Examination of Interventions to Prevent Common Lower-Limb Injuries in the New Zealand Defense Force

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ABSTRACT The biomechanical mechanisms of lower-limb injuries in the New Zealand Defense Force were identified from the circumstances of the injuries, and injury prevention strategies that addressed these mechanisms examined for their applicability to a military setting. Many of the injuries were the result of rolling or twisting movements and ankle instability was a common causal factor. Ankle bracing and stability training were identified as the strategies that address this factor and are most likely to be effective in preventing the injuries. A successful intervention strategy must also take into account the particular requirements of the user group. Concerns with ankle bracing included ongoing costs, individual fitting requirements, and the inability to remain effective under extremes of physical activity and external conditions. Stability training was considered more appropriate than ankle bracing for the defense force. Stability training is low cost and has the ability to address the biomechanical mechanisms of several lower-limb injuries. However, it requires trialing in a military setting to assess the logistics of implementation and whether the reported sport-specific programs should be adjusted for the varied physical activities undertaken by military forces.

INTRODUCTION

Lower-limb injuries are a common problem for the physically active, and such injuries may result in diminished performance, reduced participation and, in the longer term, loss of function, chronic joint disease, and disability.[1,2] In the military setting, such outcomes translate to significant costs in terms of lost working and training days, increased attrition, and decreased deployment readiness.[3,4]

In common with other military forces,[3] the New Zealand Defense Force (NZDF) experiences a high incidence of lower-limb injuries (L. McKubre, NZDF, personal communication). In an attempt to reduce the occurrence and cost of these injuries, the NZDF commissioned a study to identify an effective lower-limb injury prevention strategy. The first stage of the investigation involved a descriptive epidemiological study of lower-limb injuries sustained by NZDF personnel, using incident data provided by the NZDF.[5] There were 1,116 lower-limb injuries sustained among the approximately 10,500 members of the NZDF active during the 11-month study period. The most common of these was ankle sprain (35%), followed by knee sprain (16%), indicating that priority should be given to addressing these injuries. Fractures, although comprising only 6% of lower-limb injuries, were also regarded as a priority because of the high medical and time-loss costs associated with these injuries. The descriptive epidemiological study also found that: (1) the most common activities being undertaken at the time of injury were rugby or individual sports such as running; (2) most injuries involved no other person; and (3) the most common mechanism of injury was overexertion because of an acute event (as opposed to cumulative loading).

Understanding the causes and mechanisms of injury is critical to the development of appropriate injury prevention programs.[6] Musculoskeletal injuries occur because forces experienced by muscles, bones, and other tissues exceed their mechanical capacity, in terms of load or loading rate. Identifying the biomechanical mechanism of particular injuries is therefore an important step in determining an effective injury prevention strategy. Such information allows a program to be tailored to the particular circumstances of an injury and identification of limitations and wider implications for any proposed approach.

As well as addressing the biomechanical mechanism of the injury, an effective injury prevention strategy must take into account the particular requirements of the user group.[7] In the context of lower-limb injuries sustained by military personnel, the injury prevention approach must remain effective under extreme levels of activity and a range of climate and terrain conditions, be appropriate for all personnel, and not adversely affect performance or increase risk of injury to other body regions. It must also be cost effective, compatible with existing training and operational requirements, and elicit a high level of compliance.

This article reports the results of the second stage of the investigation into reducing lower-limb injuries in the NZDF. The first stage described the epidemiology of the lower-limb injuries sustained within NZDF personnel in an 11-month period. The aims of the second stage were first to identify the biomechanical mechanisms of the common NZDF lower-limb injuries, and secondly to determine the prevention strategy with the most promise for being able to reduce the incidence of these injuries. The second aim was addressed by examining

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prevention strategies purported to target such injuries, both for their ability to address the mechanisms and for their applicability to a military setting. Although tailored to the NZDF's circumstances, this study's approach and findings may be applicable to other military forces with similar lower-limb injury problems.

METHODS

To determine the most likely biomechanical mechanisms of NZDF lower-limb injuries, the circumstances of these injuries were assessed and the literature searched for links between circumstances and mechanisms of injury. Information on the circumstances was obtained from injury narratives in the medical claim forms lodged for lower-limb injuries in the NZDF (Army, Navy, Air Force, and headquarters personnel, both regular members and recruits) between July 1, 2002 and May 31, 2003, and reported in Davidson et al. 2008.[5] Key journals and electronic databases of published literature (Medline, Scopus, Web of Science) were searched for reports identifying the biomechanical mechanisms of lower-limb injuries. The reference and citation lists of the reports identified were searched for further relevant studies.

Guided by the results of the examination of the circumstances and likely biomechanical mechanisms of NZDF lower-limb injuries, key journals and databases were searched for literature on potential strategies for preventing the injuries of concern. Studies assessing injury incidence were included if they employed a controlled trial study design. The search focused initially on lower-limb injury prevention strategies assessed in military settings, and was then broadened to include sports applications. The reference and citation lists of the reports identified were also searched for further relevant studies. To determine the strategy most likely to be effective in reducing the incidence of NZDF injuries, both the biomechanical basis and the practicality (cost effectiveness, appropriateness, likelihood of compliance, and the ease with which they could be implemented in the regular NZDF training program) of the options were examined, and any potential adverse effects were identified. The advantages and disadvantages of each of the strategy options were discussed with the NZDF and feedback from this organization was crucial to the selection process.

FINDINGS AND DISCUSSION

Mechanism of Injury

Sprains

The most common lower-limb injury identified in the epidemiological study on NZDF personnel was ankle sprain.[5] These sprains comprised 15% of the 2,575 injuries documented and 35% of the 1,116 lower-limb injuries. The diagnosis codes used in the NZDF's medical claim forms did not classify ankle sprains further, but analysis of the narratives of the injury events revealed that 41% of these sprains occurred while the claimants were participating in running activities such as jogging or cross country (29%) or in sports such as rugby (13%) involving pivoting and cutting movements, and that only 11% of ankle sprains involved contact with another person.[5] These circumstances are characteristic of inversion sprains.[8] Claimants often described the injury as involving "rolling" or twisting of the ankle or contact with uneven ground surfaces. Such perturbations will result in injury if they are sufficient to overwhelm the stabilizing mechanisms of the ankle joint.

Stability is defined as the ability of a system to return to the original position once perturbed by an external force. Stability at the ankle is conferred by the bones, ligaments, and musculotendinous structures of the joint.[8] The ankle is most stable in dorsiflexion when its bony architecture provides protection against injurious movement. As the ankle moves to plantarflexion, however, the ligamentous and musculotendinous structures assume increased responsibility for supporting the joint. Ligaments act to stabilize the joint during stance or quiet activity, but muscles and tendons are better able to accommodate the large forces experienced during dynamic activities and become the main determinant of ankle stability under these circumstances.[9] During the running and turning activities identified as giving rise to ankle sprains among NZDF personnel, ankle stability will be conferred largely by the musculotendinous structures. Under these circumstances, an excessive inversion of the foot or twisting of the leg, beyond the capacity of the ankle evertor muscles to control or accommodate, will result in the joint becoming unstable and the ligaments or muscles being stretched beyond their normal range and damaged.[9]

Knee sprains were the second most common lower-limb injury identified in the NZDF,[5] with 56% of these diagnosed as sprains of the medial collateral ligament. As for ankle sprains, over 40% of knee sprains occurred while running (23%) or playing rugby (18%), and very few (7%) were the result of contact with another person.[5] Claimants commonly described these injuries as resulting from a twisting of the knee, often after landing badly or changing direction or speed while running.

The knee is a complex joint, acting as a hinge between the femur and tibia but also capable of rotating and pivoting movements. Its bony architecture provides little stability. Instead, stability at the knee is largely conferred by the ligaments,[8] though with musculotendinous structures having an increased role in supporting the knee and preventing injury under dynamic conditions.[10] The complexity of movement and lack of bony support of the knee, coupled with its position between the long lever arms of the femur and tibia, make the knee ligaments particularly vulnerable to injury arising from excessive or abnormal motions. Such motions include sudden twisting maneuvers and excessive or asymmetric muscle contractions. Further, since the joints of the lower limb are mechanically linked, the landing and turning activities that can give rise to ankle sprains also subject the knee to high loading and increased risk of injury, and forces and motions generated at one of these joints in response to such activities will be transmitted to the other.[9]

Several studies have linked muscle fatigue with increased risk of sprain injury.[11,12] Since military training and operations can involve high levels of physical activity, muscle fatigue is likely to be a factor in many of these situations. Muscles that span the ankle and knee joints are the prime providers of dynamic stability, and when these tissues are fatigued because of prolonged training or vigorous exercise, joint stability control will be reduced.

Fractures

All 62 lower-limb fractures identified in the epidemiological study of NZDF personnel were sustained at or below the level of the knee.[5] Fractures to the foot/toes comprised 42% of these lower-limb fractures, tibia/fibula fractures comprised 37%, and ankle fractures 20%. Almost half of all lower-limb fractures involved forces generated by the individual alone, because of either internal factors (e.g., excessive muscle force) or impact with the ground.[5] Stress fractures accounted for 23% of all lower-limb fractures and 50% of lower-leg fractures and were most commonly associated with repetitive weight-bearing activities such as strenuous running or prolonged walking. Nonstress fractures were more likely to be sustained after landing awkwardly or twisting the ankle or during intense physical activity. Such circumstances are similar to those giving rise to ankle and knee sprains.

Stress fractures, overuse injuries of bone common among athletes and military personnel,[3] can arise when bone is exposed to repetitive mechanical loading to which it is not accustomed.[13] Such loading elevates the strains on bone and stimulates bone remodeling, involving first bone resorption and then the formation of new bone.[13] Factors that either reduce bone strength or increase the load applied to bone can increase the risk of developing a stress fracture. If repetitive loading continues through the remodeling process, for example, the new bone produced may be weakened and more susceptible to damage.[11,13] Muscle activity normally serves to attenuate the impact of loading on bone and the intensity of bone strain. Under high levels of repetitive activity, muscles can become fatigued and their capacity to provide this shock attenuation will be reduced.[11,12]

Summary

Ankle sprains were the most common lower-limb injury sustained within the NZDF. On the basis of the injury circumstances, most were identified as inversion sprains. During the dynamic, forefoot-landing activities being undertaken at the time of these injuries, muscles will be the prime providers of joint stability, at both the ankle and knee. The joints of the lower limb do not operate in isolation but are mechanically linked, with the ankle joint being the body's primary interface between the ground and the knee. On the basis of this, and taking into account the similar circumstances giving rise to ankle sprains, knee sprains, and nonstress fractures, ankle instability was seen as potentially a common causal factor in many of the injuries documented. Muscle fatigue reduces the capacity of muscles to provide both stability and shock attenuation, and is also likely to contribute to lower-limb sprain and fracture incidence in the military.

Prevention Strategies

Our approach to determining the most promising injury prevention strategy for reducing lower-limb injuries among military personnel was to identify the most likely mechanism of the most common injury (ankle sprain), and then to examine the circumstances and mechanical principles that the more common injuries (ankle sprain, knee sprain, fracture) shared. This approach was expected to enable the identification of prevention strategies which, while primarily targeting ankle sprains, had the potential to reduce knee sprains and fractures as well. It should also alert us to strategies that reduce ankle sprains but may actually increase the risk of sustaining other injuries. Such strategies would clearly not be appropriate.

Many of the lower-limb injuries sustained by NZDF personnel were the result of rolling or twisting movements that produced forces and torques that overwhelmed joint stability mechanisms. Controlling and reducing these movements should, then, decrease the risk of injury. As ankle sprains were the most common injuries sustained, and ankle instability appears to be a factor in many of the injuries documented, we focused on strategies purported to improve lateral stability at the ankle and so restrict excessive inversion and reduce the risk of injury. Such enhanced stability can be achieved passively, through using external restraint devices to support the joint and limit its range of motion, or actively, through specialized training to improve control of the muscles stabilizing the joint.[14] Other interventions not specifically targeted at improving ankle stability but commonly used in sporting and military settings to reduce lower-limb injuries were also examined.

Passive Interventions

External restraint devices commonly used to support the ankle, and reduce injury to the joint, include ankle taping and ankle braces. These external supports appear to operate primarily by constraining joint range of motion, particularly inversions.[14] They have also been hypothesized to elicit their effects by improving proprioceptive function[15] and by holding the foot in a relatively everted position, i.e., further from inversion.[16] In controlled trials, ankle braces have been reported to reduce ankle injury rates in sports such as soccer[15] and basketball,[17] in parachute jump landings during paratrooper training,[18] and for military police undergoing an advanced training course.[19] Relative risks ranging from 0.32 to 0.68 have been calculated from these studies.[20]

The appropriateness and cost effectiveness of universal tape or brace use by ground military forces has been questioned, however. Physical training within military forces can be vigorous and of long duration, and braces have been shown to break down during such training in the infantry.[19] Maximum protection and compliance from brace wearing also requires the brace design to be appropriate for the anatomic structure of the individual and comfortable to wear.[21] Such a requirement for individual fitting and assessment may not be compatible with mass supply to military personnel. Taping, which is applied immediately before undertaking a period of physical exercise, would also present logistic and economic difficulties in a military training or operational setting. Recent biomechanical studies suggest also that the use of external ankle supports may transfer the load to the knee, placing it at increased risk of injury. It has been reported, for example, that rotational torque at the knee during drop landings or trunk turning movements on one leg is higher when ankle bracing is worn.[22,23] Excessive knee internal rotational and valgus moments have been reported as the main causes of anterior cruciate ligament injuries.[24]

Shoes and boots provide a form of ankle support and restraint and therefore could have a role in reducing the incidence of ankle sprains and other lower-limb injuries. Ankle injury incidence among basketball players, however, has been found to be unaffected by the wearing of high- or low-top shoes.[25] Similarly, studies examining injury incidence among military recruits wearing either three-quarter-high basketball shoes or lightweight full-height infantry boots found no differences between groups in the number of ankle sprains sustained.[26] These findings are, perhaps, not unexpected as footwear does not support ankle structures to the same extent as braces or taping. The primary function of military footwear, in particular, is to protect the foot from direct trauma because of factors such as rough terrain and the elements. Providing ankle support and shock absorption are secondary, and often competing, functions.[3]

Active Interventions

The muscles of the lower limb provide not only the means of movement but also shock attenuation and stability. The functional activation of these muscles is integral to the prevention of injury during dynamic activities. In particular, cocontraction of the muscles on both sides of a joint is thought to assist in stabilizing the joint and reducing the load on the ligaments.[27] At the ankle, dynamic stability will be provided by the activity of the main evertor (peroneal) and invertor (tibialis anterior) muscles.[9]

Training programs that improve muscle control around the ankle joint should allow more effective responses to perturbations, thus reducing ligament loading and the likelihood of injury. Such training programs, which we term "stability training," include unipedal balancing exercises and exercises conducted while standing on an unstable base. This is commonly a "wobble" or "balance" board but can also be, for example, a foam pad or mini-trampoline. Typically, such programs involve 10- to 20-minute exercise sessions carried out 3–5 days a week. They have been reported to improve balance and discrimination of inversion movements[28,29] and decrease the reaction times for the foot evertor and invertor muscles in response to perturbation.[30,31] These findings suggest the exercises may operate by improving awareness of foot position and orientation, or the person's ability to cocontract their lower-limb muscles and thereby enhance lower extremity stability. Stability training has recently been reported to selectively activate muscles to provide increased support to the knee joint.[32] In controlled trials, stability training has been shown to reduce the incidence of a number of lower-limb injury types, including both ankle sprains[28,33,34] and knee injuries,[28,35] in several sports, but has not been reported in a military setting. The rate of ankle sprain injuries was reduced by 30–40% in these studies. As all injury data were collected during or for a brief period after the intervention, it is not possible to know how long the benefits of stability training are retained if the training ceases. There was no evidence that stability training increased the risk of injury to other body regions.

Other Interventions

We also examined interventions not specifically targeted at improving ankle stability but nevertheless commonly used in sporting and military settings to reduce lower-limb injuries.

There has been much research on the effects of different insoles in reducing lower-limb injury. Both shock-absorbing and custom-made biomechanical insoles have been examined for their ability to reduce tissue loading and lower-limb injuries in a military setting. Shock absorbing insoles act to attenuate vertical impact peak forces.[36] Large-scale controlled trials with military recruits, however, have not demonstrated a beneficial effect for these devices, over cheaper standard-issue insoles, on the incidence of lower-limb injury.[37,38] The evidence for a reduction in stress fractures and other injuries through the use of biomechanical insoles, designed to realign the foot and leg and improve foot biomechanics, is equivocal.[39,40] Such devices reduce tibial strains and strain rates during treadmill walking in boots, but not in shoes or during treadmill running in either boots or shoes,[41] suggesting that they may have the potential to reduce the incidence of stress fractures among infantry recruits only during training activities that involve walking in boots. Comfort and tolerance issues that will affect compliance were also reported. In Finestone et al. 1999[39] for example, 23% of the subjects dropped out of the study citing dissatisfaction with the orthotic allocated.

Pre- and postexercise stretching is widely employed by athletes and during military training, with one of the purposes being to reduce the risk of injury. There is conflicting research evidence for this claim, however, and still debate over the injury benefits and risks associated with stretching.[42] In a randomized controlled trial with Australian Army recruits, preexercise stretching did not produce a reduction in the number of soft-tissue or bone injuries to the lower limbs.[43] Other studies evaluating the effects of stretching on military recruit injuries have reported reductions in some musculotendinous and overuse injuries but not in the injuries of interest here, i.e., ankle sprains/strains, knee sprains/strains, and lower-limb fractures.[44,45]

Low aerobic fitness is a risk factor for injury, and it has been shown that recruits with lower levels of physical fitness on entry have a higher risk of being injured during training.[3,4,13,43] In a recent study, recruits identified as unfit who undertook a fitness conditioning program (18 days on average) before entering standard training had lower injury risk and attrition levels than low-fitness recruits who did not precondition.[46] Any intervention program should therefore include a component that improves physical fitness.

Injury risk increases with increased frequency or duration of running and other weight-bearing activities. Several studies have examined the ability of modified military training programs to reduce injury while still maintaining required physical fitness levels.[3,4,47] Modifications include gradually increasing the duration, frequency, and intensity of organized running as recruits progress through the programs, or substituting high impact exercises with activities such as interval training and deep water running. Various combinations of these approaches have been reported to reduce overuse and stress fracture injuries.[3,47] At the time the epidemiological study of NZDF lower-limb injuries was conducted (July 2002–May 2003),[5] the NZDF had already incorporated several of these components into its training programs. However, there are economic and logistic restraints, for example, on the duration of training programs. As for all military forces, the NZDF needs to be able to bring its recruits to deployment readiness within a cost-effective timeframe.

Summary

Our search of the literature identified passive and active interventions purported to reduce lower-limb injury incidence by improving stability at the ankle as well as others that target different factors. Of these, the strategies that had the best evidence of effectiveness were ankle bracing and stability training. However, logistic concerns were identified in relation to the universal introduction of ankle bracing to military personnel. These concerns included ongoing costs, individual fitting requirements, equipment breakdown, and transference of the mechanical load.

CONCLUSIONS

The aims of this investigation were first to identify the biomechanical mechanisms of the common NZDF lower-limb injuries, and second to determine the prevention strategy with the most promise for being able to reduce the incidence of these injuries.

The most common lower-limb injury previously identified among NZDF personnel was ankle sprain, followed by knee sprain, and fracture.[5] In the present study, analysis of the circumstances and mechanisms of these injuries suggested that lateral ankle instability was a common causal factor in many of the injuries. Injury prevention strategies that addressed this were examined to identify the most appropriate approach for reducing lower-limb injuries among military personnel. The strategies with the best evidence of effectiveness were ankle bracing and stability training. However, a successful intervention strategy must address not only the biomechanical basis of the injury but also the specific requirements of the intended user group. Although ankle bracing may indeed address the mechanism of ankle sprains and reduce ankle injury risk, several issues precluded recommending this strategy to the NZDF to reduce lower-limb injury incidence. To maximize compliance and minimize training and operational disruption, the recommended option should not require individual fitting and should operate over the full range of activities undertaken. Other issues identified with ankle braces included ongoing cost and, of particular concern, evidence that these devices may increase load, and therefore potentially injury risk, to other lower-limb structures.

A training intervention, and stability training in particular, was seen as a more effective and viable option. Stability training brings about internal changes in the way the body copes with perturbation and therefore the benefits remain with the individual at all times and in all situations, but the mechanism by which it operates has not yet been fully elucidated. The exercises may serve to improve control of the muscles of the knee directly. However, even if they act predominately on muscles at the ankle (some of which also span the knee), the improved balance so achieved would lead to reduced loading of both the ankle joint and the mechanically connected knee joint. Improved coordination of the ankle musculature could also reduce impact stresses transmitted through the bones of the lower limb, which have been implicated in the generation of stress fractures. Stability training, by increasing control of the muscles at the ankle joint (at least), is also thought to minimize muscle fatigue, which has been linked to all three injuries of interest.

Stability training is a low-cost intervention (balance boards can be purchased for approximately NZ $60 each) that improves physical fitness and addresses the incidence of several of the common NZDF lower-limb injuries. As it has not been reported in a military setting, however, there are logistic and effectiveness issues that will need to be resolved before widespread adoption by military forces can be recommended. These include determining the feasibility of incorporating the exercises into existing physical training sessions and whether the intensity and duration of reported sport-specific stability training programs should be adjusted for the varied physical activities undertaken during military training. However, compliance should not be an issue within the military environment and, as many military forces already use balance boards and stability exercises for injury rehabilitation, it is expected trainers will be familiar with the general concept and conduct of balance exercises and only require education on the specific exercises.

If the logistics prove feasible, stability training has the potential to have a major impact on lower-limb injury incidence in military forces. We therefore recommend this intervention for trialing in a military setting. A trial should involve researchers and, for example, exercise physiologists working alongside military trainers to determine the mix of exercises (derived from published programs) most appropriate for this particular setting. As we have previously shown that the injury rate for recruits is more than five times that for trained personnel,[5] assessment during recruit training should be the priority.

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