B.D. 2003, "A prospective study of running injuries: the Vancouver Sun Run in training clinics", British Journal of Sport Medicine, vol. 37, pp. 239-244.

Taunton, J.E., Ryan, M.B., Clement, D.B., McKenzie, D.C., Lloyd-Smith, D.R. & Zumbo, B.D. 2002, "A retrospective case-control analysis of 2002 running injuries", British Journal of Sport Medicine, vol. 36, pp. 95-101.

Tenforde, A.S., Sayres, L.C., Sainani, K.L. & Michael Fredericson, M. 2010, "Evaluating the relationship of calcium and vitamin D in the prevention of stress fracture injuries in the young athlete: a review of the literature", PM&R, vol. 2, no. 10, pp. 945-949.

Thacker, S.B., Gilchrist, J., Troup, D.F. & Imsey, C.D. 2002, "The prevention of shin splints in sports: a systematic review of literature", Medicine & Science in Sports & Exercise, vol. 34, no. 1, pp. 32-40.

Thomas, J.R., Nelson, J.K. & Silverman, S.J. 2005, Research methods in physical activity, 5th edn, Human Kinetics, USA.

Tiberio, D. 1987, "The effect of excessive subtalar joint pronation on patellofemoral mechanics: a theoretical model", Journal of Orthopaedic and Sports Physical Therapy, vol. 9, no. 4, pp. 160-165.

Tiberio, D. 1988, "Pathomechanics of structural foot deformities", Physical Therapy, vol. 68, no. 12, pp. 1840-1849.

Tidball, J.G. 2005, "Inflammatory processes in muscle injury and repair", American Journal of Physiology, vol. 288, no. 2, pp. 345-353.

Touliopolous, S. & Hershman, E.B. 1999, "Diagnosis and treatment of compartment syndromes and other pain syndromes of the leg", Sports Medicine, vol. 27, pp. 193-204.

Tsai, W. C., Hsu, C. C., Chen, U., Chen, Y. J., 2006, "Plantar fasciitis treated with local steroid injection: comparison between sonographic and palpation guidance" Journal of Clinical Ultrasound vol. 34, pp. 12-16.

Tumia, N. & Maffulli, N. 2002, "Patellofemoral pain in female athletes", Sports Medicine Arthroscopic Review, vol. 10, no. 1, pp. 69-75.

Tweed, J.L., Avil, S.J., Campbell, J.A. & Barnes, M.R. 2008a, "Etiologic factors in the development of medial tibial stress syndrome: a review of the literature", Journal of the American Podiatric Medical Association, vol. 98, no. 2, pp. 107-111.

Tweed, J.L., Campbell, J.A. & Avil, S.J. 2008b, "Biomechanical risk factors in the development of medial tibial stress syndrome in distance runners", Journal of the American Podiatric Medical Association, vol. 98, no. 6, pp. 436-444.

Ullrich-French, S. & Smith, A.L. 2009, "Social and motivational predictors of continued youth sport participation", Psychology of Sports and Exercise, vol. 10, pp. 87-95.

van Gent, R.N., Siem, D., van Middelkoop, M., van Os, A.G., Bierma- Zeinstra, S.M.A. & Koes, B.W. 2007, "Incidence and determinants of lower extremity running injuries in long distance runners: a systematic review", British Journal of Sports Medicine, vol. 41, pp. 469-480.

van Mechelen, W., Hlobil, H. & Kemper, H.C.G. 1992, "Incidence, severity, aetiology and prevention of sports injuries. A review of concepts", Sports Medicine, vol. 14, pp. 82-99.

van Schie, C.H.M. 2005, "A review of the biomechanics of the diabetic foot", The International Journal of Lower Extremity Wound, vol. 4, pp. 160-170.

van Tiggelen, D., Wickes, S., Coorevits, P., Dumalin, M. & Witvrouw, E. 2009, "Sock systems to prevent foot blisters and the impact on overuse injuries of the knee joint", Military Medicine, vol. 174, no. 2, pp. 183-189.

van Tiggelen, D., Witvrouw, E., Roget, P., Cambier, D., Danneels, L., Verdonk, R. 2004, "Effect of bracing on the prevention of anterior knee pain - a prospective randomized study", Knee Surgery, Sports Traumatology, Arthroscopy; vol. 12, no.5, pp 434–439.

Vezina, M.J. & Hubley-Kozey, C.L. 2000, "Muscle activation in therapeutic exercises to improve trunk stability ", Archives of Physical medicine and Rehabilitation, vol. 81, no. 10, pp. 1370-1379.

Vickers, R.R. & Conway, T.L. 1983, The Marine Corps basic training experience: psychosocial predictors of performance, health, and attrition, Naval Medical Research and Development Command, Bethesda, Maryland.

Viitasalo, J. & Kvist, M. 1983, "Some biomechanical aspects of the foot and ankle in athletes with and without shin splints", American Journal of Sports Medicine, vol. 11, pp. 125-129.

Wang, A.A., Whitaker, E., Hutchinson, D.T. & Coleman, D.A. 2003b, "Pain levels after injection of corticosteroid to hand and elbow", American Journal of Orthopeadic, vol. 32, no. 8, pp. 383-385.

Wang, X., Wang, P. & Zhou, W. 2003a, "Risk factors of military training-related injuries in recruits of Chinese People's Armed Forces", Chinese Journal of Traumatology, vol. 6, no. 1, pp. 12-17.

Wearing, S.C., Smeathers, J.E., Urry, S.R., Hennig, E.M. & Hills, A.P. 2006, " The pathomechanics of plantar fasciitis", Sports Medicine, vol. 36, no. 7, pp. 585-611.

Wedderkopp, N., Kaltoft, M., Lundgaard, B., Rosendahl, M. & Froberg, K. 1999, "Prevention of injuries in young female players in European team handball. A prospective intervention study",
 Scandinavian Journal of Medicine & Science in Sports, vol. 9, pp. 41-47.

Westman, A.,linton, S.J.,.,Ohrvik, J., Wahlen, P & Lepert, J. 2008 "Do psycosocial factors predict disability and health at a 3-year follow-up for patients with non-acute musculoskeletal pain? A validation of the orebro musculoskeletal pain screening questionaire" European Journal of Pain, vol. 12, pp. 641-649.

White, S.C. & Lifeso, R.M. 2005, "Altering asymmetric limb loading after hip arthroplasty using real-time dynamic feedback when walking", Archives of Physical Medicine and Rehabilitation, vol. 86, pp. 1958-1963.

Whiting, W.C. & Zernicke, R.F. 1998, Biomechanics of musculoskeletal injury, Human Kinetics, USA.

Whittle, M.W. 2007, Gait Analysis: An Introduction, 4th edn, Butterworth-Heinemann, USA.

Wilk, K. & Clancey, W. 1991, "Medial collateral ligament injuries: diagnosis, treatment and rehabilitation" In Knee Ligament Rehabilitation, ed. R. Engle, Churchill Livingstone.

Wilkinson, D., Rayson, M. & Bilzon, J.L.J. 2008, "A physical demands analysis of the 24-week British Army Parachute Regiment recruit training syllabus", Ergonomics, vol. 51, no. 5, pp. 649.

Wilkinson, D.M., Blacker, S.D., Victoria L Richmond1, V.L., Horner, F.E., Rayson, M.P., Spiess, A. & Knapik, J.J. 2011, "Injuries and injury risk factors among British army infantry soldiers during predeployment training", Injury Prevention, vol. 17, pp. 381-387.

Willems, T. 2004, Intrinsic risk factors for sports injuries to the lower leg and ankle, Ghent University.

Willems, T.M., De Clercq, D., Delbaerea, K., Vanderstraetena, G., De Cock, A. & Witvrouw, E. 2006, "A prospective study of gait related risk factors for exercise-related lower leg pain", Gait & Posture, vol. 23, no. 1, pp. 91-98.

Willems, T.M., Witvrouw, E., De Cock, A. & De Clercq, D. 2007, "Gait-related risk factors for exercise-related lower-leg pain during shod running", Medicine & Science in Sports & Exercise, vol. 39, no. 2, pp. 330-339.

Williams, P.L., Warwick, R., Dyson, M. & Bannister, L.H. 1989, Gray's Anatomy, 37th edn, Churchill Livingstone, UK.

Wills, A.K., Ramasamy, A. & Etherington, J. 2004, "The incidence and occupational outcome of overuse anterior knee pain during army recruit training", Journal of the Royal Army Medical Corps, vol. 150, pp. 264-269.

Willson, J. & Davis, I. 2008, "Lower extremity mechanics of females with and without patellofemroal pain across activities with progressively greater task demands", Journal Clinical Biomechanics, vol. 23, pp. 203-211.

Willson, J.,D., Dougherty, C.P., Ireland, M.L. & McClay Davis, I. 2005, "Core stability and its relationship to lower extremity function", Journal of the American Academy of Orthopaedic Surgeons, vol. 13, no. 5, pp. 316-325.

Willson, J.D., Ireland, M.L. & Davis, I. 2006, "Core strength and lower extremity alignment during single leg squats", Medicine & Science in Sports & Exercise, vol. 38, no. 5, pp. 945-952.

Winter, D.A. 2009, Biomechanics and Motor Control of Human Movement, 4th edn, John Wiley, New Jersey.

Withnall, R., Eastaugh, J. & Freemantle, N. 2006, "Do shock absorbing insoles in recruits undertaking high levels of physical activity reduce lower limb injury? A

randomized controlled trial", Journal of the Royal Society of Medicine, vol. 99, no. 1, pp. 32-37.

Wolff, J. 1986, The Law of Bone Remodeling, Springer, Berlin Heidelberg New York.

Wolgin, M., Cook, C., Graham, C. & Mauldin, D. 1994, "Conservative treatment of plantar heel pain: long-term follow-up", Foot & Ankle, vol. 15, pp. 97-102.

Wong, L.S. & Martins-Green, M. 2004, "First hand cigarette smoke alters fibroblast migration and survival: implications for impaired healing", Wound Repair and Regeneration, vol. 12, pp. 471-484.

Wong, Y.S. 2007, "Influence of the abductor hallucis muscle on the medial arch of the foot: a kinematic and anatomical cadaver study", Foot & Ankle International, vol. 28, no. 5, pp. 617-620.

Woo, S.L., Debaski, R.E., Withrow, J.D. & Janaushek, M.A. 1999, "Biomechanics of knee ligaments", American Journal of Sports Medicine, vol. 27, no. 4, pp. 533-543.

Wrenn, R.N., Goldner, J.L. & Markee, J.L. 1954, "An experimental study of the effect of cortisone on the healing process and tensile strength of tendons", The Journal of Bone and Joint Surgery, vol. 36-A, no. 3, pp. 588-601.

Yates, B. & White, S. 2004, "The incidence and risk factors in the development of medial tibial stress syndrome among naval recruits", The American Journal of Sports Medicine, vol. 32, no. 3, pp. 772-780.

Yates, B., Allen, M.J. & Barnes, M.R. 2003, "Outcome of surgical treatment of medial tibial stress syndrome", Journal of Bone and Joint Surgery American, vol. 85-A, no. 10, pp. 1974-1980.

Yeung, S.S., Yeung, E.W. & Gillespie, L.D. 2011, "Interventions for preventing lower limb soft-tissue running injuries ", Cochrane Database of Systematic Reviews, [Online], no. 10, pp. Art. No.: CD001256. DOI: 10.1002/14651858.CD001256.pub2. Available from: http://www.thecochranelibrary.com.

Young, A. & McAllister, D. 2006, "Evaluation and treatment of tibial stress fractures", Clinics in Sports Medicine, vol. 25, no. 1, pp. 117.

Yuksel, O., Ozgurbüz, C., Ergun, M., Islegen, C., Taskiran, E., Denerel, N. & Ertat, A. 2011, "Inversion/eversion strength dysbalance in patients with medial tibial stress syndrome", Journal of Sports Science and Medicine, vol. 10, no. 4, pp. 737-742.