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Effects of Sex and Load Carried per Kilogram of Body Mass on Landing Technique

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ABSTRACT

International Journal of Exercise Science 14(1): 633-643, 2021. Sex differences and heavy load carriage may contribute to the high rate of musculoskeletal injury in military recruits, particularly within the female population. Thus, the purposes of this study were to determine if load influenced landing quality differently in females compared to males and if load carried per kg body mass was associated to quality of landing. Twenty-eight participants were recruited for this study (males: n = 14; females: n = 14). Participants were grouped by sex. All twenty-eight participants performed three drop-jumps (DJ) under unloaded and loaded conditions. The loaded condition included a combat helmet, tactical vest, and rucksack (22 kg). Two cameras recorded in the frontal and sagittal directions during the three DJ trials. DJ trials were scored using the LESS. There was no significant difference in LESS difference scores between males and females, t(26) = -1.014, p = 0.320, 95% CI = -2.01 to 0.68. Load carried per kg body mass (r_s = 0.401, p = 0.034) was significantly correlated to LESS rank order. The results suggest load does not significantly alter landing quality as measured by the LESS. However, participant body mass and load per kg of body may play a role in a person's ability to adapt to heavy loads.

KEY WORDS: Musculoskeletal injuries, military, recruits

INTRODUCTION

Musculoskeletal injuries (MSI) occur more frequently than any other type of injury among cadets attending U.S. military academies (16). Of these, ankle and lower leg sprains and strains account for the largest portion of MSI suffered in cadet basic training (16). Compared to their male counterparts, females are approximately twice as likely to suffer a lower extremity injury or MSI during cadet basic training (16). In addition, a study which monitored ACL injuries among male and female Naval Academy midshipmen over the course of seven years, found that women were 9.74 times more likely to suffer an injury as compared to their male counterparts (9). Higher incidents of injury in female as compared males is something which is not only observed in female cadets at the academies, but also enlisted female basic training recruits (2-4, 13, 15, 30). Even upon controlling for prior injury history, age, preparatory academy attendance, high school sport participation, distance running index, injury prevention program participation, academy, and cohort year it has been observed that this heightened risk largely remains unchanged for those females undergoing cadet basic training (16). Given the extent of the problem and the negative outcomes of injury (e.g., hindered performance, duty restrictions, and early onset of osteoarthritis) research focusing on load, sex, and stature may provide relevant insight into these disparities (6, 12).

The combined effect of donning heavy loads and sex may be contributing factors for such high rates of MSI among military recruits. Military personnel are often required to carry heavy loads during both training and combat (11, 31). Loads may include the Modular Lightweight Load-carrying Equipment System (MOLLE), Army Combat Helmet, and body armor. The maximum recommended weight of these loads varies depending on whether the load is carried for fighting or approach marching (31). Arguably, load carriage may increase MSI risk (26, 27). Among females, the relative risk of a MSI increased to 144% when the average load was greater than 13.6 kg compared to their male counter parts (26). A 13.6 kg load (e.g., tactical vest) has been shown to increase a soldier's risk of injury by as much as five times when worn in excess of six hours (25). Military personnel are regularly required to don loads of 20 to 40 kg while performing training exercises (1). Given the U.S. military requirements implemented in 2016, requiring all combat military occupation specialties to be open to females, women desiring to be a part of the infantry must be able to carry a minimum load of 20 kg (1).

The research in this area has been predominantly focused on load, rather than sex comparisons. The literature is clear that loads have significant negative effects of load on lower body biomechanics (17, 28, 29, 32). Load increases of as much as 10% of an individual's body weight produce significant increases in knee impulse and energy absorption, as well as in peak ankle dorsiflexion, plantarflexion angular impulse, and ankle energy absorption when performing a drop-landing task from a 45 cm box (17). Body armor consisting of a helmet, vest, and rifle replica, estimated to be of 18% of participants' body weight, increases maximum knee flexion angle and maximum vertical ground reaction force among the highly trained male Air Assault Soldiers from the 101st Airborne when performing a drop landing task from a 50 cm platform (28). At higher loads (32 kg), biomechanics during walking are adversely altered in healthy college aged males, a demographic, arguably, with very similar characteristics to that of cadet training recruits (32). Although prior studies support the negative effects of load on biomechanics, it is necessary to further investigate sex-based differences in landing mechanics under loaded conditions in order to fully understand the potential deleterious effects of load within these separate populations.

To date there appears to be minimal research investigating the difference in the biomechanical adaptions to load between males and females. A prior investigation found that females exhibited greater peak knee abduction moment compared to males when landing with 20, 25, and 35 kg loads from 30 cm drops using their normal landing technique. The group also reported that males increased knee flexion range of motion with 25 kg load as compared to 20 kg load, while females within the same study displayed no significant changes in knee flexion range of motion across loads of 20, 25, and 35 kg (29). In a recent study, it was reported that, under loaded conditions, males produced significantly greater vertical impulse upon landing on a single limb after jumping over a 30 cm high hurdle midway between a distance of 40% of participant body height, as compared to females (18). The investigators speculated that the reduced vertical landing impulse in females during loaded conditions were a result of movement adaptations to minimize the impact of the increased load magnitude (18).

The LESS is a popular clinical assessment tool that uses two standard video cameras to record an individual's landing mechanics for potentially high-risk movement patterns ("errors") during a jump-landing maneuver (24). A full description of the scored items within the LESS has been reported by Padua et al. (24). The LESS was chosen as it is a reliable, valid, and low-cost alternative to sophisticated 3-D motion capture systems for assessing jump landing biomechanics (23). Research also suggests that LESS scores may be a significant indicator of injury risk in entry-level male recruits (7). Higher LESS values indicate worse landing quality. Traditionally, the LESS is interpreted using the following scale: Excellent (< 4), good (> 4 to ≤ 5), moderate (> 5 to ≤ 6) and poor (> 6) (24). The present study has operationally defined landing quality in relation to the landing error scoring system (LESS).

Improved understanding of the biomechanical changes associated with military load carriage may provide information needed to develop prevention protocols to help minimize injury, lost training/workdays, and medical costs due to injury during basic training. Thus, the purposes of this study were to determine if load influenced landing quality differently in females as compared to males and if load carried per kg body mass was associated to quality of landing. Based upon the findings of prior research we hypothesized that LESS difference scores would be significantly different between males and females. We also hypothesized that there will be a correlation between load per kg body mass carried and landing quality.

METHODS

Participants

Twenty-eight recreationally active participants, both males (n = 14, 21.57 ± 1.40 yr., 180.67 ± 6.70 cm, 82.37 ± 18.47 kg) and females (n = 14, 21.58 ± 1.51 yr., 171.7 ± 4.57 cm, 67.02 ± 14.32 kg), were recruited for this study. In order to resemble a military recruit population most closely, all participants were recreationally active. This was defined as being engaged in moderate activity such as tennis, biking, jogging, or weightlifting at least 2-3 times per week for at least 30 minutes. Participants also reported having no prior military training experience. Prior to the commencement of the study, all participants read and signed an approved institutional review board informed consent document. Participants were excluded if they had any of the following conditions: a) sustained a shoulder, back, lower extremity injury within the last six months or b) surgery to the shoulder, back, hip, knee, or ankle within the last two years. All participants were required to be 18 years of age or older to participate in the study. This research was carried out fully in accordance to the ethical standards of the International Journal of Exercise Science (21).

Protocol

All participants reported to the research laboratory at varying times throughout the day, wearing athletic attire for the testing session. Height and weight were collected for each participant. Height was measured using a portable stadiometer (Invicta Plastics ltd., Leicester, England). Weight was measured using the Tanita TBF-300A scale and body composition analyzer (Tanita Corporation of America, Inc., Arlington Heights, Illinois). Following these measures, each participant was allowed to familiarize themselves with the test. Participants then performed three drop jump (DJ) trials from a 30 cm box placed 10% of the participants height away from a 120 cm x 80 cm target under two separate randomized counterbalanced conditions (Figure 1), unloaded and loaded, with a five-minute rest period between conditions and a 30-second inter-trial rest period. The 30 cm box was placed at 10% of the participant's height away from the target due to institutional review board safety concerns, given the inexperience of the participants landing with heavy loads.

For the unloaded condition, each participant wore shorts, t-shirt, and combat boots (Belleville 390 Hot weather boots, Belleville, IL). Combat boots were worn in both loaded and unloaded trials to control for the effects of the boots on landing quality, though previous research has determined that military boots have no significant impact on knee valgus angles (22). For the loaded condition (22 to 23 kg, dependent on vest and helmet size), the participants were fitted with a combat helmet (1.4 kg -1.6 kg), improved outer tactical vest (5.1 kg - 5.4 kg), and rucksack (15.7 kg) (Figure 2). Each trial of the DJ was recorded using two digital HD video cameras (SH-2, Olympus Imaging America, Center Valley, PA) at 120 frames per second. The first camera was positioned in the sagittal plane at a distance of 3.45 m and a height of 1.22 m (24). The second camera was placed in the frontal plane at the same distance and height as the first camera. For each condition, the three recorded trials were scored using the LESS and the overall scores from each of the three trials were averaged to compute mean LESS scores.

Figure 1. Drop Jump Task.

Figure 2. Tactical equipment: combat helmet, improved outer tactical vest and MOLLE rucksack.

Statistical Analysis
Separate independent samples t-tests were run to determine differences in demographic metrics (height, mass, age, BMI) between groups (Table 1). To analyze the influence load had on LESS scores, difference scores were calculated for each participant. Difference scores were calculated by subtracting the LESS scores under the unloaded condition from the LESS scores under the loaded condition. The Shapiro-Wilk test for normality demonstrated that the LESS difference score data for both the males (p = 0.560) and females (p = 0.772) were normally distributed. There were no outliers present in the LESS difference score data for both males and females. The difference scores between groups (males and females) were analyzed using an independent samples t-test. To address the second research question, a Spearman's rank correlation was used to determine the strength of the relationship of load per kg body mass carried to rank order LESS categories (excellent, good, moderate, and poor). Alpha level was set a prior at 0.05. All data was analyzed using SPSS Statistic 24 (IBM, Somers, NY).

RESULTS

Table 1 provides the demographics for both the males and females. As indicated in Table 1, height (p < 0.001), mass (p = 0.021), and age (p = 0.007) significantly differed between males and females. BMI did not significantly differ between groups (p = 0.853). Table 2 provides the means and standard deviations of the LESS scores for each group under the unloaded and loaded conditions. In the current study, the modified DJ task demonstrated excellent inter-rater reliability ($ICC_{3,k}$ = 0.901). LESS scores among participants most frequently fell within the moderate overall score category. The mean LESS scores did not significantly differ (p = 0.974) between groups (males and females) without load. Table 2 also provides the actual load per kg of body mass. Females did carry a significantly (p = 0.015) greater load per kg of body mass as compared to males. An independent samples t-test revealed that there was no significant difference in LESS difference scores between males and females, t(26) = -1.014, p = 0.320, d = 0.383, 95% CI = -2.01 to 0.68. Load per kg body mass carried (r_s = 0.401. p = 0.034) was significantly correlated to LESS rank order.

Table 1. Demographics.

Sex	Height (cm)*	Mass (kg)*	BMI	Age (yr)*
Male	180.67 ± 6.70	82.37 ± 18.47	25.01 ± 4.39	21.57±1.40
Female	171.70 ± 4.57	67.02 ± 14.32	25.36 ± 5.45	20.21±1.05

*Statistically significant (p < 0.05). Data is reported as mean ± SD.

Table 2. Sex, LESS and load per kg of body mass.

Sex	LESS (unloaded)	LESS (loaded)	LESS Difference Scores	Load per kg of body mass*
Male	5.16 ± 3.14	5.14 ± 2.62	-0.02 ± 1.77	0.28 ± 0.06
Female	5.19 ± 2.02	5.83 ± 1.39	0.65 ± 1.68	0.34 ± 0.07

*Statistically significant (p < 0.05).

DISCUSSION

The main findings of this study were that loads of 22 to 23 kg did not significantly influence landing quality differently in females as compared to males, but load carried per kg body mass was significantly associated to quality of landing. It was hypothesized that LESS difference scores would be significantly different between males and females. Based on prior research, it was expected that the ability of females to maintain a pre-load pattern of movement wearing a 22 kg load during a DJ task would be hampered because they were significantly smaller in height and mass compared to males (19, 29). Although, females did undergo a greater degree of change in LESS scores from unloaded to loaded when compared to their male counterparts, this change was not statistically significant (Table 2). The change may be considered clinically significant, however, as even slight reductions in landing quality have the potential to affect lower limb injury. Several factors may have contributed to these findings. First, although the load represented a significantly greater percentage of the females' body mass as compared to males (p = 0.015) (34% vs. 28%), it is possible the difference in percentage of body mass was not clinically meaningful. Thus, females were still able to maintain their prior pattern of movement. Increasing the load may increase the gap between male and female LESS difference scores. Arguably, loads exceeding 22 kg in combination with other factors, such as fatigue, may result in a greater degree of deterioration in landing technique in military personnel with a smaller stature and overall strength capacity (8). Second, it is also possible that the military style boots may have restricted ankle mobility, thereby altering landing patterns. Third, the sensitivity of the LESS may have prevented the detection of differences between groups, which is discussed later as a limitation of the study.

Lastly, it was hypothesized that there would be a correlation between load carried per kg body mass and landing quality. The present study observed that rank order LESS quality category (excellent, good, moderate, and poor) was moderately correlated to load per kg body mass carried. These results may suggest that those carrying a larger percentage of the body mass may be more susceptible to riskier patterns of movement. Further research should explore the amount of load that can be utilized without creating significant movement accommodations that could increase injury risk. The findings of this present study may further suggest that load carried per kg body mass may have more impact on landing mechanics than sex differences in military recruits. Previous research related to injury causes in recruits has found a relationship between BMI and injury during basic training, revealing significantly higher rates of injury in those who were classified as obese as compared to those in the normal category (4).

The present study is the first to the authors' knowledge to explore the relationship between the percent load carried per kg of body mass and landing quality. The results complement prior research findings which have demonstrated that higher load alters landing mechanics (17, 28). Prior research has found that the addition of military load alters landing mechanics during drop landing tasks (17, 28). A prior investigation, using a 50 cm box drop task, compared an unloaded condition to a military-style load condition equal to approximately 18% of participant bodyweight (28). The group found significant differences between the conditions, particularly in maximum knee flexion values and normalized vertical ground reaction forces (28). Using a 45 cm drop landing task, a separate group investigated the effects of a trunk load equal to 10% of participant body weight on those exhibiting a trunk extensor landing strategy, compared to those displaying a trunk flexor landing strategy (17). The group found that both load and landing strategy have significant effects on lower body kinematics when landing (17). The results of these prior investigations combined with the findings of the present study, suggest that smaller individuals may exhibit significant alterations in their landing strategies while loaded compared to larger individuals, as the load carried is proportionally greater in these smaller participants. Given the lack of significant findings between LESS difference scores between males and females within the present study, the negative alterations in landing patterns may be more related to size than sex. It is worth noting that the BMIs of the males and females in the present study did not significantly differ, arguably lending to minimal sex-based differences in landing quality.

The loads used in the present study are representative of fighting loads previously reported. Military personnel may wear loads exceeding 60 kg of equipment during emergency approach marches (14, 31). With loads nearing 60 kg, these differences in landing patterns between males and females may become more pronounced. Using a rucksack load of 32 kg, Wang et al. (32) found that load significantly altered pelvic anterior tilt, hip flexion, and knee and ankle dorsiflexion at heel contact during a five-minute walking task on a treadmill at a speed of 1.67 m/s. The group also observed alterations in maximum knee flexion at stance during the five minute walking task (32). Similar results have also been observed with trunk positioning in the sagittal plane with loads 32 kg and 47 kg during a walking task (10). Future studies should investigate the combined effects of sex and loads exceeding 30 kg on landing quality. Additionally, future research should continue to explore the effects of sex and load on different functional movement tasks such as bounding, or cutting, which are common in military personnel. The findings of the present study could have practical implications in decision-making regarding the amount of load to be carried by soldiers of both sexes, as it was shown that no differences in landing mechanics are apparent between the sexes with a load of 22 to 23 kg. The results of this study could also have practical implications when considering the appropriate body mass for a soldier who will be required to carry heavy loads. The results suggest that larger soldiers may be more capable of donning heavy loads while landing without compromising their landing mechanics.

Several limitations should be noted with respect to this investigation. First, this was a small sample, which may limit the generalizability of our findings. Future studies should be conducted with larger samples to improve the statistical power of the analysis. Second, this study used a sample population of recreationally active individuals. Thus, the results are extrapolatory and may only be generalizable to those recruits with similar athletic-bases. Further research with samples that include participants with sedentary lifestyles are required. It should also be noted that participants were required to indicate whether they were recreationally active and had not been injured in the past six months prior to the study. This could be considered a limitation as differences in activity levels or a history of lower extremity injury within the past two years could affect LESS performance. Third, the load carried (22 kg) may not have been great enough to cause instability in the participants' preferred patterns of landing. This presents a future area of research using loads greater than 22 kg. Fourth, it is likely the LESS lacks the sensitivity to detect small alterations in movement. Wang et al. (32) used 3-D motion capture a more precise and sensitive form of instrumentation. Other studies (5, 20) using 3-D motion capture have also reported alterations in joint kinematics with loads. Fourth, the drop height of the LESS may not have been great enough to elicit changes in landing quality. In a prior study by Wang et al. (33), males and females performed unloaded drop landings from two boxes of different heights (40 and 60 cm). The group reported that females exhibited significantly greater ground reaction forces, and hip stiffness from the 60 cm drop landing, than did their male counterparts (33). These results suggest that sex-based differences in landing mechanics could be more apparent using a higher starting point for the task.

This present study also did not evaluate quality of landing post-fatigue, which might more closely mimic the real-world rigors of military activities. Being in a fatigued state, which is based on a performer's individual capabilities, has been observed to alter an individual's pattern of movement in tasks such as walking (32). In an early study involving healthy college aged males and load carriage, Wang et al. (32) observed a significant alteration in ankle kinematics post-fatigue. Further investigation is required to determine if this pattern of landing is persistent across conditions while participants (i.e., performer) are in a fatigued state.

Although the results of this study provide insight regarding the differences in landing mechanics between men and women, further research is required to determine the differences in landing technique in tasks followed by a proceeding athletic movement/maneuver such as a jump. For example, military personnel may be required to disembark a vehicle or aircraft while donning heavy loads and quickly move to a more secure or safer location. In conclusion, our results demonstrate that 22 kg load carriage does not significantly alter female landing quality as compared to males, and that load per kg body mass carried was significantly correlated to LESS rank order. Strategies to improve injury rates in military recruits should not only focus on equipment modification and load carriage progression standards, but also on improving movement quality.

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