Load carriage and the female soldier

Robin M Orr[1], Venerina Johnston[1], Julia Coyle[2], Rodney Pope[1,2]

Introduction

There are obvious differences between men and women, differences which are taken into consideration when training athletes. Numerous texts discuss the gender-specific requirements of the female athlete, from coaching styles[1] and training methods1, to dealing with social pressures[2] and the impact of factors that selectively affect the female athlete[3,4]. On this basis, when it comes to athletic endeavours, the specific requirements of the female athlete are well considered. Unfortunately, when it comes to the female soldier and load carriage, there is a notable lack of such dedicated research literature. While several load carriage studies have included female soldiers as participants or even had female participants as their only subjects[5-12], load carriage research traditionally fails to consider the lessons learned from female athletes and apply them to the female soldier undertaking heavy load carriage tasks.

While there may be many more females in the general population engaging in sport and other athletic activities than are serving in defence forces, the number of women serving in the defence forces is growing[13]. Furthermore, while some forces still restrict the employment of women in direct combat roles,[13] the changing nature of warfare and combat environments[14] have seen female soldiers engaging with the enemy[15], receiving awards for combat actions[14], and becoming combat fatalities[14]. These warfare changes require the female soldier, like their male counterpart, to wear body armour and carry increasingly heavy loads[16,17], loads ranging between 40 to 60 kg in Iraq and Afghanistan, as an example[17].

With these loads increasing and the number of female soldiers exposed to these heavy loads increasing, an understanding of the impact of load carriage on the female soldier is of importance, as is consideration of factors already identified as impacting on the female athlete and the female soldier. This paper will review the physiological, biomechanical and health impacts of load carriage on the female soldier, as well as extending to include issues acknowledged as impacting on the female athlete.

Load carriage and its physiological impact

The greater the load carried, the greater the energy cost of standing and moving[6,18,19]. With load carriage a part of a female soldier's vocational tasks, and the absolute loads carried by soldiers increasing[16,17], these findings suggest that whether they be standing while controlling a vehicle check point, or walking on a patrol, the weight of a female soldier's load is going to extract a physiological cost.

The amount of load carried, together with its position, impacts on energy cost[20]. In addition, the speed of march[18,19], march duration[11], gradient of incline[21], and nature of the terrain[22] all impact on the energy cost of carrying a given load.

It has been suggested that load carriage ability has a relationship to a subject's absolute strength[21]. Absolute strength is related to body mass, with heavier men and women tending to have greater absolute strength[23]. A study by Patterson, et al.[11] found that the female soldiers who successfully completed a 15 km march (5.5 km/h, 35 kg load) were taller, heavier, stronger, and had a slightly greater aerobic capacity than the females who failed to finish. Similar findings were made by Pandorf et al.[24] who observed that larger female participants, with more muscle mass, were able to carry heavy loads (40.6 kg load) more rapidly over a 3.2 km distance than their smaller female colleagues. Similarly, other load carriage studies have observed that heavier personnel were less affected by the carried loads[25] than their lighter fellow soldiers. Furthermore, heavier participants wearing 18 kg battle dress were able to work for longer durations[26] and achieve faster casualty rescue times (i.e. dragging an 80 kg manikin 50m)[27]. Thus, for the female soldier, it appears that being heavier and stronger with a slightly greater aerobic capacity may be beneficial during load carriage tasks.

Lyons et al.[28] claim that body composition is more important than total body mass in meeting the aerobic demands of heavy load carriage. This claim is supported by research findings where female participants with increased body fat mass were associated with a reduced aerobic capacity and load carriage task performance[28], [29]. Even when wearing a relatively light load (10 kg body armour), the amount of body fat of female (and male) participants was negatively correlated with physical task performance[29]. Conversely, several studies suggest that body fat (21-32%) does not impact on load carriage task performance for events like an obstacle course and a 3.2 km loaded run[24,30]. It is interesting to note that the studies finding a negative effect of body fat on ability were all load carriage walking activities[28,29,28,29], while the studies failing to find any significant differences were assessed on obstacle course performance and the completion time of a loaded run activity[24,30]. A possible reason for the differences in results may be the differences in task requirements with the low intensity -high volume of prolonged walking being different to the higher intensity-shorter volume of running and obstacle course negotiation in several ways, most notably energy system requirements.

Load carriage and its biomechanical impact

As the carried load increases, the biomechanical posture and movements of the load carrier are altered. Soldiers have been found to increase forward lean from the trunk with increasing backpack loads[31-33]. This postural adaptation alters biomechanics further up the spine, with the head adopting a more forward posture and moments of force around the trunk increasing to counterbalance the load[32]. Increasing load also brings with it changes in spinal curvatures[12,33,34]. While the majority of studies finding changes in spinal shape from heavy load carriage were conducted with male participants[33,34], a study by Meakin et al.[12] employing postural Magnetic Resonance Imaging and Active Shape Modelling (a statistical model of object shape) on both male and female participants identified changes in spinal curvature with loads of 8 kg and 16 kg[12] respectively. Increasing loads unilaterally accentuates lateral lumbar spine curve, increasing the concavity on the opposing side[35]. Therefore, it is understandable that increases in backpack loads have the potential to increase spinal injuries by increasing strain on the musculoskeletal system[32]. As will be discussed, intrinsic factors, like pelvic floor muscle dysfunction, have the potential to further increase the potential for lower back injuries.

Increasing loads also impact on the kinematics of gait for female soldiers. With gait speed the product of stride length and stride frequency3[6], shorter stride lengths, typical of shorter female soldiers, require higher stride frequencies to maintain a given pace[16]. With the exception of a study by Ling et al.[7], whose female participants did not alter stride frequency as loads increased, female participants have been found to further increase stride frequency rather than stride length when required to carry greater loads or increase walking speed[16]. Harman et al.[37] suggest that there may be a point where stride frequency can no longer be increased, which means that stride length must increase to maintain a given speed. This stride frequency limitation, which may explain the results of Ling et al.[7] whose female participants failed to increase stride frequency significantly as loads increased, raises potential concerns if load carriers normally utilise this mechanism to accommodate increases in load and speed. With the load carrier no longer able to increase stride frequency as loads or march speeds increase, they have to increase stride length. In addition soldiers are often forced to maintain a given pace or 'keep in step'. This practice likewise limits stride frequency and forces stride lengths to increase if a given speed is to be maintained. For some soldiers, and particularly shorter soldiers, this may require a stride length that is greater than their maximum comfortable and safe stride length, meaning they overstride. This adaptive overstriding can place additional shearing stress on the pelvis, leading to stress reactions or stress fractures in the pelvic bones[38]. Pope[38] found that the incidence of pelvic stress fractures in female army recruits was reduced by 95% when a multifaceted preventive intervention was implemented by Physical Training Instructors. This intervention included, among other elements: reducing marching speed; reducing the requirement to 'keep in step'; and encouraging recruits to march at comfortable stride lengths.

Changes in gait mechanics are coupled with changes in forces acting on the body. Ground reaction forces (GRF), which are the result of all the reaction forces between the foot and the ground as the foot makes contact with the ground[39], have been found to increase in both female and male participants as loads increase[31]. These increases in GRF create shearing forces which can induce blisters[40] and, by increasing the total volume of impact forces, can increase the risk of overuse injuries[41].

Load carriage and its health impact

Load carriage places strain on the musculoskeletal system of the carrier[31,37]. On this basis, load carriage tasks have the potential to cause acute and chronic overuse injuries. During military load carriage activities, military personnel have presented with blisters[40], stress fractures[38], knee pain[41], foot pain[16,41], brachial plexus palsy[16], and lower back injuries[41]. Increased fitness may provide one means of mitigating the negative impact of load carriage[16,42].

Low levels of fitness are associated with an increased risk of injury during both general military training[43] and load carriage activities[44]. Therefore, physical conditioning to increase fitness levels may constitute one means of limiting load carriage injuries[16,42].

Traced back as far as the Roman Legionnaires and Macedonian foot soldiers[17], recognition of the need to condition soldiers to carry loads is not new. However, load carriage conditioning needs to be applied with care. Even though initial training has been found to increase the fitness levels of female soldiers[45], studies have found that injury rates at the commencement of initial training can be relatively high. A review of a six week Marine Corps Officer Basic Training Course found a cumulative injury incidence of 80% for female candidates[46]. In addition, over the longer 11 week Marine Basic Training Course, female recruits showed increases in levels of bone resorption markers, indicating bone stress, in Weeks 2, 8, 9, 10 and 11 of training. These examples highlight the need for the general conditioning process, including the load carriage conditioning, to be slow, progressive, and include adequate and appropriately-timed periods of recovery[42]. In addition, consideration needs to be given to gender-specific concerns identified as impacting on female athletes; concerns like the female athlete triad, poor nutrition and hydration practices, urinary incontinence (UI) and pelvic floor muscle function, and poor equipment fit. These additional considerations are further discussed below.

The female athlete triad

The term "female athlete triad" was first coined in a special American College of Sports Medicine (ASCM) conference in 1992[47]. The concept was developed following concern over three risk factors associated with female athletes, these being amenorrhoea, osteoporosis and eating disorders[48]. Alone, or in combination, these three factors pose a significant threat to physically active women and hence female soldiers involved in load carriage[49].

By definition, amenorrhoea is a dysfunction of the menstrual cycle which leads to an absence of a regular menstrual cycle[50]. With the cessation of menstruation, hormone balances are disrupted and the uptake of calcium is affected, thus leading to bone loss and porosity 2 and in turn increasing the risk of stress fractures[51]. In a study by Rauh et al.[51], female soldiers who reported being amenorrheic, missing six or more menses during a 12 month period, were found to have an almost threefold increase in lower-extremity stress fracture risk. This is important in the knowledge that an amenorrhoea prevalence rate of around 45% has been found for female military recruits[52].

Amenorrhoea can be caused by several factors prevalent in female military soldiers. High intensity physical exercise, for example, has been found to cause amenorrhoea in female athletes[53]. The stress of war has also been shown to induce menstrual abnormalities including amenorrhoea[50]. In addition, recent studies have reported that female soldiers have been found to favour menstrual suppression during deployment[54]. With the long term health implications of menstrual suppression requiring further study[55], some research has found participants on certain programs, like medroxyprogesterone injections, to have lower bone mineral density[56]. This bone mineral loss is reversible on cessation of the treatment[56]. Other programs, like monophasic oral contraceptives, may have a neutral or positive effect[55] on bone density while programs using vaginal rings have, at this stage, an unknown impact[55]. Considering all this, there is the potential for amenorrhoea to increase the female soldier's risk of adverse health sequelae, like osteoporosis.

Osteoporosis is an increase in the porosity of bone caused by a decrease in bone mineral density[48]. Although osteoporosis is more common in post menopausal women, athletes suffering from eating disorders and amenorrhoea are highly susceptible to osteopenia and osteoporosis, with disordered eating reducing important nutrient intake and menstrual disturbances decreasing bone protection[3,49]. As the number of missed menstrual cycles accumulate, the loss of bone mineral density also accumulates[57]. This loss may not be completely reversible[49]. For the younger female soldier, these conditions may lead to them never attaining a normal peak bone density and, with natural age related bone loss, may make them susceptible to osteoporotic fractures at an early age[3] and increase their risk of postmenopausal fractures[58].

Osteoporosis and amenorrhoea may also be caused by an eating disorder[49]. A study by Lauder, et al.[59], 60 found an incidence of 8% for diagnosed eating disorders in female soldiers. This result was higher than that for the general population but lower than that for a female athlete population. They also found that 33% of these female soldiers were 'at risk' of an eating disorder and fell into the category of disordered eating, a term used to describe eating behaviour rather than being a definitive clinical diagnosis[3]. Having a third of the cohort with dietary concerns that can be linked to the female athlete triad is of concern. Stressful environments like combat zones have the potential to further increase the number of women suffering from eating disorders in the military[61]. Disordered eating in female soldiers may increase the incidence of amenorrhoea and osteoporosis and the subsequent prevalence of fractures[49,51], through activities like load carriage[38].

In their 2007 position stand on the female athlete triad, the ACSM suggested that it is low energy availability rather than disordered eating which is of concern[49]. This conclusion has ramifications for female soldiers on exercise or deployment, where sustenance comes from combat ration packs. Female soldiers may simply not consume sufficient energy[62]. Even though ration pack meals are designed to provide sufficient energy, many soldiers discard portions of their ration packs due to personal taste and thus fail to meet required energy intakes63. This is of notable concern as research has shown that load carriage during field tasks increases energy requirements[64] thus making the divide between energy intake and energy expenditure even greater and placing the female soldier at greater risk in relation to the features of the female athlete triad.

Additional Nutrition Concerns

Even when consuming enough food to meet their daily energy requirements, female soldiers may not be meeting their recommended daily iron intake requirements[64]. As iron is essential for haemoglobin production, low iron intake will impact on haemoglobin synthesis[65]. Low haemoglobin production reduces the ability of the body to transport oxygen in the blood to the working muscles, thereby impairing performance of physical tasks[65,66], like load carriage.

In addition, while dietary iron intake may be insufficient, iron requirements may increase during physical activity, as physical training is known to create an iron cost for the body[65,66]. Therefore, it is not surprising that the commencement of military training, with its increase in physical demands, has led to findings of an increase in iron deficiency in female soldiers and of iron deficiency anaemia occurring during, and immediately following, basic training[65,67]. While no studies that examine the impact of military pre-deployment training on iron status could be found, the sudden increase in physical training and field exercise training could be expected to increase the prevalence of iron deficiency and iron deficiency anaemia. A notable concern becomes evident if this deficiency occurs just prior to deployment, a protracted period where combat stress and ration pack meals may have a further negative impact on dietary iron uptake and iron status. Even mild iron deficiency has been found to impair cognitive function, and clear thinking specifically[65]. Load carriage has also been found to impact on alertness and vigilance[5]. On this basis, the combination of these two factors may profoundly impact on a soldier's ability to notice visual cues when scanning for enemy and other threats (like Improvised Explosive Devices), and steps should be taken to prevent this situation.

Urinary Incontinence and Pelvic Floor Muscle Function

Female soldiers have reported experiencing urinary incontinence (UI) during heavy load carriage activities, with one study reporting an incidence rate as high as 26%[68]. A study of American active duty female soldiers by Davis et al.[68] found that 31% of female soldiers reported suffering UI whilst on duty to such an extent that it interfered with their job, was socially embarrassing, and was considered particularly debilitating during field exercises. UI is a symptom of pelvic floor muscle (PFM) dysfunction or fatigue[68]. Of importance to load carriage is the established link between PFM function and spinal stabilisation[69,70]. The transverse abdominal muscles have been found to improve spinal stabilisation through increasing intra-abdominal pressure[69]. Research has also found that it is essential for effective spinal stabilisation that pelvic floor and diaphragm muscles contract as the transverse abdominals contract[70]. With dysfunctional pelvic floor muscles, the ability of the transverse abdominals to contribute to spinal stabilisation is lost and the lower back becomes more susceptible to injury[70].

In the load carriage context, heavy loads have been found to increase trunk forward lean, increase lumbar compression and shear forces, change thoraco-pelvic rhythm and increase spinal torques[12,31]. Thus, the PFM dysfunction often associated with UI has the potential to reduce spinal stability and increase the risk of lower back injury in female soldiers.

Some self-administered preventative strategies for UI also have the potential to cause illness during load carriage events. Davis et al.[68] and Sherman et al.[71] both found that approximately 13% of female soldiers who reported experiencing UI significantly restricted their fluid intake during field activities. Therefore, in order to reduce experiencing an incontinence episode, female soldiers put themselves at risk of heat related illnesses through becoming dehydrated during periods of high physical exertion, like field exercises and when conducting load carriage tasks.

Poor Equipment Fit

It is widely acknowledged in the sporting field that poor equipment fit can lead to injury and reduced performance[72]. When it comes to carrying loads, female soldiers have raised concerns over load carrying equipment[44,73]. Problems with pack fit, shoulder strap fit and position of the waist belt have been identified as the more common concerns[7,44,73]. These load carriage equipment concerns are thought to be exacerbated when female soldiers are required to wear body armour[73]. A study by Fullenkamp et al.[74], capturing the anthropometric data of defence force soldiers from four NATO countries, highlighted the fact that designing protective equipment to accommodate female soldier structure was not as simple as scaling down male-proportioned figures. Likewise, data collected by Harman et al.[73] led the authors to recommend that female soldiers required more specific sizing options than male soldiers due to greater variability in chest-waist-hip ratios. An immediate example is the failure of body armour designs to accommodate female breast tissue. As such, it is of no surprise that female soldiers raise concerns that body armour is not comfortable and restricts breathing[73].

Failure to accommodate soldier anthropometrics in one piece of equipment can impede the function of other pieces of equipment even if these factors were addressed in these other pieces of equipment. For example, the looseness of the Interceptor Body Armour around the waist was found to impede the cinching of the waist belt of the pack being carried[73]. The inability to cinch the waist belt impedes a design intent of the US Modular Lightweight Load-Carrying Equipment (MOLLE) pack – that being to remove load from the shoulders and shift it to the pelvis[75]. The inability to cinch the waist belt will mean the load carrier becomes less efficient[44] and more prone to injuries16. A lack of accommodation of female soldier requirements in equipment design may contribute to a reduction in female load carriage performance[25] and compromise soldier safety[74]. However, before load carriage and body armour equipment designers consider how best to meet female soldier requirements, Browne[76] offers a poignant caution that military equipment should focus first and foremost on combat effectiveness before considering anthropometric concerns or personnel.

Summary

Physiological factors, like body fat mass, strength, and aerobic endurance, as well as biomechanical factors, like stride length and forward lean, have the propensity to increase both the energy cost of completing a load carriage task, and the potential for injury. The female athlete triad, which can be induced or worsened by intense physical activity (like load carriage), poor nutritional intake, and stressors within the combat environments, likewise raises injury potential concerns. Furthermore, iron deficiency, PFM dysfunction or fatigue, and military equipment issues can reduce performance, increase fatigue and increase the risk of injury in female soldiers.

Strategies to improve female load carriage performance and minimise injuries

This paper has reviewed and discussed the physiological, biomechanical and health impacts of load carriage on the female soldier. The discussion of factors affecting load carriage by female soldiers and its impacts on the female soldier has been broadened and diversified to include issues known to affect female athletes and hence also many female soldiers engaged in load carriage. In order to address issues affecting load carriage performance and minimise load carriage injuries in female soldiers, several strategies should be considered, including: structured physical conditioning, improving nutrition and hydration practices, and modification of load carriage equipment to meet female soldier requirements.

Structured Physical Conditioning

Load carriage conditioning needs to be structured and carefully implemented. With consideration of the susceptibility of female soldiers to nutritional deficiencies, the female athlete triad and subsequent general overuse conditions, the load carriage program needs to include 'deloading' periods to facilitate musculoskeletal and metabolic recovery. While load carriage conditioning sessions should be conducted at least once every two weeks[42], supplemental aerobic conditioning and strength training should be included[42]. The introduction of pelvic floor muscle education and training may also be of benefit[69]. The impacts of this multi-layered approach will assist in addressing several concerns identified within this report, most notably being the need to increase lean muscle mass, control body fat mass at a low healthy level, increase muscle strength, increase aerobic capacity, and improve pelvic floor muscle function.

Complementing these conditioning programs would be the implementation of an effective injury surveillance program. This program should be both proactive, through ongoing monitoring and forward adaptation of training, and reactive, responding to findings and initiating improvement strategies within training programs. The benefits of these types of programs are highlighted by the findings of a study into recruit injuries at the Australian Army Recruit Training Centre. The study noted that the injury surveillance system played a strong, positive role in identifying, controlling, and influencing the causation of injuries, thereby reducing injury rates[77].

Improving Nutrition Practices

To improve iron status, nutritional education programs, which highlight the importance of iron intake and daily requirements and provide information on good iron sources from daily lifestyle diet, should be provided and these choices made easily available[65-67]. Oral iron supplementation may be considered a viable option to improve iron intake. Although a study by Carins et al.[65] found that a daily iron supplement of ~18mg did not affect the iron status of female soldiers, other literature supports the use and effectiveness of iron supplementation[66,67]. However, Johnson[78], recommends that the conservative education approach be tried before single-nutrient supplementation is warranted. On this basis, caution is advised regarding iron supplementation until further research validates the efficacy of its use.

Improving Hydration Practices

Awareness of the impact of fluid avoidance and the subsequent consequences must be raised and assured among female soldiers. However, future research in this field is needed as no literature could be found that examines the use of awareness-building strategies to reduce the impact on performance and health of fluid avoidance as a means of preventing urinary incontinence. Furthermore, alternatives to hydration avoidance (like pelvic floor muscle conditioning and promotion of acceptable means of managing urinary incontinence in the field and during load carriage tasks) must be made readily available and promoted in order to address the underlying causes of hydration avoidance among female soldiers engaging in load carriage[68,71].

Modification of Load Carriage Equipment to meet Female Soldier Requirements

Soldier modernisation programs are currently being undertaken by numerous defence forces around the globe, including Australian (Land 125/project WUDURRA), Canadian (IPCE), German (IdZ), Dutch (Dutch Soldier Modernisation Program), French (FELIN), Italian (Combattente 2000), Spanish (Combatiente Futuro), South African (African Warrior), British (FIST) and US (LAND WARRIOR / OBJECTIVE FORCE WARRIOR) defence forces, as well as the Greek, Israeli and Norwegian defence forces[79]. These modernisation programs include focus on several areas that either directly or indirectly impact on soldier load carriage systems[79]. With claims by Ling et al.[7] that the MOLLE military backpack was created based on male anthropometric characteristics and with the female-specific fitting concerns and need for a greater range of sizes available to female soldiers identified, it would seem logical that these future warrior programs specifically tailor equipment to include female anthropometric features. Failing to do so could impact on future force generation and sustainment.

Limitations of this paper and recommendations for future work

While this paper has started to merge scientific evidence from the fields of female soldier load carriage and the female sporting athlete, many topics have yet to be discussed. The impacts of pregnancy, menstrual and ovarian cycles, and potential psycho-sociological issues provide examples of topics that, although explored in regards to the female athlete, have yet to be explored in the context of military load carriage. Furthermore, while several key strategies have been discussed, other potential strategies, like soldier selection, have yet to be reviewed. It is hoped that this paper provides the impetus for future discussion papers and research in which the field of female soldier load carriage and the field of the female sporting athlete are further considered and expanded

Conclusions

It is clear from the research evidence presented in this paper that sufficient evidence exists to inform the development and implementation of strategies to enhance load carriage performance and reduce associated risks in female soldiers – an area which has historically received little attention. Some of this evidence is drawn from research in the military context, and some from research in the context of female athletes. While much further research is warranted, it is timely in light of recent developments in the nature of military operations for military forces worldwide to consider the available evidence and implement appropriate strategies to enhance load carriage performance and reduce associated risks among female soldiers.

Authors' affiliations: [1] The University of Queensland,
[2] Charles Sturt University
Corresponding author: LT Robin Orr, c/- Level 7, Physiotherapy Division, School of Health and Rehabilitation Sciences, The University of Queensland,St Lucia, QLD 4072
Email: Robin.Orr@defence.gov.au

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