A research pilot project to test the efficacy of current pedorthic practices in the Canadian Forces

Thomas W. Pelham\textsuperscript{a}, Peter R.T. Rowe\textsuperscript{b}, Michael G. Robinson\textsuperscript{c} and Laurence E. Holt\textsuperscript{d,∗}

\textsuperscript{a}Canadian Forces Base, Shearwater, Nova Scotia, Canada
\textsuperscript{b}Canadian Forces Health Services Group Headquarters, Ottawa, Ontario, Canada
\textsuperscript{c}Faculty of Kinesiology, University of Calgary, Calgary, Alberta, Canada
\textsuperscript{d}School of Health and Human Performance, Dalhousie University, Halifax, Nova Scotia, Canada

Abstract. Impact loading is a major factor in the high prevalence of musculoskeletal injuries among military personnel during operational tasks. One of the therapeutic purposes of a pedorthic approach is to attenuate impact load through footwear and supportive device cushioning. The following research pilot project attempts to investigate this relationship. Vertical acceleration was collected at the fourth lumbar level in 30 members of the Canadian Forces (CF) during two ladder descents on a CF warship. Body weight, time of descent, and a description of footwear and any additional supportive appliances were also collected. None of the evaluated variables were significantly different between members wearing standard issue footwear and medically prescribed footwear and supportive devices. Although the results of this research pilot must be viewed with caution, the preliminary findings of this pilot tends to suggest that the current pedorthic practices may not effectively reduce peak impact forces at the fourth lumbar level of the spine among CF personnel during a selected naval activity.

Keywords: Orthotics, footwear, shock attenuation, naval operational task

1. Background

Currently, in the Canadian Forces, as in civilian practice, a variety of custom footwear and support devices (CFSD) are prescribed by health professionals for members of the Canadian Forces (CF) diagnosed with a variety of painful and dysfunctional conditions. One of the basic purposes of a pedorthic intervention is shock absorption. However, little objective data exists regarding the efficacy of these appliances within the military milieu, particularly the highly unique naval environment.

Given the fact that a prescription for a CFSD requires a medical diagnosis, it is quite surprising to find that in both civilian and military practice, there is often no comprehensive assessment procedure, or summary follow-up information on the short, or long-term benefits/shortcomings of this intervention approach. Nor is there any information on the negative, or positive outcomes of CFSD with CF members, particularly profiles of CF members currently wearing CFSD, although some preliminary data is now being captured. This data is very important, and may help in the identification of indicators that could be applied in the assessment procedure for CFSD with potential recipients. In the unique environment of a warship, most activities of CF members involve high impact accelerations (forces) during both horizontal and vertical travel on steel surfaces. Most evident while descending any of the steep ladders of most warships of the CF. Repetitive impacts on joints and soft tissues are significant and accumulative. Attenuation of these forces would be beneficial. Hamill [6] has found that insufficient shock attenuation

∗ Address for correspondence: L.E. Holt, PhD, School of Health and Human Performance, Dalhousie University, Halifax, Nova Scotia, Canada B3H 3J5. Tel.: +1 902 494 1151; Fax: +1 902 494 5120; E-mail: Larry.Holt@dal.ca.

1051-9815/06/$17.00 © 2006 – IOS Press and the authors. All rights reserved
can have severe consequences on the musculoskeletal system leading to various overuse injuries. He suggests that external factors including: speed of movement, foot-surface interface, and footwear significantly influence outcomes.

Footwear and other CFSD with features and materials that emphasize cushioning have been suggested to be important in energy dissipation, reducing compression forces, controlling acceleration/deceleration and the perceived feeling of discomfort [5]. The effect is to reduce insults to the bones and soft tissues of the body. Although cushioning may be a key design consideration for injury prevention, supportive proof of its efficacy is lacking [23]. More precisely, within the population under study in this project, there is no research data as to the effectiveness of CFSD on CF personnel serving on warships.

In the only Canadian study involving CF personnel, Mündermann et al. [17] investigated the effectiveness of inserts in 206 military personnel in reference to injury control and perception of comfort. These Canadian researchers suggested that when insert selection is based on the specific anthropometric characteristics of the subject, they can improve the perception of comfort and decrease injury frequency in a military population. However, there are several limitations in this study. First, a variety of shoe inserts were given to subjects, no objective mechanism of determination, which inserts designs were superior and which inserts were ineffective was incorporated into the design of the study. Secondly, although a preliminary anthropometric assessment was done for each subject, evaluation of effectiveness of insert was through subjective questionnaire, no follow-up biomechanical assessment was conducted. Finally, subjects of the study were all members of an army unit, generalizing the findings of the study to Air Force, or Navy units would be inappropriate.

Given that millions of dollars are spent each year within the CF for these devices, this intervention has become a controversial and debatable therapeutic approach. The objective of this pilot project is to determine the effects of CFSD on impact forces (shock attenuation) at the fourth lumbar level, during ladder descent by military personnel on a Canadian warship.

2. Setting and method

The multi-role patrol frigate and its officers and crew, HMCS Ville de Québec (VdQ) were used in this pilot project. Subject matter experts recommended using the main forward (bow) ladder from 2nd and 3rd deck (11 footfalls). It is a ladder with a heavy volume of traffic, and typical of a CF warship ladder, steep with a narrow entry clearance.

Thirty (18 men and 12 women) active duty CF members of the VdQ volunteered to serve as subjects in this study that received approval from the CF Health Services Centre (Atlantic) Ethical Committee.

Prior to testing, each member was asked specific questions regarding the use of prescribed CFSD. A CFSD was defined as a prescribed custom boot (a boot that was given to a member by a pedorthic professional), custom orthotic, or an off-the-shelf insole. The appliance(s) have been prescribed by a health professional as an intervention for a medical condition. CFSD are usually approved to members with foot, ankle, knee, hip, or back pain, as well as, members with pes cavus, pes planus, abnormal gait and leg length differences. CF personnel are routinely prescribed orthotics when medically indicated. In the past, military and civilian health professionals working for the CF have prescribed CFSD for a variety of conditions including: plantar fasciitis, heel spurs, metatarsalgia, Patella Femoral Syndrome, Sciatica, Diabetes, and various arthritic conditions.

Following the interview, the advanced, customized Dalhousie Sport Science Laboratory accelerometer (padlog) was attached to the fourth lumbar level (L4) of the member. Kaufman et al. [10] has used similar accelerometers for gait analysis/injury prevention research with American Navy Sea, Air, and Land (SEAL) candidates. Indeed, accelerometry is the method of choice among researchers exploring shock attenuation [6,16].

The profile of musculoskeletal injuries is different between Army and Navy units. In an extensive study, Jones et al. [9] clearly showed that lumbar back injuries were the major musculoskeletal injury group among American Navy personnel versus lower extremity musculoskeletal injuries in Army personnel. Therefore, we looked at shock attenuation at L4. In one closely related study, Larsen et al. [13] found less back and lower extremity problems among Danish military conscripts after 3 months of custom biomechanic shoe orthoses use versus controls.

In our pilot, members descended the ladder twice. Along with time of descent, acceleration data was collected in the y-axis, or vertical direction. This quantification approach has been used by Ogon et al. [23] where shock transmission (acceleration at the third lumbar level) was collected while healthy subjects jogged...
wearing a variety of CFSD, or barefoot. These researchers found that peak acceleration was significantly less with all inserts versus barefoot jogging. However, for the purposes of this pilot, we also recorded the body weight of all participants and converted the accelerometric data using Newton’s second Law of Motion (F = m x a) to assess shock attenuation.

Supporting this approach are two principles: First, a regular application of increased force may cause micro-trauma, and over time lead to major structural macro-trauma. Secondly, without a mechanism to counter and reduce (attenuate) these forces, various pathological conditions could develop, such as bone and joint surface degeneration, soft tissue damage and dysfunction. These conditions can lead to specific and general disability.

Peak accelerations were determined for each trial for each participant, and data was converted to peak impact force (Newtons = N). The member’s impact score was the mean of the two trails. The mean peak impact force for each group was calculated.

3. Findings

The acceleration curves were clear with a high degree of resolution, and individual impacts were easily determined. From general observations, it would appear that intra-subject variability was low, whereas, inter-subject variability was high. In other words, each member was consistent in the strategy used to descend, but it was unique (spinal posture) to that person.

Based on the results, subjects were categorized into two groups: Members with no CFSD (Group A) and members with at least one CFSD (Group B). Members of Group A wore standard issue sea boots with no supportive devices. Group B members were found wearing at least one of the following: Custom boots, custom orthotics, or off-the-shelf insoles. In all cases, a medical officer prescribed the CFSD. All members in Group B had worn the CFSD for at least 3 months. The characteristics of groups are summarized in Table 1.

In Group A, the mean peak impact force (maximum amplitude during contact) at the L4 level while descending the ladder of the ship was 238.38 N, (SD, 66.1 N), males 254.92 N, females 215.74 N, and Group B, 284.97 N (SD, 74.7 N), males 284.21 N and females 286.32 N. Although these compressive loads were well below the National Institute for Occupational Safety and Health (NIOSH) maximum permissible limit for manual lifting [21], the mean load produced by members of Group B does exceed the values found at the third lumbar in a number of poor static work postures [30].

In addition, although no statistical differences were found, it may be due to the large SD found, particularly in Group B. However, this does not diminish the fact that the mean value for peak impact force for Group B is 46.59 N, or 19.5% larger than Group A. This raises questions regarding the impact absorbing ability of the CFSD prescribed to members of Group B.

Given Newton’s second law, these peak impact force values are related to the weight of members of the groups, members of Group B are heavier, on average than their counterparts in Group A. More specifically, both males and females in Group B were heavier (males 16.4%, females 11%) than their counterparts in Group A.

A simple regression analysis peak impact force versus weight found no relationship (R-squared = 0.048; p = 0.3669) in Group A, and no relationship (R-squared = 0.057; p = 0.4782) in Group B. As well, no relationship was found between peak impact force versus sea duty (R-squared = 0.116; p = 0.3058), or age (R-squared = 0.113; p = 0.3116) in Group B. Relationships were found between peak impact force and peak acceleration (R-squared = 0.565; p = 0.0002) in Group A, as well in Group B (R-squared = 0.613; p = 0.0044). The mean peak acceleration for Group A was 2.94 G (SD = 0.515) versus Group B, 3.14 G (SD = 0.917) a 0.2 G, or 6.8% difference. These results raise more questions than answers, however, they lead to the tentative suggestion that CFSD do not influence (attenuate) the weight factor in the impact force equation.

Therefore, again addressing Newton’s second law, the findings of the regression analysis would suggest that peak impact force may have more to do with the generation of peak acceleration during the descent, and a consequence of the behavior of the member (i.e., poor method of descent). In that case, a technique modification would be a more appropriate intervention than a CFSD. In either case (weight as the major factor, or skill) CFSD as the first line of intervention for a lumbar spine condition would appear not to be the best choice.

No notable differences were found between mean total time of descent for Group A, 4.55 seconds (SD = 1.01) and Group B, 4.78 seconds (SD = 0.93) over the 2 trials. That is, on average members traveled down the ladder at a similar speed, suggesting, given all the facts discussed above, the various variables related to loading
Table 1

<table>
<thead>
<tr>
<th>Group</th>
<th>Males</th>
<th>Females</th>
<th>Weighta (Kgs)</th>
<th>Weightb (Kgs)</th>
<th>Sea dutyc (years)</th>
<th>Age (years)</th>
<th>Trade: Standingd</th>
<th>Trade: Sittingd</th>
</tr>
</thead>
<tbody>
<tr>
<td>Group A</td>
<td>84.1</td>
<td>76.4</td>
<td>80.8</td>
<td>(14.8)</td>
<td>4.7</td>
<td>29.7</td>
<td>42%</td>
<td>58%</td>
</tr>
<tr>
<td></td>
<td>(N = 19)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Group B</td>
<td>97.9</td>
<td>84.8</td>
<td>93.2</td>
<td>(4.6)</td>
<td>7.96</td>
<td>36.1</td>
<td>64%</td>
<td>36%</td>
</tr>
<tr>
<td></td>
<td>(N = 11)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Notes: 
a Mean (Standard Deviation = SD) weight of males, or females within group. b Mean (SD) weight of males and females within group. c Within group mean (SD): Total cumulative time at sea. d In the opinion of the authors, trades of members were classified as standing, or sitting, if tasks of the reported trade required 80%, or greater cumulative task time in a standing, or sitting position.

Sitting trades were: Maritime surface officer (deck officer), finance clerk, medical technician, naval combat information operator, and naval electronic sensor operator. Standing trades included: Boatswain (deck crew), hall technician, marine electrician, naval electronics technician, naval weapon technician, steward, and supply technician.

should be comparable between the groups. This information provides further evidence that current CFSDs used in the CF are not effective for shock attenuation (cushioning) of the lumbar spine region.

Although the data represents a limited number of members, and as mentioned above, a high level of inter-subject variability was found with the acceleration curves, the researchers observed several commonalities in movement patterns among the members:

1. The sequence of stepping was similar between members – managing the first step was achieved by leading with the right foot following with the left, placing both feet on the first tread, then pivoting, (facing the hatch) and processing down the ladder with single footfalls (one per step) till termination with both feet on the lower deck.
2. All descents were of a closed kinetic nature. Although there was some grabbing of the overhang, it was only briefly, and not during a period of peak impact acceleration.
3. There were no cases of full foot/tread contact during descents.
4. In all cases, lower limb joint movements during descents were limited (reduced active range of motion of ankle, knee and hip joints). A possible explanation may be the fact that the spine was moving through excessive amounts of extension and rotation as the member moved through the hatch (narrowest section of the descent). From a kinesiological standpoint, we suggest that in these awkward postures, hips are extended, the body’s center of mass is posterior, and as the member attempts to maintain balance without falling towards the ladder, he/she will limit the movements of the knees and ankles (stiff leg strategy). Conversations with members found that they learned the stiff leg strategy during sailing in stormy winter weather in the North Atlantic. Although the stiff leg strategy may keep the member from falling during severe sea states, it generates increased kinetic energy (shock) through the joints of the body.

Finally, in the confined spaces of a ship, asymmetric working postures are common. Monitoring the activities of workers, van Wendel et al. [29] found 38% of the worktime was spent in awkward postures of the back, resulting in 8 of 10 workers complaining of back pain. Correct ergonomic designs may not always be possible due to military operational requirements. From observations during the pilot this appears to be the case during a ladder descent in a CF warship.

As mentioned above, during all trials members maneuver the narrow hatch and ladder by aligning their back to the ladder (facing the opposite bulkhead), and at the narrowest level of the ladder cleared the space by extending and rotating their spine. This strategy will increase the shear load applied to the lumbar spine. Yang and Ruiting [31] found that the Pars Interarticulars of the 5th lumbar vertebra receives 73% of the shear load during movements involving an extension of the spine compared to 27% during correct (erect) spinal posture. The risk of a fracture of this structure is very high, particularly, in sports involving extension postures such as volleyball; fractures are high [31]. It is not unreasonable to suggest that during these awkward postural maneuvers, the soft tissue supportive structures of the lumbar spine are vulnerable to injury and not efficient in aiding the lumbar spine against insults of compressive loading.
4. Discussion

The occupational lifestyle of military personnel serving with Navy units are physically stressful. Members of a Navy unit face a number of physically challenging tasks while onboard, particularly at sea. At minimum, they must climb on wet and slippery steep ladders, stand and work on cold steel decks, and sometimes work at great heights in a pitching and rolling ship in stormy weather. At the other end of the spectrum, members of a Navy unit must travel to (usually up/down ladders), and fight shipboard fires in small, confined compartments while wearing protective equipment [2]. They must be able to perform all duties and tasks with speed and efficiency. Indeed, the operational and occupational physical demands of the duties and tasks of naval personnel are great.

Research conducted by the Naval Health Research Center in San Diego found that 70% of duties and tasks performed by American Navy personnel were physically demanding [22]. Within the Canadian Navy, all members, regardless of rank are required to have the physical capacity to meet the physical demands of general military duties and tasks. For example, all, particularly CF personnel serving with Navy units, including officers must be able to lift and carry heavy loads up and down ship ladders [2]. Training and testing of this operational task (i.e., sea evacuation task) is carried out regularly. Moreover, all CF personnel must meet a minimum physical fitness standard for the sea evacuation task: “carry one end of a stretcher bearing 80 kgs up and down a ship’s ladder” [2]. During an onboard emergency, or search and rescue operation the survival of an individual may depend on a member’s capacity to perform this task. However, performing this task can generate large shear and compressive forces on the lumbar spine.

Conversations with experienced CF personnel who have served with Navy units leads to the suggestion that manual material handling is very common while traveling on ship ladders during normal operations. Most members suggested that 80% of the trips on ladders involves manual material handling. Indeed, the majority of naval personnel consider lifting and carrying activities central in most operational duties and tasks. Again, these activities can place physical stress on the lumbar spine.

Descending a set of stairs has been shown to produce larger joint moments around the weight-bearing joints than during level walking [1]. Lee et al. [14] found that biomechanical loading increased with an increase in speed, or ladder grade, and there was a greater displacement of the center of mass posterior. This differential is more pronounced while working on ships. Torner et al. [26] found many of the activities performed by Swedish fishermen at sea on trawlers were related to high musculoskeletal loads, particularly compression at the lumbar vertebral level. Heus et al. [8] found energy expenditure was appropriately 30% higher for the same activity on a moving platform versus a stable stationary condition. At sea, individuals can experience high accelerations, particularly at the pelvis, due to water action that can result in severe human injuries [32].

Most naval activities are physically demanding, requiring full weight bearing, usually on steel decks, and performed at high tempo. These closed kinetic activities have the potential to overload the musculoskeletal system and overuse musculoskeletal syndromes can result. Musculoskeletal injuries among naval personnel have been shown to result in a decrease in time at work, or military training, increase in medical costs, and overall decrease in operational readiness [12]. Potential interventions designed to reduce the risk of these injuries and optimize operational performance should be explored. CFSD may have a potential in this capacity.

However, the results of this pilot suggest that CFSD may only marginally attenuate shock at the lumbar spine. These results are supported by McNair and Marshall [15], where only small and subtle peak acceleration differences were found between barefoot and cushion shoe running. The authors concluded that these changes were insufficient to counter impact stresses.

Overall, there appears to be no major differences between Group A and Group B with regards to the factors that influence the peak impact force equation. These values are similar (2 to 3 times body weight) to the peak vertical impact forces experienced in the heel of the foot at heel strike during running [20]. However, our values are the resultants of transmission of the shock wave through the body traveling from the heel to the L4 level. If the purpose of the CFSD was the attenuation of lower limb shock through cushioning, it would appear that they were not successful.

Reinschmidt and Nigg [24] believe that cushioning is a subjective response of the user towards the CFSD, more related to comfort. Recent research found only a partial relationship between a subject’s perception of the level of comfort of an orthotic and its functional biomechanical features [18]. This would explain why the heavier members of Group B, and involved in standing trades (Group A, 42% versus Group B, 64%) wear
The best method of determination of CFSD potential as a medical intervention is through a formal biomechanical evaluation by a highly skilled clinician. Biomechanical markers can be helpful in the determination of the mechanics of injury, diagnosis, treatment plan, and discharge criteria. Most important, these factors can aid in the applications of ergonomic interventions and prevention of re-injury. Currently there is no model to differentiate a successful outcome versus failure using CFSD. A prediction model is required. A potentially important finding of this study, which cannot be overlooked, is the relationship between weight and sea duty. As mentioned above, members of Group B were heavier with more accumulative years of sea duty. In a study conducted by King-Lewis and Allsopp [11] involving members of the British Royal Navy, they found that military personnel deployed at sea for a moderate (sixteen week) period demonstrated significant detrimental affects in health-related and physical parameters upon return to base. It may be the case that members in Group B were quite physically deconditioned, or worse, and require these devices to maintain some level of functionality. Previous, present and future operational obligations with special reference to the tasks and duties of military occupation must be considered during a CFSD evaluation involving CF personnel.

Finally, the results of this pilot project must be viewed with caution. However, a problem with injuries exists, and shock attenuation appears to be an important, yet little understood factor.

Most military medical researchers believe equipment that can attenuate lower extremity-ground impact shock is critical in the prevention of tibial stress fractures in soldiers [17], and there is research to support this claim. For example, shock attenuation abilities of various insoles while used in military boots during running and marching in Royal Marines carrying weight has been studied [30]. Although there were differences between these off-the-shelf insoles, all models recorded less mean peak pressures during the loading phases of gait than during controlled trails. Similar results have been found with recruits in the Israeli Defense Forces using custom biomechanical shoe orthoses [4]. However, recent research has challenged these findings [3].

5. Conclusions and future directions

To the best knowledge of the investigators, the effectiveness of CFSD for shock attenuation among CFSD. As well, older members with almost double the years of sea duty experience (Group A, 4.7 versus Group B, 7.96) use CFSD. Yet, from a biomechanical standpoint, there is no objective evidence for the prophylactic use of CFSD. In other words, the older, heavier, more experienced member of Group B, although wearing CFSD produced approximately 20% greater impact force at the L4 level while descending the selected ladder of the ship compared to the younger, lighter, less experienced member of Group A.

Discomfort is a negative sensation related to a complex group of physiological responses and can be associated with biomechanical factors in the case of footwear. On the other hand, comfort can be defined as the absence of sensation (no physiological responses), and biomechanical factors are not necessarily involved. Although comfort is a very important factor in footwear selection, a medical prescription of a CFSD with weight as a central issue may not be the solution. An evaluation of CFSD based solely on comfort is especially subjective, more objective (applied anatomy, kinesiological and biomechanical) information is required during the assessment process.

Comfort and shoe cushioning has been suggested to alter the expectations of a person to precisely perceive the severity of impact [25]. In this situation, a person will ignore kinesiological strategies to attenuate contact impact, such as landing with, and maintaining knee extension with little or no dorsiflexion at the ankle, thereby eliminating a potential important method of shock absorption, and allowing the transmission of the shock up through the body. However, there is little support for this position [7].

Little research has been carried out in the unique environment of the warship looking at the effects of CFSD. Most research as been conducted in the sterile environment of the academic laboratory with university students walking on stable floors. To the best knowledge of the authors, data has not been collected on the steel decks and ladders of a warship, particularly during an operational task. However, advances in technology have produced accelerometers capable of operating in the confined spaces of the warship.

A discriminate analysis of all the factors involved is critical in assessing the success of a therapeutic intervention. The results of this pilot demonstrate that there are several ‘indicators’ as to which members are wearing CFSD. As mentioned above, it would appear that in general, CFSD are prescribed for older, heavier, more experienced (sea duty) members in standing trades. It is unclear if gender is a factor.
personnel in the microenvironment of the warship has not been documented.

The major finding of this pilot is that CFSD do not significantly reduce impact force at the L4 level during ladder decent on a CF warship. Therefore the use of CFSD for shock absorption, particularly as a therapeutic intervention for such conditions as lower back pain must be questioned for this highly unique part of the CF population.

Advancements in efficacy of treatment programs are essential to optimize the military readiness of the CF member and decrease medical costs. This pilot moves towards that end by identifying shortcomings in a common, but unproven intervention. More precisely, the information contained in this pilot project may be useful in the preliminary screening of CF personnel as potential candidates for CFSD. However, more comprehensive research is required.

All CF Health Service members, including both military and civilian physical therapists are committed to the improvement of all aspects of patient care. As such, research and clinical CF physical therapists continue to be vigilant and actively involved in the development and implementation of the best performance indicators of treatment approaches. This is one of the main priorities of the CF Physiotherapy Services and as a result, policy changes are already on-going that are meant to address many of the issues raised throughout this paper [27].

References


