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IMPACT OF REDISTRIBUTING TORSO-BORNE LOADS ON SOLDIER BIOMECHANICS, PHYSIOLOGY, COGNITIVE PERFORMANCE AND COMFORT

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14. ABSTRACT This effort focused on understanding the impact of redistributing torso-borne loads from the shoulders to the pelvic region on Soldier biomechanics, physiology, cognitive performance, and comfort. The goal was to determine whether an optimal load re-distribution between the shoulders and the pelvis exists. Soldiers serving as study participants were outfitted in a military fighting load as they executed neck flexion-extension movements and engaged in 10-min and 2-h trials of treadmill walking under conditions that differed with regard to the proportion of the load imposed on the shoulder region. Pressure measurements at the skin surface were captured at the shoulders and hips to quantify the load conditions. To achieve the load redistribution, a commercially available weight distribution device was used. Pressures measured at the top of the shoulders were used to establish four offloading levels: high (70-90%), medium (40-60%), low (10-30%), and no offloading relative to shoulder pressure when the fighting load was worn without the weight distribution device. Load redistribution had minimal impact on Soldier performance. While no specific offloading condition performed better or worse than any other, load redistribution from the shoulders to the pelvis did have an impact on bicep femoris muscle activity and comfort measures at the shoulders and hips.						
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GAIT	KINETICS	RUCKSACKS	PHYSIOLOGY	RANGE OF MOTION		
TORSO	COMFORT	BODY ARMOR	TREADMILLS	LOAD DISTRIBUTION		
PELVIS	COGNITION	COMPONENTS	BIOMECHANICS	DEMOGRAPHIC DATA		
DESIGN	BACKPACKS	EVALUATION	ACCEPTABILITY	DISMOUNTED SOLDIER		
MOTION	VARIABLES	HUMAN BODY	MEASUREMENT	POSTURE(PHYSIOLOGY)		
WALKING	COMPARISON	METABOLICS	LOAD CARRYING	SHOULDERS(ANATOMY)		
PRESSURE	KINEMATICS	MOVEMENTS	ANTHROPOMETRY	PERFORMANCE(HUMAN)		
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PREFACE AND ACKNOWLEDGEMENTS

The study reported here was conducted between January 2015 and July 2015 by personnel of the Biomechanics and Engineering Team, Soldier Performance Optimization Directorate, U.S. Army Combat Capabilities Development Command Soldier Center (DEVCOM SC), Natick, MA. The purpose of the study was to assess the impact of redistributing torso-borne loads from the shoulders to the hip region on variables related to the physiology, biomechanics, cognitive performance, muscle strength, and comfort of the load carrier. The effort was carried out under Project #13-155 (Impact of Redistributing Torso-Borne Loads on Neuromuscular, Biomechanical, Cognitive, and Physical Performance Variables Essential for Successful Execution of Mission Critical Tasks).

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Special recognition is owed to the Soldiers who participated in this study. Their participation and feedback were critical to the completion of this undertaking.

EXECUTIVE SUMMARY

Background and Purpose. The heavy loads carried by dismounted troops can reduce mobility, agility, and endurance. They also increase the probability of musculoskeletal injury. Surveys of musculoskeletal problems experienced by U.S. Army personnel who have deployed to Iraq and Afghanistan revealed very high incidences of neck, shoulder, and back pain that were ascribed to carrying heavy loads, and particularly to wearing armor vests. The high incidence of musculoskeletal pain and injuries experienced by dismounted troops has led the Army to undertake programs to reduce load weights, and emphasis has been placed on addressing issues associated with armor vests. Efforts include investigating materiel solutions that decrease the weight of body armor and an exploration of ways to reduce the load burden by improving body armor designs. Another design approach being considered to specifically address the issue of neck, shoulder, and back pain associated with the current military load is incorporating a capability for Soldiers to redistribute the torso-borne load by reducing the load borne on the shoulders. As currently envisioned, offloading of the shoulders would be accomplished by providing a means to lift the shoulders of the armor vest off the Soldier's shoulders and to transfer the load to the pelvic region and the legs, allowing the spine to be relatively free from loading. Understanding the effects of redistributing the Soldier's torso-borne load, in conjunction with specific offloading conditions, is a critical first step in assessing the value of this approach and in devising Army requirements for future armor vest designs. The applied research study reported here was an investigation of the impact of different amounts of shoulder offloading on Soldier performance.

Between January and July 2015, the U.S. Army Combat Capabilities Development Command – Soldier Center (DEVCOM SC) conducted a laboratory-based study in which Soldier-participants wore a military fighting load as they engaged in 10-min and 2-h trials of walking on a treadmill and executed neck flexion-extension movements under conditions that differed with regard to the proportion of the load imposed on the shoulder region. Physiological, biomechanical, cognitive, muscle strength, and subjective responses of the participants were recorded and analyzed. The purpose of the study was to assess the efficacy of providing a load redistribution capability to Soldiers and to determine whether the proportion of load reduction achievable at the shoulder is a critical consideration in design of devices to redistribute loads on the torso.

Methods. Seventeen U.S. Army enlistees ($M \pm SD$: Age 20.4 ± 3.2 years; Stature 175.3 ± 6.0 cm; Weight 75.0 ± 7.7 kg), 16 men and 1 woman, volunteered to participate in the study and gave their informed consent. The participants had recently completed Advanced Individual Training and were awaiting their first assignments to operational Army units. Their time in service was approximately 6 months. During most of the testing, participants wore an Army fighting load. The fighting load included combat boots, an Army Combat Helmet, a Tactical Assault Panel, a water-filled hydration system, and a 3rd Generation Improved Outer Tactical Vest (IOTV). Shorts and a sleeveless spandex shirt were worn in place of the blouse and trousers of the Army Combat Uniform. The Enhanced Small Arms Protective Inserts were placed in the front and the back pockets of the IOTV and the Enhanced Side Ballistic Inserts were placed in the side pockets. The participants carried a simulated M-4 carbine during activities that involved treadmill walking. The mass of the items comprising the fighting load, including the M-4, was 30.4 kg.

A commercially available load distribution device, the Dynamic Weight Distribution (DWD) system (SOURCE Tactical Gear, Virginia Beach, VA), was used to control the amount of load borne on the participants' shoulders. The device was comprised of a sheath, a spine bar, and a waist belt. The sheath was rigid and served to attach the adjustable spine bar to the IOTV. The spine bar was also attached to the waist belt with an interface designed to allow freedom of movement of the torso. The spine bar could be lengthened or shortened, lifting the load up off the wearer's shoulders or lowering the load onto the shoulders. Lifting the load off the shoulders resulted in transfer of the load to the pelvis via the spine bar. Thus, the spine bar, together with the waist belt, was the means for transferring the load between the shoulders and the hips. The mass of all components of the load distribution device was 1.13 kg.

Setting of the load distribution device to predetermined levels of shoulder offloading was accomplished using a dynamic pressure distribution measurement system (Novel Electronics, Inc., St. Paul, MN). The system included flexible pressure measurement pads consisting of elastomeric capacitive transducers. Four sensor pads were used to obtain the distributed pressure across the right and the left shoulders and the right and the left aspects of the hips. The pads were taped in place on the skin at these locations.

Six load conditions were tested by participants during the study. One condition (NL) entailed wearing only combat boots, shorts, and a spandex shirt. In a second condition (FL), the components of the fighting load were worn. In a third condition (FL/N_{off}), the FL items and the DWD were worn, but the spine bar was not engaged. The remaining three conditions also involved wear of the FL components and the DWD, but the spine bar was engaged and the DWD was used to offload the shoulders. For the three conditions that involved offloading the shoulders, the DWD was adjusted to set the proportion of the load resting on the tops of the shoulders. The baseline FL pressure, the mean of the pressure readings recorded from the tops of the left and the right shoulder regions during a 10-s period of quiet standing immediately after the participant had donned the FL components, was taken to equal the load on the shoulders. The DWD was adjusted to reduce the pressure to an amount within a range of percentages of that value: 10 to 30% (FL/L_{off}); 40 to 60% (FL/M_{off}); and 70 to 90% (FL/H_{off}). For the FL and the FL/N_{off} conditions, as well as the three conditions that entailed offloading of the shoulders (FL/L_{off}, FL/M_{off}, and FL/H_{off}), pressure readings were taken immediately before a test trial was initiated and immediately upon trial completion to document shoulder and pelvic area pressures at these points in the testing.

The activities carried out by the participants during the five testing sessions comprising the study and the principal measures taken in conjunction with the sessions were:

- Cervical Flexion Relaxation Ratio Evaluation — Neck flexion-extension movements (the cervical Flexion Relaxation Ratio) were performed under each of the six load conditions (NL, FL, FL/N_{off}, FL/L_{off}, FL/M_{off}, FL/H_{off}) during one session. Cervical erector spinae muscle activity [electromyography (EMG) of surface muscles] was recorded. Erector spinae activity during neck flexion-extension has been associated with the potential for developing neck pain during extended periods of rucksack use.
- 10-min Walking Trials — Metabolic, biomechanical, and EMG responses were recorded and subjective responses were elicited during two testing sessions consisting of trials of treadmill walking. There were five, 10-min periods of walking at each session on a treadmill set at a speed

of $1.34 \text{ m}\cdot\text{s}^{-1}$. At one session, treadmill grade was 0% and, at the other session, the grade was 9%. At each session, participants carried out one trial under each of the following load conditions: FL, FL/N_{off}, FL/L_{off}, FL/M_{off}, FL/H_{off}.

- 2-h Walking Trials — Metabolic responses and cognitive task performance (auditory go/no-go response inhibition task and visual target detection task) were recorded and subjective responses were elicited during a 2-h period of treadmill walking at a speed of $1.34 \text{ m}\cdot\text{s}^{-1}$ on a 0% grade. There were two sessions of prolonged treadmill walking. At one session, the participant was tested in the FL condition and, at the other, testing was conducted in the FL/H_{off} condition. Isometric and isokinetic strength testing was conducted before and after the 2-h trials.

Results. Pressure readings taken immediately before and immediately after each trial of treadmill walking were calculated to determine whether, for a given load condition, there were changes in pressures at the shoulder over the course of the dynamic activity of walking. The particular point of interest was changes in shoulder pressure for the three offloading conditions (FL/L_{off}, FL/M_{off}, and FL/H_{off}). The mean percentages of post-trial pressure reduction relative to the pre-trial FL pressures remained within the specified range for the FL/L_{off} condition. The percentages at the end of a trial were less than the minimum established for both the FL/M_{off} and the FL/H_{off} conditions. However, the relationships among the conditions remained the same: relative to pressure for the pre-trial baseline FL condition, the FL/H_{off} condition reflected the greatest percentage reduction in pressure, followed by the FL/M_{off} condition, with the percentage of pressure reduction being lowest for the FL/L_{off} condition.

Statistical analyses were carried out on the response measures from this study to determine whether the load conditions differed significantly ($p < .05$) from each other. The data from the 10-min treadmill walking trials were also analyzed for the effects of the grade of the walking surface (0% and 9%) and interactions between load conditions and grade.

The participants generally had positive opinions of the DWD, regardless of the level of shoulder offloading. The participants indicated that using a load distribution device for field exercises would improve their comfort during load-carriage activities; however, there were issues such as hip belt slippage that would have to be addressed. With regard to analyses of the physiological, biomechanical, cognitive, and strength measures, over all testing there were no response measures that yielded significant differences among the three load conditions that entailed offloading of the shoulders (FL/L_{off}, FL/M_{off}, FL/H_{off}). Additional findings follow.

- Cervical Flexion Relaxation Ratio Evaluation — Activity of the cervical erector spinae muscle was not significantly affected by load condition during execution of neck flexion-extension movements. Thus, the flexion-extension ratio did not yield an indication that potential for developing neck pain was greater for one of the load conditions than for another.

- 10-min Walking Trials — As expected, the grade of the walking surface had a significant effect on the rate of oxygen uptake, a measure of energy consumption, and on heart rate, indicating that walking up the 9% grade was more strenuous than walking on a level surface. At both grades, more energy was consumed with the FL/H_{off} than with the FL condition. For the kinetic (force-related) measure of second peak vertical force during walking, the force to which the body is exposed as it pushes off from the ground into the next step, a significant interaction between load and grade was largely due to the higher demand at the 9% grade. The FL/H_{off}

condition had the largest difference in force with it being lower than the forces for the other load conditions at the 0% grade and higher than the forces for the other load conditions at the 9% grade. This was a contributing factor to the statistically significant load x grade interaction. There was also a large difference in minimum hip moment between the FL and the FL/H_{off} conditions, reflecting greater demands placed on the muscles with the FL/H_{off} condition. Gait kinematics (motion-related) were unaffected by load condition, as were spatial and temporal gait variables. There was a large difference between the FL and the FL/H_{off} conditions for activity of the biceps femoris, a major hamstring muscle, with the FL/H_{off} showing greater muscle activity.

- 2-h Walking Trials — Contrasts of the FL and the FL/H_{off} conditions revealed that carbon dioxide production was higher with the FL/H_{off} than with the FL condition, but heart rate did not differ. Performance on the two cognitive tasks during the 2 h of walking was highly similar for the FL and the FL/H_{off} conditions. However, there was a tendency on the auditory go/no-go response inhibition task for the proportion of false alarms to be lower midway through the trial with the FL/H_{off} condition than with the FL condition. Isokinetic testing of trunk muscle strength indicated a significantly greater change in maximal force production at 20 deg·s⁻¹ for the FL/H_{off} than for the FL condition. From follow-up analyses, however, it was found that this difference was ascribable to pre-trial trunk muscle strength values being higher for the FL/H_{off} condition; therefore, post-trial values for the two conditions were essentially equal.

Discussion. The pressure readings at the tops of the shoulders changed during the 10-min and the 2-h treadmill trials. Regardless of load condition, the pressure increased during the trials relative to the baseline FL pressure, which was taken early in each testing session. The change in pressure is understandable given the dynamic nature of the walking activity. However, it compromised the reduction in shoulder pressure that each of the three load conditions involving offloading the shoulders had been selected to represent (FL/L_{off}: 10 to 30%; FL/M_{off}: 40 to 60%; FL/H_{off}: 70 to 90%). On the positive side, the relationship among these three conditions remained the same (lowest to highest pressure reductions were from FL/L_{off} to FL/H_{off}).

Participants' responses to the DWD were positive. Those few participants who had suggestions for improvement focused on the waist belt. Among the suggestions were that the padding on the waist belt be increased and that some means be provided to prevent the waist belt from slipping down on the body. Hip belt slippage was an issue observed for some participants, particularly during the 2-h walking session, and since this study did not include other dynamic mobility tasks, it is not known how problematic this is. For future use, participants also requested a means to adjust the amount of offloading while they are underway. The DWD has that capability, but the study protocol required that the DWD not be adjusted by the participants during testing activities.

The physiological, biomechanical, cognitive, and strength measures taken in the study revealed few significant differences among the load conditions and there were no significant differences among the three conditions that involved offloading of the shoulders. There was a finding that the energy consumption and carbon dioxide production with the FL/H_{off} condition was greater than that with the FL condition during treadmill walking. There were also increased minimum hip moments and greater activity of the biceps femoris with the FL/H_{off} condition than with the FL. Based on these results, it can be posited that setting the load distribution device at the highest

level of shoulder pressure reduction impeded push off from the ground into the next step as participants walked on the treadmill.

Conclusions and Recommendations. Within the limitations of the current study, it was observed that load redistribution can provide benefits to the Soldier in the form of improved comfort in the shoulders; however, the potential remains for increasing discomfort in the hips. Load redistribution can be achieved by a device that physically redistributes the load from the shoulders to the hips or by redistributing the carried load differently between the torso and the hip region. Recommendations regarding design of a load redistribution device are put forward here.

- As to the proportion of load reduction at the shoulders that the device should be designed to achieve, a greater reduction will not necessarily result in a better product. The design of the waist belt of the device is critical and may be a major determinant of acceptable levels of pressure reduction at the shoulders.
- With offloading of the shoulders, there is transfer of the load to the hips. During development of load distribution devices, the devices should be placed on people regularly and pressure sensor pads used to check contact pressures at the skin surface, not only in the shoulder region, but in the hip region as well. Mechanical loads can occlude blood flow, damage soft tissue, and induce pain. Regular checks of the design are a means to ensure that recommended safe pressure limits at the skin are not exceeded.
- The device in this study achieves load redistribution by lifting the body armor up and away from the shoulders, resulting in the body armor being displaced from its intended position. This can result in destabilizing of the torso load and shifting the covered area of ballistic protection. The design of the device must take this into account. A human factors/anthropometric assessment of any device should occur to ensure that ballistic protection is not compromised during the load distribution application.
- The load distribution device selected for use in the current study could be adjusted to vary the amount of shoulder offloading, a requirement for the testing protocol executed here. The amount of offloading was set by the investigators. The participants indicated that they liked the adjustment feature and wanted a device that could be adjusted over a range of offloading levels while a Soldier was underway.
- A related design feature viewed positively by the participants was the ability to make initial adjustments of the device and to don the device without assistance.

During development of load distribution systems, there will be a need to evaluate design concepts and prototypes as they become available. Recommendations regarding future testing on Soldiers follow.

- Use of pressure sensor pads at the shoulders and the hips, as was done in the current study, should be continued in future testing to assess the system's offloading capability. Recording of pressures at the beginning and at the end of a physical activity, with the participant in a stationary standing position, is recommended. If testing involves setting

of shoulder pressures as was done in the current study, pilot testing should be conducted to characterize pressure changes during performance of the activity. In the current study, the baseline pressure readings were taken during a period of quiet standing and the pressure reduction settings for the offloading conditions were implemented immediately upon outfitting the participants in the appropriate attire for the test condition. Thus, the participants did not have the opportunity to move around in the attire and to make minor adjustments that may have stabilized the items being worn. In the future, pilot testing should be carried out to assess whether having participants engage in short periods of dynamic activity, after they have been outfitted and before pressure settings are made, can minimize the changes in pressure readings over the course of testing.

- Physiological, biomechanical, cognitive, muscle strength and subjective data were collected and analyzed in the current study and should be collected in future studies that entail locomotor activity performance with load distribution devices.
- This study was limited to analyses of treadmill walking. In future work on load redistribution, the repertoire of physical activities should be expanded to include running, rushing, dive to prone, and rifle firing, at a minimum.
- Use of a load distribution device with a fighting load was investigated in the current study. In future efforts, an approach march load should be included so that testing of the device under a condition in which a rucksack is used can be accomplished.
- The cervical FRR evaluation included in the current study did not yield any significant findings. However, cervical FRR testing should be included in future studies in which a rucksack is used along with the load distribution device.
- The device was not evaluated on female Soldiers. The variations in biomechanics of females versus males should be assessed.

IMPACT OF REDISTRIBUTING A TORSO-BORNE LOAD ON SOLDIER PHYSIOLOGY, BIOMECHANICS, COGNITIVE PERFORMANCE, STRENGTH, AND COMFORT

1 INTRODUCTION

This report details an applied research study performed by the U.S. Army Combat Capabilities Development Command – Soldier Center (DEVCOM SC) from January 2015 to July 2015. Soldiers serving as study participants were outfitted in a standard Army armor vest and the other components of a military fighting load as they executed neck flexion-extension movements and engaged in 10-min and 2-h trials of walking on a treadmill under conditions that differed with regard to the proportion of the load imposed on the shoulder region. Using a device that interfaced with the armor vest and also had a hip belt, the load was redistributed between the shoulders and the hip region by setting pressures on the shoulders within predetermined ranges. Physiological, biomechanical, cognitive, and muscle strength variables were analyzed, along with the participants' opinions regarding carrying the load, to assess the efficacy of providing a load redistribution capability to Soldiers. The variables were also examined to determine whether the proportion of load reduction achievable at the shoulders is a critical consideration in design of devices to redistribute loads on the torso.

1.1 Background

In the U.S. Army, the three categories of loads that dismounted Soldiers may carry during combat operations are a fighting load, an approach march load, and an emergency approach march load (Department of the U.S. Army, 2017). The fighting load is the lightest of the three, and Soldiers are outfitted with this load for the duration of field operations. The fighting load is comprised of items needed for close combat. It includes a weapon, field clothing, boots, a hydration system with a supply of water carried on the back, a carrier with pouches containing a basic load of ammunition and grenades worn on the front of the body at about chest level, a ballistic protective helmet, and an armor vest with ballistic protective plates covering the front, back, and sides of the torso. The approach march and the emergency approach march loads are comprised of the fighting load and additional equipment required for Soldiers to fight and survive during prolonged dynamic operations, such as more ammunition, batteries, clothing, food, and water (Department of the U.S. Army, 2017). The additional items are carried in a rucksack. The rucksack is doffed when there is direct contact with the enemy, reducing the items that the Soldier carries to the components of the fighting load.

According to U.S. Army guidance (Department of the U.S. Army, 2017), the ideal weight of a fighting load is about 30% of an individual's body weight and the ideal weight of an approach march load is about 45% of body weight. However, the loads borne by Soldiers during combat operations often exceed these limits. In a survey of load weights carried by U.S. Army infantry squads during operations in Afghanistan, it was reported that, for 48- to 72-h missions, the fighting loads for some squad positions were as much as 44% of the load carrier's body weight, the approach march loads as much as 78%, and the emergency approach march loads as much as 98% (Task Force Devil Combined Arms Assessment Team, 2003). Riflemen had light loads relative to individuals in other squad positions, and the survey data indicated that fighting loads

averaged about 36%, approach march loads averaged about 55%, and emergency approach march loads averaged about 71% of the body weights of the riflemen (Task Force Devil Combined Arms Assessment Team, 2003).

The negative implications of carrying heavy loads include reduced mobility, agility, and endurance (Attwells, Birrell, Hooper, & Mansfield, 2006). Research has also shown that carrying loads on the torso can increase spinal compression (Chow, Li, & Pope, 2011) and degrade balance control and situational awareness (May, Tomporowski, & Ferrara, 2009). From a military perspective, a critical outcome of carrying heavy loads is the increased probability of musculoskeletal injuries (Cohen, Gallagher, Davis, Griffith, & Carragee, 2012; Konitzer, Brininger, & Reid, 2008; Porter & Stryker, 2011). Rucksack palsy is among the types of injuries associated with load carrying. It is a traction injury of the fifth and sixth cervical (C5 and C6) nerve roots of the upper brachial plexus. It has been attributed to the carrying of heavy rucksack loads suspended from the shoulders (Knapik, Reynolds, & Harman, 2004; Wilson, 1987). Symptoms include numbness, paralysis, cramping, and minor pain in the shoulder girdle, elbow flexors, and wrist extensors. Reduction of the pressure on the shoulders through use of rucksack waist belts has been found to reduce the incidence of rucksack palsy (Bessen, Belcher, & Franklin, 1987).

The occurrence of musculoskeletal injuries is costly in terms of time lost from duty for recuperation and medical resource requirements. For example, the rate of recovery from rucksack palsy can be very slow, with periods from 3 to 22 weeks being required for full recovery (Bessen et al., 1987). Further, such nonbattle injuries compromise military readiness during deployments. It has been reported that musculoskeletal injuries in deployed environments account for over twice as many evacuations as do combat injuries (Skeehan et al., 2009).

In a survey of musculoskeletal problems occurring among 850 U.S. Army personnel deployed to Iraq, Konitzer et al. (2008) found a very high incidence of neck, shoulder, and back pain. About 31% of the troops reported experiencing neck pain, 41% shoulder pain, and 66% back pain at some time during deployment. When asked about pain prior to deployment, a lower number of personnel responded that they had had pain at one or more of these sites before beginning duty in Iraq. Focusing on pain in the spinal area, Cohen et al. (2012) also found that complaints of back pain increased in number when troops were on deployments, compared with the number of complaints when troops were “in garrison”. In investigating neck, shoulder, and back problems occurring during deployments of military personnel to Iraq and Afghanistan, Konitzer et al. (2008), Cohen et al. (2012), and other researchers (Nagai et al., 2016; Roy, Ritland, & Sharp, 2015; Roy et al., 2016) maintained that the carrying of heavy loads, and particularly wear of the armor vest component of a fighting load, results in pain and injury. In their responses on surveys regarding occurrences of musculoskeletal pain, deployed troops themselves have identified armor vests as being a major contributor to the neck, shoulder, and back pain they experience (Konitzer et al., 2008; Roy et al., 2015). Konitzer et al. (2008) found significant, positive relationships between reported severity of neck, shoulder, and back pain and the amount of time per day that Soldiers reported wearing an armor vest. They also found that Soldiers who wore an armor vest for 4 h or more each day reported significantly higher amounts of musculoskeletal pain than Soldiers who wore the body armor for fewer than 4 h.

The high incidence of musculoskeletal pain and injuries experienced in Iraq and Afghanistan by dismounted troops has led the U.S. Army and the U.S. Marine Corps (USMC) to undertake

programs to reduce load weights, and emphasis has been placed on addressing issues associated with armor vests (U.S. Government Accountability Office, 2017). Current armor vests and other ballistic protective items that may be attached to the vests were introduced into the U.S. military services in the early 2000s to protect against the threats dismounted troops were facing in Iraq and Afghanistan. The vest itself is soft armor and hard ballistic protective plates can be added to the front, back, and sides of the vest. A removable protective collar, throat and neck protectors, a groin protector, and deltoid and axillary pieces are also available to provide further body coverage. The weight of the U.S. Army vest with the hard plates in it comprises about 40% of the total weight of a rifleman's fighting load and 30% of a rifleman's approach march load (Task Force Devil Combined Arms Assessment Team, 2003). Thus, achieving weight reductions in the vest and ballistic protective items that attach to it is an important step in reducing the load burden on dismounted troops.

The U.S. Army efforts in load reduction are addressing the helmet and other personal protective equipment, in addition to the armor vest. They include development of a plan to decrease the weight of armor plates by 20% by employing new technologies and manufacturing techniques (U.S. Government Accountability Office, 2017). The U.S. Army and the USMC are also exploring ways to reduce the load burden by improving armor vest designs. The Australian Army, as well, is pursuing armor vest improvements in light of the occurrence of musculoskeletal injuries and reports of discomfort associated with the use of body armor (Lenton, 2017).

One design approach to specifically address the issue of neck, shoulder, and back pain and injury potential associated with the current military load is incorporating a capability for the load carrier to redistribute the torso-borne load by reducing the load on the shoulders. As currently envisioned, offloading of the shoulders would be accomplished by providing a means to lift the shoulders of the armor vest off the load-carrier's shoulders and to transfer the load to the pelvic region and the legs. This concept would allow the shoulders to be relatively free from loading and would place some of the load on the hips, a major load-bearing structure of the body.

To examine the viability of redistributing loads carried by Marines, the USMC devised a prototype of a novel body armor system consisting of an armor plate carrier vest with an internal frame. A portion of the internal frame was a single vertical strut, which extended down the midline of the user's back, connecting the vest to a waist belt. The strut was designed to reduce the load on the shoulders and to distribute the load evenly over the back. Kelly, Jaworski, and Sessoms (2014) conducted an initial test of the item on 10 male Marines under laboratory conditions. Testing included the recording of heart rate, muscle activity, gait kinematics, and subjective ratings of discomfort as the Marines walked for 1.6 km (1 mi) on a treadmill set at a 0% grade and a speed of $1.34 \text{ m}\cdot\text{s}^{-1}$ ($3.0 \text{ mi}\cdot\text{h}^{-1}$). At this distance and speed, trial duration equaled approximately 20 min. The treadmill was part of a Computer Assisted Rehabilitation Environment (CAREN) system. At random intervals, targets were presented on a 3-m (10-ft) high curved screen that was part of the CAREN system and partially surrounded the treadmill. Participants were to fire a mock rifle at the targets and time to fire was recorded. The participants also walked overground at self-selected speeds as kinematic data were collected for computation of spatial and temporal gait variables. The Marines were tested in the prototype body armor system alone, with a hydration system added, and with the addition of a hydration system and an assault pack. The total masses of the external loads on the body for these three conditions

averaged 18.1, 25.4, and 34.7 kg, respectively (40.0, 56.0, and 76.5 lb, respectively). Testing was also conducted with the Marines outfitted in a standard USMC armor vest alone, with the hydration system, and with the hydration system and an assault pack. The masses of the external loads under these three conditions averaged 17.4, 24.8, and 34.0 kg, respectively (38.4, 54.7, and 75.0 lb, respectively).

Kelly et al. (2014) reported a number of statistically significant effects of load mass. For example, heart rate and caloric expenditure increased significantly with the mass of the load, as did the maximum forward lean of the trunk and the participants' ratings of overall feelings of exertion. However, there were few measures that yielded significant differences between the prototype system and the standard armor vest. Physiological responses and trunk lean were not significantly affected by the armor vest system worn. Overall back discomfort was rated significantly lower with the prototype than with the standard armor and time to fire the weapon was found to be significantly faster, by about 0.2 s, with the prototype. Kelly et al. (2014) did not present results of statistical analyses performed on the muscle activity data, but they maintained that the mean data for the quadratus lumborum and the multifidus muscles, which stabilize the back, indicated lower activity levels with the prototype than with the standard armor for each load mass. Kelly et al. (2014) posited that the lower level of activity of these muscles was attributable to the stabilizing effect of the prototype, including greater abdominal pressure and improved postural alignment compared with the standard armor. Kelly et al. (2014) also maintained that the quadriceps and the gastrocnemius muscles revealed somewhat higher activity levels for the approximately 25-kg (55-lb) load when the prototype was used, compared with use of the standard armor.

As a follow-on to the laboratory testing, Kelly, Niederberger, Sturdy, and Sessoms (2017) conducted a field evaluation with an additional group of 10 male Marines. These Marines participated in a 24-km (15-mi) hike during which their subjective responses were recorded. Employing a randomized, crossover, repeated measures design, the Marines wore the prototype body armor with a hydration system and an assault pack for half the distance of the hike and the standard USMC armor vest with the hydration system and the assault pack for the other half of the hike. The total masses of both loads were approximately 34.0 kg (75.0 lb). The Marines reported reduced overall effort and reduced back discomfort when hiking with the prototype compared with the standard armor.

Approaches for redistributing loads carried by Australian service members have also been examined. With 20 Australian Army male reservists serving as participants, Lenton and his colleagues (Lenton, 2017; Lenton, Bishop, Saxby, et al., 2018; Lenton, Doyle, Lloyd, et al., 2018; Lenton, Doyle, Saxby, et al., 2018; Lenton et al., 2019) tested five systems designed to offload the shoulders and transfer the load to the hips. Four of the five load distribution systems studied consisted of an armor vest, a waist belt, and vertical struts, which connected the vest to the waist belt (Lenton, 2017). The remaining system included a waist belt and struts, but this system was worn with the standard Australian Army armor vest. Testing also included the standard Australian Army armor vest, which did not have a load redistribution capability.

Testing of the Australian Army reservists consisted of treadmill walking at $1.53 \text{ m}\cdot\text{s}^{-1}$ ($3.42 \text{ mi}\cdot\text{h}^{-1}$) for 10 min and then at $1.80 \text{ m}\cdot\text{s}^{-1}$ ($4.03 \text{ mi}\cdot\text{h}^{-1}$) for 10 min (Lenton, 2017). Kinematic, kinetic, and muscle activity data were captured for 30 s during the final minute of the 10-min walking periods. Each participant carried out the treadmill walking in the five load distribution systems

and in the standard armor vest under two load mass conditions, 15-kg (33-lb) and 30-kg (72.8-lb). The lighter load consisted of a load distribution system or the standard vest. Pouches were attached to the vests and weighted to simulate ammunition magazines, grenades, and a radio. A weighted backpack was added to these items to achieve the heavier 30-kg (72.8-lb) load.

A focus of Lenton and his colleagues was assessing whether redistributing loads to the hips would alter gait mechanics in a manner that increased the likelihood of musculoskeletal injuries compared with loads borne on the shoulders. Lenton et al. (2019) reported that use of the load distribution systems did not increase hip, knee, or ankle joint loading compared with use of the standard armor vest alone. Further, with the 15-kg (33-lb), but not with the 30-kg (72.8-lb) load, the participants maintained a more upright posture and had lower hip abduction moments when wearing the load distribution devices than when using the standard vest alone. Lenton et al. (2019) concluded that load distribution devices do not have a negative effect on joint kinematics and may even reduce stresses on the lower extremities.

In further analysis of the study data, Lenton, Bishop, Saxby, et al. (2018) used muscle activity data and carried out neuromusculoskeletal modeling to estimate tibiofemoral joint contact forces. Significant differences were not obtained between the load distribution systems or between any of these systems and the standard armor vest alone. These findings were interpreted as providing evidence that redistributing loads to the hips does not alter the likelihood of occurrence of musculoskeletal injuries.

In their testing of a prototype body armor system for USMC use, Kelly et al. (2014, 2017) did not measure the skin contact pressures in the shoulder area imposed by the standard USMC armor vest and by the prototype body armor system. Therefore, they had no basis to assess the amount of offloading achieved with the prototype. Lenton, Doyle, Saxby, et al. (2018), on the other hand, used pressure sensor pads placed on the skin in the shoulder area to make direct measurements of the pressures associated with the different systems they tested. Pressure measurements were recorded for 30 s toward the end of each 10-min walking period. The pressure data from the right shoulder area were processed to obtain total force, which was defined as the sum of forces from all activated sensors for each frame in the 30-s data capture period. Maximum pressure from the same shoulder region was also obtained by identifying the highest pressure reading from any sensor for every frame in the data capture period. Prior to analyzing the total force and the maximum pressure data, means were calculated over the data for the 30-s recording period.

In addition to measuring skin contact pressures, Lenton, Doyle, Saxby, et al. (2018) elicited subjective responses from the 20 Australian Army reservists who served as study participants. They administered the Rating of Perceived Exertion (RPE) scale (Borg, 1970, 1982) toward the end of the walking period at each speed [$1.53 \text{ m}\cdot\text{s}^{-1}$ ($3.42 \text{ mi}\cdot\text{h}^{-1}$) and $1.80 \text{ m}\cdot\text{s}^{-1}$ ($4.03 \text{ mi}\cdot\text{h}^{-1}$)]. They also administered questionnaires to obtain participants' opinions of the amount of load borne on the shoulders and the comfort of the systems tested.

Lenton, Doyle, Saxby, et al. (2018) did not find significant effects of walking speed on their dependent measures. Therefore, they pooled the data for the two levels of speed and proceeded to analyze their pressure and RPE data for the armor system and the load mass variables. The pressure data collected by Lenton, Doyle, Saxby, et al. (2018) revealed differences among the load distribution systems in the extent to which total force and maximum pressure were changed

relative to the pressure measures taken when the standard armor vest alone was worn. Total forces with the load distribution systems were reduced by 18 to 29% relative to the standard vest alone and maximum pressures with the systems ranged from approximately 80% to approximately 112% of the values with the standard vest.

On the RPE, higher ratings of perceived exertion were obtained with the 30-kg than with the 15-kg load, but the RPE responses were not significantly affected by the armor system used (Lenton, Doyle, Saxby, et al., 2018). Load mass also had a significant effect on participants' ratings of the amount of load on their shoulders, with fewer participants perceiving a reduction of load on the shoulders when they carried the heavier load. Perceptions of load reduction at the shoulders were also significantly affected by the system worn: more participants reported feeling a greater reduction of load on the shoulder with the load distribution systems than with the standard armor alone. In addition, participants reported less discomfort at the shoulders and more discomfort at the hips with the load distribution systems than with the standard armor.

The results reported by Kelly et al. (2014, 2017) and by Lenton, Doyle, Saxby, et al. (2018) indicate that armor vests incorporating a load redistribution function for offloading the shoulders can improve users' comfort. Positive findings regarding shoulder offloading suggest that development of design requirements for load distribution systems should continue with the goal of providing military users with systems that effectively redistribute the load, are comfortable, and do not impose physiological or biomechanical burdens on the load carrier. One effort addressing load distribution system designs is the applied research study reported here.

Lenton, Doyle, Saxby, et al. (2018) collected pressure data from sensor pads placed in the shoulder area. In the current study, sensor pads were also located in the hip region in order to measure skin contact pressures in that location associated with load redistribution. Kelly et al. (2014, 2017) and Lenton and his colleagues (Lenton, 2017; Lenton, Bishop, Saxby, et al., 2018; Lenton, Doyle, Lloyd, et al., 2018; Lenton, Doyle, Saxby, et al., 2018; Lenton et al., 2019) tested the effectiveness of a number of systems, each comprised of a load distribution device and an armor vest. A distribution device and a vest were unique to each of the different systems under test. Only one armor vest, a standard Army item, and one load distribution device were included in the current study. Further, the load distribution device used here was adjustable, allowing for selection of the proportion of the load to be imposed on the shoulder region. The standard armor was tested alone, without a load distribution device, as well as with the device. The current study was conducted to examine the efficacy of providing a load redistribution capability to Soldiers and to determine whether the proportion of the load imposed on the shoulders is a critical feature in the design of a load distribution device. Subjective responses of the Soldiers serving as test participants were elicited and physiological, biomechanical, cognitive, and muscle strength measurements were made as study participants walked on a treadmill for 10-min and for 2-h periods. A number of the variables analyzed in the current study have been used in past research to examine the effects on Soldier performance of body-borne loads, such as loaded backpacks.

1.2 Current Study

1.2.1 Pressure Measurements

The systems for offloading the shoulders used in the studies conducted by Kelly et al. (2014, 2017) and by Lenton, Doyle, Saxby, et al. (2018) did not have a means of varying the amount of

offloading from the shoulders to the hips. Also, Kelly et al. (2014, 2017) did not measure the pressure at the shoulders. In the study described in this report, contact pressures were measured at the skin surface in the shoulder and in the pelvic regions of the body using pressure sensor pads affixed to the skin. The pads were comprised of a matrix of individual sensors. Guided by the outputs of the sensors, the investigators adjusted a load distribution device to achieve predetermined levels of pressure at the shoulders.

Contact pressures at the skin surface have been measured in a number of load-carriage studies to evaluate equipment designs and materials (Lenton, Doyle, Saxby, et al., 2018; Martin & Hooper, 2001), to identify threshold mechanical loads related to occlusion of blood flow to the skin (Hadid, Epstein, Shabshin, & Gefen, 2011), and to better understand the relationship between subjective perceptions of discomfort and the mechanical stresses and strains on skin and subcutaneous soft tissue imposed by load-carriage equipment elements, such as shoulder straps and waist belts (Stevenson et al., 2004; Wettenschwiler et al., 2015). The shoulders are more susceptible to skin and soft tissue damage when subjected to sustained loading than other load-bearing body sites, including the hip area (Birrell & Hooper, 2007; Holewijn, 1990; Scribano, Burns, & Barron, 1970). Thus, as in the current study, the body sites selected by other researchers for the taking of pressure measurements have been the shoulder region primarily and, secondarily, the pelvic area.

Research has been conducted to determine the contact pressure at the shoulders that should not be exceeded if soft tissue injury; neck, shoulder, and back pain; and rucksack palsy are to be avoided. The recommended values differ somewhat with the study objectives and the experimental methods employed, including exposure durations and measurement techniques. Stevenson et al. (2004) recommended that average skin contact pressures in the load carrier's shoulder and lumbar areas be less than 20 kPa and that maximum point pressures in the same areas of the body be less than 45 kPa. Holewijn (1990) projected that pressure applied on the skin under shoulder straps should be below 10 kPa, particularly during periods of prolonged load carrying.

In most load-carriage studies in which contact pressures have been measured, pressure sensor outputs were used to document the effects of some experimental manipulation, such as effects on shoulder pressures of different rucksack shoulder strap materials (Martin & Hooper, 2001). In the current study, the pressure sensor outputs were used in this manner as well, but additionally they were used to provide feedback to the investigators as they adjusted the load distribution device on the test participants to specific levels of shoulder offloading. There are a number of dependent measures that have been calculated from pressure readings. Some researchers have treated the pressure sensor outputs to obtain maximum pressure, defined as the highest reading obtained from any single sensor in the sensor pad or in some region of the pad (Lenton, Doyle, Saxby, et al., 2018; Martin & Hooper, 2001). Others have obtained an average pressure by calculating a mean over the readings from the individual sensors in a pad or in a region of the pad (Hadid et al., 2011). The pressure sensor data in the current study were treated to obtain average pressure. Average pressure was determined to be an appropriate measure of pressure distribution over an area of the body and, therefore, a useful metric for setting the shoulder offloading levels. For some of the experimental conditions in the current study, further calculations were done on an individual participant's average pressure data to obtain values expressed as percentages of baseline readings taken on that individual.

Pressure sensor systems have limitations that may lead to sensor outputs deviating from actual contact pressures. For one, the sensors measure pressure normal to their surfaces and, thus, shear strain is not measured. There also may be variations in sensitivity across the individual sensors that make up a pad, output creep with constant applied force, and changes due to temperature (Lenton, Doyle, Saxby, et al., 2018; Morin, Bryant, Reid, & Whiteside, 2001). When the sensor pads are placed on the body, inaccuracies may be introduced by body surface curvatures and surface compliance (Wettenschwiler et al., 2015). In the current study, sensor limitations were recognized by testing each participant in all experimental conditions, as well as by setting some conditions as percentages of a baseline pressure measured on each individual participant.

1.2.2 Load Distribution Devices

Unlike the studies conducted by Kelly et al. (2014, 2017) and by Lenton and his colleagues (Lenton, 2017; Lenton, Bishop, Saxby, et al., 2018; Lenton, Doyle, Lloyd, et al., 2018; Lenton, Doyle, Saxby, et al., 2018; Lenton et al., 2019), the current study was not an assessment of acceptability of particular load distribution devices for use by military personnel. Rather, the research was conducted to examine the effects on Soldier performance of redistributing a torso-borne load in a controlled manner. The load distribution device selected for the current study was a commercially available item that interfaced with a standard U.S. Army armor vest and could be adjusted to vary the pressure at the shoulders. Through pilot testing, several levels of shoulder pressure reduction relative to a baseline condition were selected for use in the current study (Carboni, Gregorczyk, & Mitchell, 2014).

There are a number of load distribution devices available for purchase that have been developed by private industry and are purported to redistribute military loads from the shoulders and upper back to the pelvic region. In preparation for the current study, a pilot study was carried out to identify a load distribution device that could be systematically adjusted to achieve various levels of shoulder offloading (Carboni et al., 2014). Several commercial load distribution devices were investigated. The Dynamic Weight Distribution (DWD) from SOURCE Tactical Gear, Inc. (Virginia Beach, VA) proved to be acceptable. The company had developed the DWD for use with a specific armor vest, which they also developed. However, pilot testing indicated that the DWD was adaptable for use with the standard Army armor vest. To achieve offloading of the shoulders, the DWD raised the vest, lifting the shoulder straps of the vest above the wearer's shoulders. At the lowest offloading setting, the shoulder straps were about 0.5 cm (0.2 in.) above the tops of the shoulders and, at the highest setting, the shoulder straps were up to 2.5 cm (1.0 in.) above the tops of the shoulders.

Seven individuals participated in the pilot testing (Carboni et al., 2014). Pressures were measured at the tops of their shoulders as the DWD was adjusted. Shoulder pressures were also measured while the individuals wore the armor vest without the DWD. It was found that average pressure, calculated from the outputs of all individual sensors in a region of a pressure sensor pad, was a reliable measure with small variances. Shoulder pressures were obtained when the armor vest was worn alone and with the DWD attached and set to various offloading levels. With the armor vest alone as a baseline condition, pressure reductions at the shoulders when the DWD was also used were expressed as percentages of the baseline.

The pilot testing (Carboni et al., 2014) revealed that three distinct levels of offloading were achievable using the DWD device ($M \pm SD$): 24% $\pm$ 4; 53% $\pm$ 10; and 79% $\pm$ 15 ($p < .05$). Due

to differences between individuals in the fit of the armor and the DWD and differences within individuals in DWD adjustments, identical percentages of offloading could not be achieved from trial to trial. Therefore, three ranges of pressure reduction were defined, based upon the percentage values. The three shoulder offloading conditions determined through the pilot testing were: low (10-30% reduction in shoulder pressure relative to the armor vest alone); medium (40-60% reduction in shoulder pressure relative to the armor vest alone); and high (70-90% reduction in shoulder pressure relative to the armor vest alone). Two more conditions were examined during pilot testing and subsequently included in the current study. One was the armor vest alone and the other was the armor vest outfitted with the DWD, but the DWD was not engaged to function as an offloading device. The weight of the items comprising this last condition equaled the weight of the items for the conditions in which offloading was used. The condition in which the armor vest alone was tested was lighter by 1.13 kg (2.5 lb), the weight of the DWD.

1.2.3 Study Protocol

Participants in the studies conducted by Kelly et al. (2014) and by Lenton and his colleagues (Lenton, 2017; Lenton, Bishop, Saxby, et al., 2018; Lenton, Doyle, Lloyd, et al., 2018; Lenton, Doyle, Saxby, et al., 2018; Lenton et al., 2019) walked under controlled conditions while carrying the load configurations being studied. The current study, as well, included walking. Participants were tested in the different load conditions during 10-min trials and during 2-h trials of walking on a treadmill at externally controlled speeds and grades. The dependent variables included measures of participants' metabolics, gait kinetics and kinematics, muscle activity, and cognitive function. Muscle strength (isometric and isokinetic) was also measured before and after the 2-h walking trials. Participants' ratings of perceived exertion and of pain were obtained throughout the study, as were their opinions regarding the comfort and the utility of the load distribution device. An additional aspect of the current study, aside from the walking activities and the dependent variables associated with them, was measurement of the cervical Flexion-Relaxation Ratio (FRR). For this, participants assumed a standing position while muscle activity of the cervical erector spinae was recorded (Lee, Yoo, An, Kim, & Oh, 2011).

In the body of research into the effects of military load carriage on Soldier performance, it is also the case that walking has been an activity typically studied, and the response measures employed here during the walking trials have been used in previous investigations into effects of carried loads (Knapik, Harman, & Reynolds, 1996; Knapik et al., 2004). Much of the literature on load carrying deals with the effects of varying the weight of loads placed in rucksacks. In the current study, however, participants were tested in a fighting load configuration — a rucksack was not carried. The only item placed on the back was a hydration system weighing 3.9 kg (6.5 lb), which was worn throughout testing. Further, load weight was not an independent variable in the current study. The difference between the heaviest and the lightest experimental conditions tested here was 1.13 kg (2.5 lb), which was the weight of a load distribution device. Thus, findings from the load carriage literature as they relate to load weight effects have limited applicability in the context of the current study. However, some research has been done that has focused on varying the placement of loads on the torso, rather than on varying the load mass on the body. These studies are more relevant to the current study, although a rucksack was used in some of the investigations and load placement was manipulated by varying the location of weights within the rucksack.

1.2.3.1 Cervical FRR

To address the question of how redistributing the load from the shoulders to the hips affects the potential for developing neck pain, the cervical FRR of the participants in the current study was examined using electromyographic (EMG) techniques while the participants carried the fighting load and the various load conditions. This assessment built on the seminal work of Floyd and Silver (1951), who recorded and analyzed activity of the lumbar erector spinae during execution of a controlled neck flexion-extension movement. Floyd and Silver (1951) found that flexing of the trunk from an upright standing to a full flexion position was accompanied by relaxation of the lower back erector spinae, as evidenced by minimal EMG activity at complete flexion. This “silencing” of the lumbar extensor musculature during an upright standing to full trunk flexion maneuver has been found to be modulated by the clinical status of the individual, specifically the presence or absence of low back pain (Colloca & Hinrichs, 2005; Kaigle, Wessberg, & Hansson, 1998). Kaigle et al. (1998) reported a mean reduction in EMG activity of only 13% in individuals who experienced low back pain, compared with a mean reduction of 78% among healthy individuals, free of back pain.

In addition to its occurrence in the lumbar region, the flexion-relaxation phenomenon has been observed in the cervical spine (Maroufi, Ahmadi, & Mousavi Khatir, 2013; Murphy, Marshall, & Taylor, 2010). In this case, the movement performed consists of neck flexion and extension. As was found for the lumbar region, the cervical flexion-relaxation phenomenon appears to be modulated by the health status of the individual, specifically the presence or absence of neck pain (Pialasse, Dubois, Choquette, Lafond, & Descarreaux, 2009). In addition, the cervical flexion-relaxation phenomenon has been found to be affected by the external load carried on the body. Lee et al. (2011) recorded from the erector spinae at the level of the 4th cervical vertebra (C4) as men executed neck flexion-extension movements. The men were tested without a rucksack and with rucksack loads equaling 10% and 20% of body mass [approximately 7 kg (15 lb) and 14 kg (31 kg), respectively, based on mean body mass of the participants]. Lee et al. (2011) divided the mean value of muscle activity during the extension phase by the mean value of muscle activity during the flexion phase to obtain a dimensionless quantity referred to as the cervical FRR. They reported that the FRR significantly decreased as load mass increased, indicating that muscle activity during the flexion phase increased relative to that during the extension phase as the mass increased. Lee et al. (2011) asserted that their findings of a decrease in the FRR with increasing load mass may indicate the potential for developing neck pain with continuous use of rucksacks. The FRR measure was included in the current study to investigate whether increasing load mass and redistributing a load from the shoulders to the hips affected the FRR, suggesting the possibility of development of neck pain when using a load distribution device.

1.2.3.2 Metabolics

For marching with rucksack loads, the rate of oxygen uptake ($\dot{V}O_2$), an index of energy consumption, has been demonstrated to increase with increases in load mass (Beekley, Alt, Buckley, Duffey, & Crowder, 2007; Sagiv, Ben-Sira, Sagiv, Werber, & Rotstein, 1994; Soule, Pandolf, & Goldman, 1978). Factors other than the weight of the external load borne on the body have also been found to increase energy consumption. These include walking velocity, grade of the walking surface, and the body mass of the load carrier (Soule & Goldman, 1972; Soule et al., 1978). In addition, prolonged carrying of heavy loads can result in higher oxygen uptake late in a

march compared with earlier in the march period (Epstein, Rosenblum, Burstein, & Sawka, 1988; Patton, Kaszuba, Mello, & Reynolds, 1991).

Instead of contrasting the effects of different load masses carried in rucksacks, DeMaio et al. (2009) compared data acquired on military volunteers performing with and without an armor vest and helmet, a weight difference of 9.8 kg (21.6 lb). DeMaio et al. (2009) reported that body armor loads significantly reduced aerobic capacity, by 11%, when the participants performed an incremental maximum treadmill test designed to represent a realistic warfighter scenario, carrying a load up a steep hill.

Although load distribution effects on energy consumption have not been as extensively studied as the effects of load mass variations, a number of investigations have been performed in which the position of a load within a rucksack has been manipulated. Oxygen uptake during walking on a 0% grade has been found to be lower when the load in the rucksack is placed high relative to the load carrier's back than when it is placed in a low position (Abe, Muraki, & Yasukouchi, 2008; Obusek, Harman, Frykman, Palmer, & Bills, 1997; Stuempfle, Drury, & Wilson, 2004). Liu (2007) evaluated the effects of load placement in a rucksack on participants walking for about 10 min on a 0% and on a 6% grade. Weights equaling 15% of study participants' mean body mass, or approximately 11.0 kg (24.2 lb), were located either high or low in the rucksack. Regardless of load position, oxygen uptake was significantly higher when walking up the 6% grade than when walking on the level. Considering load position effects at the 0% grade, mean $\dot{V}O_2$ was lower with the load in the high position, but the difference due to load position was not statistically significant. However, for the 6% grade, Liu (2007) found that $\dot{V}O_2$ was significantly greater when the load was in the high position compared with the low position, suggesting that optimum load center of mass location in the backpack may be dependent on grade. Given Liu's (2007) findings, participants in the current study were tested on a horizontal treadmill surface and while ascending a 9% grade on a treadmill to assess whether walking grade and load condition interacted to affect energy consumption.

A few studies have been done in which the suspension of the load on the body has been investigated. In this work, rather than vary load placement within a rucksack, the portion of the load suspended from the shoulders has been varied and displaced to the hips. In one of these studies, Holewijn (1990) tested two rucksack designs. One rucksack, which had shoulder straps and an integral waist belt, was designed to place most of the load on the hips. With the other rucksack, which had shoulder straps, but not an integral waist belt, most of the weight was borne on the shoulders. Men carried loads of 5.4 or 10.4 kg (11.9 or 23.0 lb) in the rucksacks while walking on a level surface for 20 min at a speed of 1.33 m·s⁻¹ (3.0 mi·h⁻¹). The loads approximated 7 to 14% of the mean body mass of the men. Holewijn (1990) reported that energy consumption did not differ significantly between the rucksack designs with either load mass. Winsmann and Goldman (1976) investigated two rucksack designs that were similar to those studied by Holewijn (1990) to the extent that the load was suspended from the shoulders with one design and was redistributed to the hips with the other. Soldiers participating in this study walked for 20 min on the level and also ascended a 6% grade with a rucksack load of 30 kg (66 lb), which was approximately 39% of the mean body mass of the participants. Like Holewijn (1990), Winsmann and Goldman (1976) did not find differences in energy consumption attributable to design of the rucksack suspension system.

Holewijn (1990) and Winsmann and Goldman (1976) studied the amount of load borne on the shoulders by selecting rucksacks with suspension systems purposely designed to place most of the load on the shoulders or to distribute most of the load to the hips. They did not control the amount of load on the shoulders as was done in the current study. By implementing methods to control the shoulder load and by testing both level walking and walking while ascending a grade, data were acquired in the current study to further explore the effects on energy consumption of varying suspension of the load on the body.

1.2.3.3 Gait Kinetics and Kinematics

Research has demonstrated that increasing the load mass on the body changes the gait kinetics and kinematics. In terms of kinematics, studies have shown that increases in rucksack mass result in increases in the forward inclination of the trunk (Attwells et al., 2006; Harman, Han, Frykman, & Pandorf, 2000; Kinoshita, 1985; Martin & Nelson, 1986), decreases in pelvic rotation range of motion (ROM) in the transverse plane (Birrell & Haslam, 2009; LaFiandra, Holt, Wagenaar, & Obusek, 2002; Smith et al., 2006), and increases in overall knee flexion resulting in a decrease in total knee ROM in the sagittal plane (Birrell & Haslam, 2009). In addition, it has been found that, as rucksack mass increases, step rates increase, stride lengths decrease, stance times and double support times increase, and swing times decrease (Birrell & Haslam, 2009; Martin & Nelson, 1986). With regard to kinetic parameters, a number of studies have been done to quantify the effects of rucksack loads on ground reaction forces (GRFs) during walking. Researchers have reported that the peak values of GRFs and loading rates increase as the load mass carried increases (Kinoshita & Bates, 1981; Polcyn et al. 2002; Wang, Frame, Ozimek, Leib, & Dugan, 2012).

Park et al. (2011) studied weight effects on gait kinematics using an armor vest, rather than a rucksack load. Their participants walked overground on a level surface. Compared with a condition in which an armor vest was not worn, the addition of a vest weighing 8.2 kg (18 lb) resulted in changes in gait kinematics typical of increasing the mass of the load on the body. Compared with the no-armor condition, use of the armor vest increased knee flexion, decreased swing times, and increased stance and double support times. In a follow-on study, Park et al. (2013) tested a no-armor condition and conditions in which the weight of an armor vest was varied. It was again found that increasing weight resulted in increases in stance and double support times.

Seay, Fellin, Sauer, Frykman, and Bense (2014) also used an armor vest and varied the load on the torso. In addition to a condition in which a vest was not worn, they tested a vest with a carrier containing pockets for ammunition and grenades that was attached to the front of the vest at chest level. The weight of the vest and the loaded carrier was 15 kg (33 lb). In a third condition, the vest and the carrier were used and weights were added symmetrically to the vest for a total load of 55 kg (121 lb). The response measures analyzed were joint kinematics and joint moments captured as military men walked on a level treadmill at a speed of $1.33 \text{ m}\cdot\text{s}^{-1}$ ($3.0 \text{ mi}\cdot\text{h}^{-1}$). It was found that ROMs of the hip, knee, and ankle increased with increasing load mass. Further, hip, knee, and ankle joint moments increased as load was increased, although some increases were not statistically significant.

Like the literature on energy consumption as affected by load carrying, few studies have been done in which the effects of load distribution on gait kinetics and kinematics have been

investigated. Johnson, Pelot, Doan, and Stevenson (2001) conducted one of the studies, varying the position of a load within a rucksack. They placed a mass of 25 kg in either high, intermediate, or low positions within the pack and tested men walking on a level treadmill at a speed of $1.6 \text{ m}\cdot\text{s}^{-1}$ ($3.5 \text{ mi}\cdot\text{h}^{-1}$). Stride length and frequency were unaffected by the load location. However, the values of trunk angle and minimum hip angle were significantly smaller when the load was carried in the high position as opposed to the low one. The smaller trunk and hip values with the load in a high position indicated a more upright body posture during walking than was achieved with the load low on the back.

Birrell and Haslam (2010) also collected biomechanical data under different load distribution conditions. As was done by Johnson et al. (2001), Birrell and Haslam (2010) studied conditions in which a loaded rucksack was carried. However, Birrell and Haslam also included a rucksack load plus a load located in pouches around the waist or in a web vest worn on the front of the body and extending from chest to waist level. Kinetic measures were recorded as men walked on a level surface at a speed of $1.5 \text{ m}\cdot\text{s}^{-1}$ ($3.4 \text{ mi}\cdot\text{h}^{-1}$) carrying loads ranging from 8 to 32 kg (18 to 70 lb). Birrell and Haslam (2010) found that, for 16- and 32-kg loads (35- and 70-lb loads), the vertical force produced at push-off of the foot from the ground was significantly lower when the load was carried solely in a rucksack, as compared to carrying the same load mass in pouches around the waist and in a rucksack. Further, for all load masses, vertical push-off force was lower in the rucksack only condition, compared to conditions in which the load was distributed between the rucksack and the web vest, although not all differences were statistically significant. Birrell and Haslam (2010) maintained that the backpack load, as compared to the distributed load, increased the amount of forward lean, which in turn aided in the forward advancement of the load carrier and thereby reduced the forces needed to propel the body forward during mid-stance and into toe-off. Birrell and Haslam (2010) also found that maximum braking force was significantly lower, by about 10%, when the load was distributed between the rucksack and a web vest, compared to carrying the load solely in the rucksack.

In the current study, aside from the armor vest that covered the upper torso, a water-filled hydration system weighing 3 kg (6.5 lb) was the only portion of the load that participants carried on the back. However, pouches containing dummy ammunition and grenades and totaling 9.1 kg (20.1 lb) were worn on the front of the body in all experimental conditions. The pouches were attached to the armor vest and extended down toward the waist from about chest level. Trunk, hip, knee, and ankle angles were analyzed in the current study to assess whether the combination of the hydration system on the back and the loaded pouches on the front of the body would result in body angle differences between the condition in which the load distribution device was not worn and one or more of the conditions in which the device was used to lift the torso load up off the shoulders.

1.2.3.4 Muscle Activity

Muscle activity while walking with an external load on the body has been examined using EMG techniques in only a limited number of studies, and the studies that have been conducted have differed in the muscles included and the characteristics of the tested loads. As is the case with much of the load-carriage literature, research into muscle activity has involved manipulation of load mass. Bobet and Norman (1982) conducted one such study, varying the mass of a rucksack load from 20.0 to 32.0 kg (44.1 to 70.5 lb). Male participants carried the rucksack loads as they walked overground on a 0% grade at an average speed of $1.6 \text{ m}\cdot\text{s}^{-1}$ ($3.5 \text{ mi}\cdot\text{h}^{-1}$). Bobet and

Norman (1982) recorded from muscles of the shoulder (upper trapezius), the back (lumbar portion of the erector spinae), and the lower extremities (tibialis anterior, vastus lateralis, and biceps femoris). The mass of the rucksack load did not significantly affect the activity of any of the muscles examined.

Silder, Delp, and Besier (2013) also varied load mass, but used a weighted vest rather than a rucksack. Loads equaling 10, 20, and 30% of the body mass of the load carrier were placed on the vest, in both the front and the back. Lower extremity muscle activity was recorded as male and female participants walked on a 0% grade on a treadmill set at the individual's preferred walking speed. Silder et al. (2013) proposed that there would be greater muscle activity with increases in the load mass on the body because of greater demand for forces required to propel the body forward into the next step and, during the stance phase of the gait cycle, greater activity would be required to support the body and the load. Examining muscle activity across the entire gait cycle, Silder et al. (2013) reported that activity increased significantly with load mass for the plantar flexors (soleus, gastrocnemius) and for the quadriceps (vastus medialis, vastus lateralis, rectus femoris). Analysis of just the stance phase of the gait cycle revealed that activity increased significantly with load mass increases in the soleus, gastrocnemius, vastus medialis, and vastus lateralis, but not in the rectus femoris.

There are a few studies into the effects of load distribution on muscle activity. One of the studies was conducted by Bobet and Norman (1984) using a rucksack. A 20-kg (44.1-lb) weight was placed either high or low in the pack. Bobet and Norman (1984) recorded from the upper trapezius and the lumbar portion of the erector spinae, but not from muscles of the lower extremities, as men walked overground on a 0% grade at an average speed of $1.6 \text{ m} \cdot \text{s}^{-1}$ ($3.5 \text{ mi} \cdot \text{h}^{-1}$). Bobet and Norman (1984) found that the high load placement evoked activity of both the trapezius and the erector spinae that was significantly higher than the activity levels with the low load placement. They attributed this finding to the moments due to angular and horizontal linear acceleration acting on the back, proposing that the dynamic moments due to the combined mass of the load-carrier's trunk and the carried load were larger with the load in the higher position.

Devroey, Jonkers, de Becker, Lenaerts, and Spaepen (2007) also studied the effects of load placement within a rucksack on shoulder, back, and abdominal muscles. Additionally, they recorded muscle activity of the lower extremities and varied the load mass carried. Male and female participants were tested while walking on a level treadmill at their preferred speed with an empty rucksack (0% of body mass) and with rucksack loads of 5, 10, and 15% of body mass. The loads were located either high or low in the rucksack. Devroey et al. (2007) purposely used relatively light loads in order to explore whether there would be any changes in muscle activity. They reported that the activity levels of muscles of the shoulder (trapezius, sternocleidomastoid) and the lower extremities (rectus femoris, biceps femoris) were not significantly affected by load mass or load placement. However, for both high and low load placements, there was a significant decrease in erector spinae activity and a significant increase in activity of abdominal muscles (rectus abdominus, obliquus externus abdominus) as load mass increased. Further, the rectus abdominus showed an effect of load placement: activity was somewhat, but not significantly, higher with the higher load placement. There was no change in the activity of the other muscles as a function of load placement.

As the studies reviewed here suggest, the findings regarding muscle activity as affected by load mass and load placement during walking are disparate. The current study was an opportunity to

expand on the existent database. The EMG electrodes could not be placed on shoulder or back muscles due to the placement of the pressure sensor pads — muscle activity recording in the current study was limited to the lower extremities.

1.2.3.5 Cognitive Performance

Although research has documented that arduous load carriage activities increase energy expenditure (Epstein et al., 1988; Patton et al., 1991), lead to decrements in subsequent physical performance (Harman et al., 1999; Knapik et al., 1997; Martin & Nelson, 1986), and increase susceptibility to a variety of musculoskeletal injuries (Knapik & Reynolds, 2012; Knapik et al., 2004), much less is known about how physical exertion affects cognitive performance.

The available literature relating physical exertion to cognition is often confusing and contradictory (Paas & Adam, 1991; Tomporowski, 2003; Tomporowski & Ellis, 1986). Exercise appears to facilitate performance on some tasks under some conditions, while inhibiting performance on other tasks, or on the same tasks under different conditions. Findings of facilitation, inhibition, or no effect are common, sometimes under similar conditions. Differences in the nature, duration, and intensity of the physical exertion undergone by participants in these studies, as well as in the type of cognitive tasks employed and the fitness level of the participants, may explain this complicated and contradictory picture.

Tomporowski (2003) attempted to impose order on this confusing literature by organizing the extant research into three categories based on the intensity and duration of the exercise. The first category he considered was based on intense, brief episodes of exertion where maximal anaerobic exercise was employed. He weakly concluded that brief, intense exercise tends to increase response speed on a variety of tasks, but the evidence concerning effects on accuracy is more disparate. For instance, treadmill running near the aerobic threshold impaired trained athletes' ability to interpret topographic maps, but enhanced short term memory for the maps (Hancock & McNaughton, 1986). Another study evaluated decision making during soccer, where participants were shown images of soccer plays and asked to determine the next best action. Exercise enhanced speed but not accuracy of decision making (McMorris & Graydon, 1996, 1997; McMorris et al., 1999).

The second category Tomporowski (2003) employed shifted emphasis from exercise intensity and attempted to relate exercise to arousal level and the Yerkes-Dodson Law (Yerkes & Dodson, 1908), which posits an inverted U-shaped function between arousal level and performance. Tomporowski (2003) regarded exercise as an arousing activity and found the evidence here ambiguous, with some studies strongly supporting this type of increasing and then decreasing function and other studies not finding a clear relationship. For example, studies of simple and choice response time tasks (Levitt & Gutin, 1971) and choice spatial response time tasks (Salmela & Ndoye, 1986) found improved (i.e., decreased) response time as heart rate reached 115 beats·min⁻¹, but impaired (i.e., increased) response time when heart rate increased to 145 or 175 beats·min⁻¹. However, other studies found no evidence for an effect of exercise on choice response time (Cote, Salmela, & Papathanasopoloulou, 1992). Similarly, when participants pedaled on an exercise bike, simple reaction time was fastest at moderate pedaling rates and slowest at high pedaling rates (Brisswalter, Durand, Delignieres, & Legros, 1995). Choice reaction time was faster as participants increased exercise intensity to 250 W (approximately 76% of peak

$\dot{V}O_2$), then slower reaction time was found when the intensity reached 300 W (Chmura, Nazar, & Kaciuba-Uscilko, 1994).

The third category employed by Tomporowski (2003) included studies concerned with the effects of lengthy aerobic exercise on information processing. Of the 15 studies in this category that employed exercise durations between 20 and 60 min, 11 reported facilitation of performance on a variety of cognitive tasks, whereas studies that employed exercise durations beyond 60 min found that, when dehydration also occurred, there were discernible decrements in some aspects of performance (Cian et al., 2001; Cian et al., 2000).

Tomporowski's (2003) schema is not entirely successful in imposing order on the existing research literature, particularly when so many of the studies reviewed use non-standard tasks whose reliability and validity is not established. In addition, the non-standard nature of some of the tasks employed in these studies makes it difficult to specify what aspects of cognition are being tested and to relate these data to broader models of cognition, existing data on cognition, and the underlying neural structures.

In addition to these limitations, it appears that part of the confusion in the cognitive research literature resides in the very nature of the experimental paradigm most often used to study the relationship between physical exertion and cognitive performance. The typical experiment is characterized by preliminary or baseline cognitive testing (pre-test), followed by exercise of various durations or intensities, which is then followed by cognitive testing (post-test). In this paradigm, there is often a sufficient lapse of time following the bout of strenuous exercise for individuals to recover, marshal their resources, and successfully perform cognitive tasks at a fairly high level. For example, in a study with very high physical demands, Soldiers carried rucksack loads that ranged between 34 and 61 kg (75 and 134 lb) for 20 km (12.4 mi). There were no changes in cognitive performance on a complex synthetic task, the administration of which was initiated about 10 min after march completion (Knapik et al., 1997). Similarly, in a study of treadmill running to exhaustion, Tomporowski (2003) found no effect on a short-term memory task that participants completed after the termination of treadmill running. In another study of heavy exercise, performance on a signal detection task was improved following a marathon (Gliner, Matsen-Twisdale, Horvath, & Maron, 1979). Conversely, several studies that investigated cognition during exercise seemed more likely to detect changes in cognitive performance, even when the physical requirements of the exercise were relatively mild (Crowell et al., 1999; Krausman, Crowell, & Wilson, 2002; Mastroianni, Chuba, & Zupan, 2003). Thus, it appears that measures of cognitive performance made *during* physical exertion are more likely to be sensitive to any effects of exercise than those administered *after* termination of exercise.

In the current study, cognitive testing was performed during the 2-h long treadmill marches. Thus, there was no lapse between exercise and cognitive testing. Previously, Eddy et al. (2015) conducted an investigation in which cognitive tasks were carried out while participants engaged in marches. In their study, Army men performed two cognitive tasks: an auditory go/no-go task and a visual target detection task, at intervals throughout a 2-h treadmill march. The participants were tested in two configurations. One consisted of clothing, an armor vest, a rucksack, and a simulated M-4 carbine [total load on body = 40 kg (88 lb)]. In a second configuration, the vest and the rucksack were not used [total load on body = 6 kg (13 lb)]. In addition to measuring cognitive performance, Eddy et al. (2015) recorded energy consumption during the march, which they expressed as the percentage of each participant's peak oxygen uptake ($\dot{V}O_{2peak}$).

The auditory go/no-go task paradigm used by Eddy et al. (2015) taps response inhibition, a higher order cognitive process. It involves executive control and requires sustained attention to constantly monitor for the no-go stimulus and to inhibit responding. For this type of task, more efficient response inhibition has been associated with greater activation in the frontal cortices (Criaud & Boulinguez, 2013). Based on the transient hypofrontality hypothesis proposed by Dietrich (2013), decrements in cognitive performance during acute exertion are more likely for frontally mediated tasks due to a decrease in frontal neural activity with the demands of exercise (Dietrich, 2003). The second cognitive task used by Eddy et al. (2015), a visual target detection test, measures visual attention. This task taps lower-level cognitive processes related to attention and vigilance. The visual target detection task is thought to involve motor and sensory pathways in the brain (Eddy et al., 2015) and, according to the hypofrontality hypothesis (Dietrich, 2003), performance on this task is projected to be minimally affected by physical exertion.

The go/no-go task and the target detection task each required 5 min to complete and Eddy et al. (2015) administered the go/no-go task followed by the target detection task at 20-min intervals during the 2-h treadmill march. Participants walked at a speed of $1.34 \text{ m}\cdot\text{s}^{-1}$ ($3.0 \text{ m}\cdot\text{h}^{-1}$) throughout testing, but treadmill grade profiles differed at different study sessions. For some sessions, participants walked at a 4% grade for 60 min followed by 60 min at a -8% grade. For other sessions, participants walked at a 4% grade for 60 min followed by 60 min at variable grades (changing between -8%, 0%, and 4% every 10 min).

Eddy et al. (2015) reported that the proportion of false alarms on the go/no-go task revealed a performance decrease over time with the heavier load, but remained relatively unchanged when the lighter load was used. In line with this finding, the percentage of $\dot{V}\text{O}_{2\text{peak}}$ data indicated that physical exertion with time on the march was greater with the heavier load. These results for the go/no-go task support Dietrich's (2003) hypofrontality hypothesis. On the visual target detection task, the mass of the load on the body had little effect on performance, as would be predicted from Dietrich's (2003) hypothesis. However, accuracy initially decreased then improved as the march progressed and reaction time slowed, whereas Dietrich (2003) would predict that these measures would not change over time. Eddy et al. (2015) maintained that some of their findings supported the idea that higher level, mediated cognition is affected by the metabolic demands of physical exercise more so than lower-level cognitive processes are, as posited by the transient hypofrontality hypothesis (Dietrich, 2003). Eddy et al. (2015) also cautioned that other results were not consistent with the hypothesis, suggesting that there is a complex relationship between acute exercise and higher and lower-level cognition.

The go/no-go and the visual target detection tests were used again in the current study. Data were collected on cognitive performance during prolonged physical activity using lighter loads than those studied by Eddy et al. (2015). The acquisition of metabolic data in parallel with the cognitive testing in the current study during a 2-h march enabled the monitoring of the changes in both the physiological and the cognitive measures that may occur during a prolonged period of controlled physical exertion.

1.2.3.6 Isometric and Isokinetic Muscle Strength

Neuromuscular impairment of skeletal muscles has been observed after prolonged running, cycling, and skiing exercises (Millet & Lepers, 2004), as well as after prolonged load carriage (Blacker, Fallowfield, Bilzon, & Willems, 2010a). Muscle impairment, measured as a reduction

of maximal force production by a muscle, can be an indicator of muscle damage and of a reduction in muscle function (Blacker, Fallowfield, Bilzon, & Willems, 2010b). Decreases in neuromuscular function following a strenuous event impair physical and skilled performance (Byrne, Twist, & Eston, 2004) and, thus, are likely to have a negative effect on Soldier performance. Dynamometry is used for measuring muscle strength. A typical procedure is to measure the maximum amount of work, power, or peak torque a muscle group can produce before an activity is carried out and then to measure recovery by retesting the same muscle group immediately upon activity completion and, possibly, in the following hours and days.

Very little research has been accomplished on muscle strength as affected by load carrying. Blacker, Fallowfield, Bilzon, and Willems (2013) focused on load mass effects in one load-carriage study. Male participants conducted 2-h treadmill marches on a 0% grade at a speed of $1.8 \text{ m}\cdot\text{s}^{-1}$ ($4.0 \text{ mi}\cdot\text{h}^{-1}$) while carrying a 25-kg (55-lb) rucksack load and repeated the march without a rucksack. Maximum voluntary contractions (MVCs) of the biceps femoris were measured before the march and again immediately upon march completion. The pre- and post-march measurements were compared. Blacker et al. (2013) reported that there was no change in isometric MVC force when the march was conducted without a loaded rucksack. When the 25-kg (55-lb) was carried on the march, MVC force was approximately 15% lower after the march compared with the pre-march values.

Blacker et al. (2013) proposed that, compared with marching without a load, carrying the 25-kg (55-lb) rucksack resulted in the recruitment of additional muscle fibers in order to maintain posture and movement on the treadmill and that carrying the load also altered gait, causing increases in knee and thigh ROMs. Further, they posited that the rucksack load increased GRFs, increasing the amount of force the supporting muscles must absorb. Blacker et al. (2013) concluded that all these changes increase mechanical damage to muscle tissue as greater force is absorbed, causing the neuromuscular impairment following the loaded marches that was not observed when the rucksack was not used.

Blacker et al. (2010a) conducted another study in which male participants executed 2-h treadmill marches at a speed of $1.8 \text{ m}\cdot\text{s}^{-1}$ ($4.0 \text{ mi}\cdot\text{h}^{-1}$). In this investigation, participants were tested at two treadmill grades, 0% and -8%, and a 25-kg (55-lb) rucksack was carried for all testing. Muscle strength assessment consisted of performance of isometric contractions of the knee extensors and isokinetic contractions of the trunk, shoulder, and knee extensors and flexors before a 2-h march trial, immediately upon march completion, and at 24, 48, and 72 h after march completion. Considering only the results related to treadmill grade, Blacker et al. (2010a) did not find that marching on the -8% grade resulted in greater decreases in muscle function than walking on the 0% grade did.

Batty, O'Donovan, Bense, and Hasselquist (2015) also studied grade effects, but they varied load mass, as well, during 2-h treadmill marches conducted at a speed of $1.33 \text{ m}\cdot\text{s}^{-1}$ ($3.0 \text{ m}\cdot\text{h}^{-1}$). For some sessions, the Army men who served as participants walked at a 4% grade for 60 min followed by 60 min at a -8% grade. For other sessions, the participants walked at a 4% grade for 60 min followed by 60 min at variable grades. The variable grade protocol consisted of 10 min of walking at each of three grades (-8%, 0%, and 4%, in order), followed by another 10 min at each of these grades. The participants were tested in two load configurations. One consisted of clothing, an armor vest, a rucksack, and a simulated M-4 carbine [total load on body = 40 kg (88 lb)]. This load mass was substantially greater than the 25-kg (55-lb) mass used in the series of

studies by Blacker and his colleagues (2010a, 2010b, 2013). In a second configuration tested by Batty et al. (2015), the vest and the rucksack were not used [total load on body = 6 kg (13 lb)]. Batty et al. (2015) collected isokinetic trunk muscle flexion and extension data before the march and immediately upon march completion and calculated the difference between the pre- and the post-march MVCs.

Batty et al. (2015) found that muscle strength was affected by both grade and load mass. However, the relationship between these variables differed with the isokinetic velocities tested. At $20^{\circ}\cdot\text{s}^{-1}$, the slower velocity, there were strength decrements for the 40-kg (88-lb) load compared with the 6-kg (13-lb) load and for the variable compared with the constant downhill grade, but the interaction between load and grade was not significant. There was a significant interaction at the faster velocity, $60^{\circ}\cdot\text{s}^{-1}$. At this velocity, there was little change in muscle strength as a function of grade condition, but strength decrements were substantial for the heavier load carried on the variable grade, compared with the constant downhill grade. Batty et al. (2015) proposed that the fast isokinetic test velocity revealed generalized, whole-body muscle fatigue, whereas the slower test velocity reflected a more localized fatigue of the lumbar muscles.

As the studies reviewed here indicate, there has been only limited research on muscle strength as affected by prolonged load carrying. The investigations that have been done have not contrasted effects of varying placement of loads on the torso while keeping load mass constant. The 2-h treadmill march undertaken in the current study was an opportunity to expand the database on muscle strength as affected by external loads on the torso. Strength of muscles of the trunk, the shoulder, and the knee before and after the 2-h, 9.65-km (6.0-mi) march were evaluated in the current study under a condition in which the load distribution device was not worn and under a second condition in which the load distribution device was set to a high offloading level.

1.2.3.7 Participants' Ratings and Questionnaire Responses

Toward the end of trials of treadmill walking in the current study, the 15-category RPE scale (Borg, 1970, 1982) was administered to assess the participants' perceived exertion associated with walking. The RPE is widely used in clinical diagnostics, athletic training, and epidemiological evaluations of exercise intensity (Noble, 1982; Pandolf, 1982). The RPE has also been successful in differentiating between levels of exertion and comfort during load-carriage studies. It has consistently been found that ratings of perceived exertion increase with increases in the load mass carried (Devroey et al., 2007; Goslin & Rorke, 1986; Lenton, Doyle, Saxby, et al., 2018; Pimental & Pandolf, 1979; Simpson, Monroe, & Steele, 2011). In a study in which Army enlisted men marched for 20 min carrying rucksack loads, Pimental and Pandolf (1979) found that the mean RPE increased by about 26% with the doubling of the load from 20 to 40 kg (44 to 88 lb). Although load mass has been the most commonly manipulated variable in load-carriage studies in which the RPE has been used, the effects of load distribution have also been researched. Stuempfle et al. (2004) found that RPE ratings were significantly lower when the load in a rucksack was placed high in the pack compared to low in the pack. However, Lenton, Doyle, Saxby, et al. (2018) did not obtain significant differences between ratings given to load distribution devices for armor vests and ratings given to a condition in which an armor vest without a load redistribution capability was worn.

The rating of pain, soreness, and discomfort questionnaire (RPSD; Corlett & Bishop, 1976) was also administered in the current study upon termination of treadmill walking trials. In the RPSD questionnaire, the respondent uses a 5-point scale to rate the level of pain, soreness, discomfort, or restriction being experienced on specific parts of the front and the back of the body. The scale ranges from *none* to *extreme pain, soreness, discomfort, or restriction*. The RPSD has been used in studies of different backpack designs (Hasselquist et al., 2013) and different designs of body armor systems (Hasselquist, Bense, Corner, & Gregorczyk, 2012) to compare the locations and extent of movement restriction and discomfort experienced by users.

In general, increasing the mass of a rucksack load increases feelings of fatigue, exertion, and discomfort. In addition, how the load is distributed on the body has been shown to affect exertion ratings and comfort. The current study examined the perceived exertion of carrying a fighting load as the load was redistributed from the shoulders to the pelvis. Further, to quantify local factors that may affect perceived exertion, subjective pain, pressure and discomfort ratings were assessed for anatomical regions using the RPSD.

A questionnaire was administered as an additional means of acquiring information on the participants' opinions of the load distribution device and the concept of offloading the shoulders. The questionnaire was devised specifically for this study and sought to elicit participants' opinions based upon their experiences throughout the study. Participants' suggestions for improving offloading were also sought.

2 METHODS

2.1 Participants

Participants in the study were recruited from among U.S. Army enlistees who serve as human research volunteers assigned to Headquarters Research and Development Detachment, DEVCOM SC. Seventeen Soldiers, 16 men and 1 woman, volunteered to participate and gave their informed consent. The Soldiers had recently completed Army Advanced Individual Training and were awaiting their first assignments to operational Army units. Their time in service was approximately 6 months. Ten of the men had Military Occupational Specialties (MOSs) in the infantry series (MOS 11B). The woman and three of the men were radio operator/maintainers (MOS 25C) and three of the men were supply specialists (MOS 92Y). All the Soldiers indicated that they had experience wearing an armor vest with front and back plates.

The participants were healthy and without musculoskeletal injuries, as confirmed by medical screenings, including physical examinations and clinical review of their medical records. The study was approved by the local Institutional Review Board and was conducted in accordance with the Federal Policy for the Protection of Human Subjects, U.S. Department of Defense, 32 Code of Federal Regulation Part 219, under the CCDC SC Assurance for the Protection of Human Subjects, DoD A20124, dated 1 April 2008.

2.2 Load Conditions

2.2.1 Components of the Fighting Load

Throughout most of the testing, participants wore a modified version of an Army fighting load (FL; Department of the U.S. Army, 2017). The FL included combat boots, an Army Combat Helmet (ACH), a Tactical Assault Panel (TAP), a water-filled CamelBak hydration system, and a 3rd Generation Improved Outer Tactical Vest (GEN III IOTV). Shorts and a sleeveless spandex shirt were worn in place of the jacket and trousers of the Army Combat Uniform. The participants carried a simulated M-4 carbine during testing activities that involved treadmill walking. The Enhanced Small Arms Protective Inserts (ESAPI) were placed in the front and the back pockets of the IOTV and the Enhanced Side Ballistic Inserts (ESBI) were placed in the side pockets. The neck collar, yoke, and crotch protector that can be attached to the IOTV were not used. The TAP, which was secured to the front of the vest at about chest level, had pouches holding weighted, simulated ammunition and grenades. The hydration system was worn on the upper back. The only occasion during which the FL was not used was in the testing of one condition included in the FRR evaluation. For this, only combat boots, shorts, and a spandex shirt were worn.

The masses of the FL items in a size medium are listed in Table 1. There were small differences among participants in the total mass of the FL that were attributable to differences among sizes of items.

Table 1. *Fighting Load Composition and Approximate Item Masses in Size Medium*

Item	Mass
Combat boots	1.7 kg (3.8 lb)
Socks	0.1 kg (0.2 lb)
Shorts	0.2 kg (0.4 lb)
Spandex shirt	0.2 kg (0.5 lb)
ACH	1.6 kg (3.6 lb)
TAP, with ammunition/grenades	9.1 kg (20.1 lb)
CamelBak hydration system, filled with water	3.0 kg (6.5 lb)
GEN III IOTV, with front, back, side plates	12.2 kg (26.9 lb)
Simulated M-4 carbine	2.3 kg (5.0 lb)
Total	30.4 kg (67.0 lb)

2.2.2 Load Distribution Device

A commercially available load distribution device, the DWD system (SOURCE Tactical Gear, Virginia Beach, VA), was used to control the amount of load borne on the study participants' shoulders. The DWD is comprised of a sheath, a strut, or spine bar, and a waist belt (Figure 1). The sheath is rigid and serves to attach the adjustable spine bar to the IOTV. The spine bar is also attached to the waist belt with an interface designed to allow freedom of movement of the torso (Figure 2). The spine bar can be lengthened or shortened, lifting the load up off the wearer's shoulders or lowering the load onto the shoulders. Lifting the load off the shoulders results in transfer of the load to the hips via the spine bar. Thus, the spine bar, together with the waist belt, is the means for transferring the load between the shoulders and the hips. SOURCE Tactical Gear had developed the DWD for use with a plate carrier vest, which they also developed. Pilot testing (Carboni et al., 2014) indicated that the DWD was adaptable for use with the standard Army armor vest, the GEN III IOTV, and the Army vest was used in this study. A plastic stiffener plate (Figure 3), 0.165 cm (.065 in.) thick, was placed inside the back plate pocket of the IOTV to help spread the load evenly and to assist with shifting the IOTV up when the DWD was adjusted to offload the shoulders. The DWD was designed with the capability for users to adjust the amount of offloading while they are underway. This capability was not used in

the current study; all offloading adjustments were carried out by the investigators. The mass of all components of the DWD, including the stiffener plate, was 1.13 kg (2.50 lb).

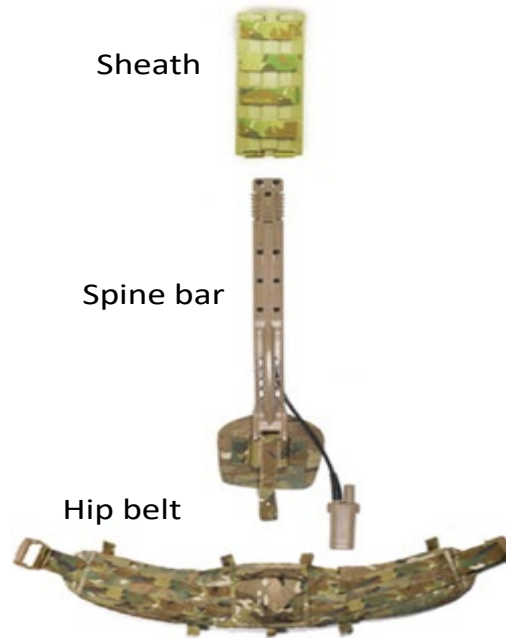


Figure 1. *DWD components.*



Figure 2. *Demonstration of DWD integrated with a ballistic protective vest.*



Figure 3. The IOTV pictured with plastic plate used to provide additional stiffness to the back pocket where the DWD sheath was attached.

2.2.3 Pressure Measurements

Setting of the load distribution device to predetermined levels of shoulder offloading was accomplished using a Pliance[®] dynamic pressure distribution measurement system (Novel Electronics, Inc., St. Paul, MN). The system includes pressure measurement pads consisting of elastomeric capacitive transducers (Figure 4). The transducers have a measurement range of 2 to 240 kPa and a manufacturer-reported accuracy of $\pm 5\%$. Four sensor pads were used to obtain the distributed pressure across the right and the left shoulders and the right and the left aspects of the hips. Each pad had 256 sensors arranged in a 32 x 8 matrix. A pad was approximately 45.2 cm (18.0 in.) long, 11.3 cm (4.4 in.) wide, and 0.26 cm (0.10 in.) thick and had a sensing area of 467.0 cm² (72.3 in.²). The pads were connected to a Pliance electronic analyzer, which outputted to a PC running manufacturer-supplied software (Pliance, Novel Electronics, Inc., St. Paul, MN). Each sensor was queried at a frequency of 20 Hz.



Figure 4. Pressure distribution measurement pads.

Before beginning a participant's test session, the four sensor pads were zeroed on a flat surface in accordance with the manufacturer's instructions. The sensor pads were then placed on the participant's skin, at the shoulders and the hips. To secure the sensor pads in place on the skin,

each pad was taped along its four edges. The participant also wore a tight-fitting, sleeveless, spandex shirt, which further served to keep the pads in place.

Once the sensor pads and the shirt were in place, the participant maintained a stationary standing position while a series of pressure measurements were made to identify the locations of 10 anatomical landmarks underlying the pads. The landmarks were identified by palpation through the sensor pads and the shirt. Two landmarks were identified on each shoulder — the clavicle along its length and the top of the scapula. Three landmarks were identified at the hips on each side of the body — the anterior superior iliac spine (ASIS), the iliac crest, and the posterior superior iliac spine (PSIS). Figure 5 is an example of the pressures produced on each sensor pad at the landmark locations during palpation. The Pliance software was used to divide each pad into three regions based upon the locations of the anatomical landmarks (Figure 5). The regions for each shoulder were designated as chest, top of shoulder, and back. The regions for the left and the right sides of the hips were designated as anterior, lateral, and posterior hip.

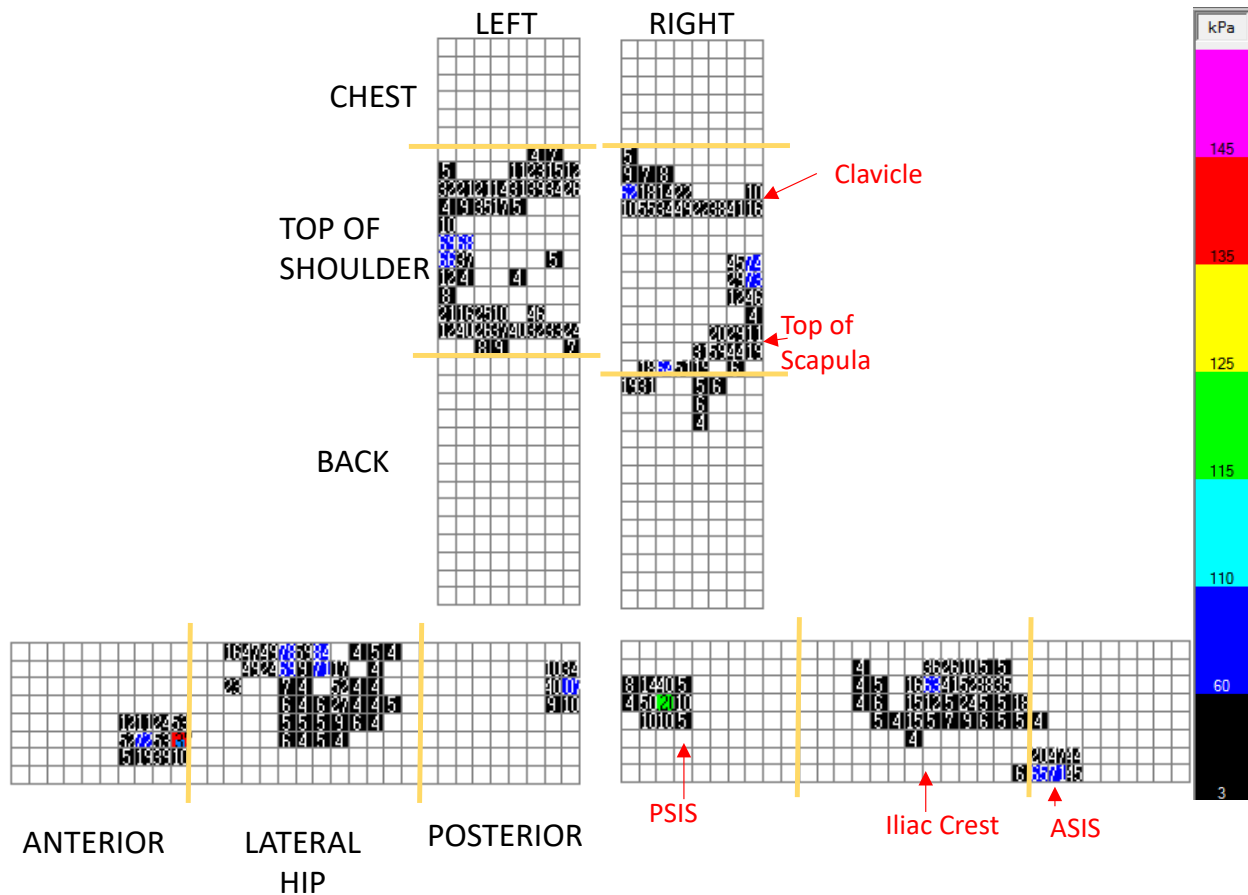


Figure 5. Example of sensor pressures at anatomical landmark locations at the shoulders and the hips and illustrations of sensor pad regions.

With the anatomical sections of each sensor pad identified, the participant was outfitted with the IOTV and the other FL components (Table 1). The load distribution device was not placed on the body at this time. After the FL components had been donned, the participant stood stationary for about 10 s and pressure measurements were taken. The data acquired were used to establish the

baseline FL pressure. To accomplish this, a mean of the pressure readings taken during the 10-s period was obtained for the top of each shoulder region and a grand mean was then calculated from the means of the two top of shoulder regions. The tops of the shoulder regions were defined as the areas of the left and the right shoulders between the clavicle and the top of the scapula (Figure 5). The grand mean of the left and the right top of shoulder regions was the basis for the setting of offloading of the shoulders for that test session.

A custom graphical user interface (GUI) was developed to quickly process the pressure data from the tops of the shoulders using the following processing steps: 1) plot the right and the left top of shoulder pressure time history and check for artifacts; 2) select the appropriate pressure window void of measurement artifacts (timeframe approximately 10 s); 3) calculate the average pressure of all sensors within the right and the left top of shoulder regions and obtain a grand mean for the pressures over the two shoulders; and 4) save and store data.

The Pliance software was used during this testing preparation period and the subsequent testing to obtain a mean pressure for each region of each pad. The mean was calculated from the pressure outputs of all sensors in a region of the pad. If a sensor did not yield a value, it was assumed that pressure at that site was less than 2 kPa. In those instances, the software assigned 0 kPa as the pressure reading and that value was included in the calculation of the mean for the region.

2.2.4 Composition of the Load Conditions

Six load conditions were tested by participants during the study. One condition entailed wearing only combat boots, shorts, and a spandex shirt. In a second condition, the components of the FL listed in Table 1 were worn. In a third condition, the FL items and the load distribution device were worn, but the device was not engaged. That is, the spine bar, the sheath, and the waist belt were worn (Figure 1), but the spine bar was not attached to the waist belt. The remaining three conditions also involved wear of the FL components and the load distribution device. In all three of these conditions, the spine bar was engaged, and the device was used to offload the shoulders.

For the three conditions that involved offloading the shoulders, the load distribution device was adjusted to set the proportion of the load resting on the tops of the shoulders. The baseline FL pressure—the mean pressure readings recorded from the tops of the shoulder regions during the 10-s period of quiet standing immediately after the participant had donned the IOTV and the other FL components—was taken to equal the load on the shoulders. The load distribution device was adjusted to reduce the pressure to an amount within a range of percentages of that value: 10 to 30%, 40 to 60%, or 70 to 90%. For example, given a baseline FL pressure at the tops of the shoulders of 10 kPa, a 10 to 30% reduction would result in pressure at the shoulders adjusted to 9 to 7 kPa and a 70 to 90% reduction would result in pressure being set at 3 kPa or less.

To set the offloading, an investigator held the waist belt in place and a second investigator released the locking mechanism on the DWD spine bar and lifted the IOTV. A pressure measurement was then taken with the participant standing in place for 10 s and the GUI was used to determine if the targeted amount of offloading had been met. If not, the load and DWD were adjusted and the measurement process repeated until the desired proportion of offloading was achieved. During this process, the investigators took care to ensure that the percentages of offloading at the tops of the right and the left shoulders were similar.

Descriptions of the six load conditions and the designator used for each condition follow.

- **No Load (NL)** — No body armor, load carriage equipment, or load distribution device is worn. The participant is outfitted in combat boots, shorts, and a spandex shirt.
- **Fighting Load (FL)** — FL components (Table 1) are worn without the load distribution device.
- **Fighting Load With Load Distribution Device Disengaged (FL/N_{off})** — FL components are worn with the load distribution device and the device is not engaged. The DWD spine bar is not inserted into the waist belt.
- **Fighting Load With Low Offloading (FL/L_{off})** — FL components are worn with the load distribution device engaged. The DWD is set to reduce the pressure at the tops of the shoulders by 10 to 30% relative to the baseline FL pressure.
- **Fighting Load With Medium Offloading (FL/M_{off})** — FL components are worn with the load distribution device engaged. The DWD is set to reduce the pressure at the tops of the shoulders by 40 to 60% relative to the baseline FL pressure.
- **Fighting Load With High Offloading (FL/H_{off})** — FL components are worn with the load distribution device engaged. The DWD is set to reduce the pressure at the tops of the shoulders by 70 to 90% relative to the baseline FL pressure.

Illustrations of two load conditions are presented in Figure 6. Figure 7 is an exemplar display of pressure sensor outputs for the FL condition.

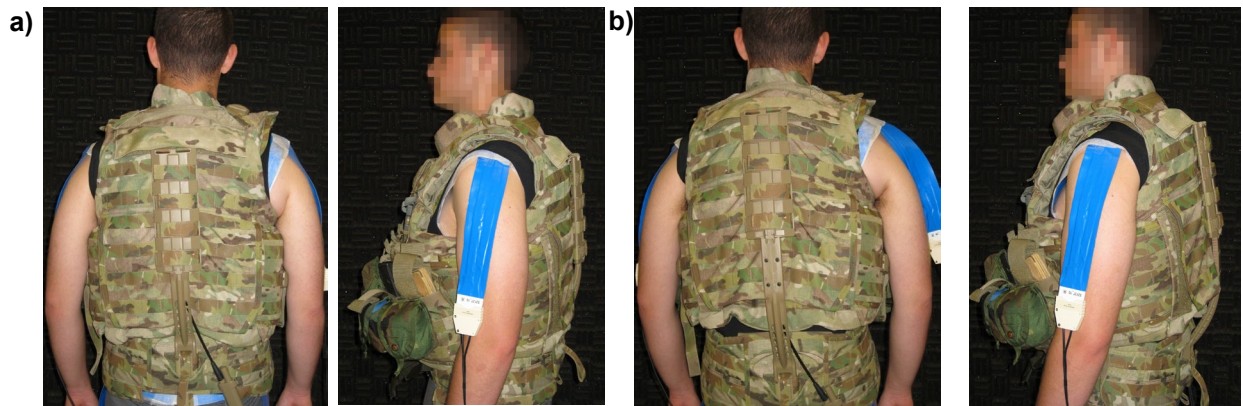


Figure 6. Back and side views of the IOTV with the DWD attached. The photos illustrate: a) a situation in which the DWD is not engaged and b) a situation in which the DWD is engaged to achieve a 70 to 90% offloading of the shoulders.

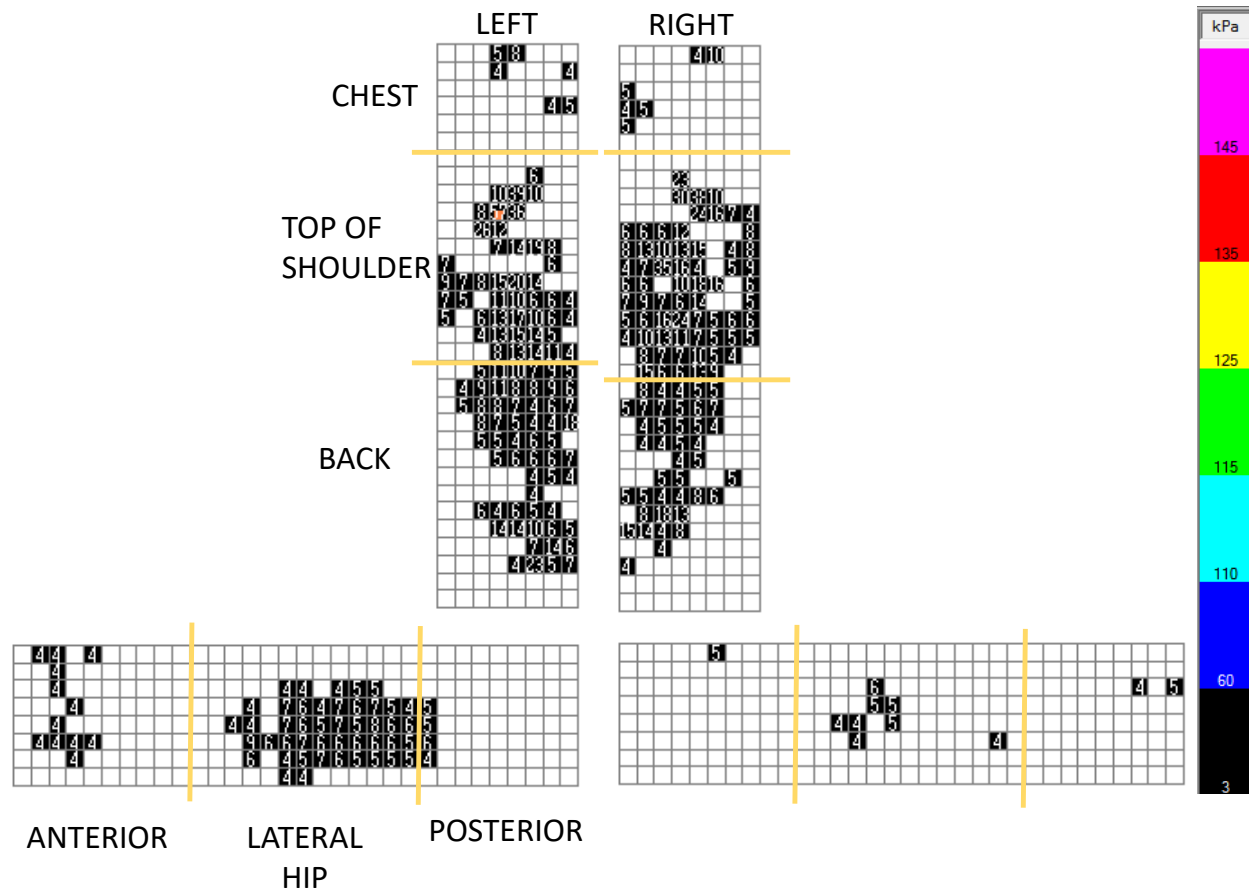


Figure 7. Exemplar display of the pressures measured in the FL condition.

2.3 Test Activities

2.3.1 Overview

This study was conducted at the Center for Military Biomechanics Research, DEVCOM SC. The participants attended six sessions: one orientation and five testing sessions. Depending upon the study activities scheduled, session durations were between 2.5 and 3.5 h. The activities carried out by the participants during the five testing sessions and the principal measures taken in conjunction with the sessions were:

- **Cervical FRR Evaluation** (one session) — The cervical FRR was determined under each of the six load conditions during one session. Muscle activity was recorded using surface EMG.
- **10-min Walking Trials** (two sessions) — Metabolic, biomechanical, and EMG responses were recorded and subjective ratings were elicited during two testing sessions comprised of trials of treadmill walking. Each session consisted of five, 10-min periods of walking on a treadmill set at a speed of $1.34 \text{ m} \cdot \text{s}^{-1}$ ($3 \text{ mi} \cdot \text{h}^{-1}$). At one session, treadmill grade was 0% and, at the other session, the grade was 9%. At each session, participants carried out one trial under each of five load conditions. The conditions were: FL, FL/ N_{off} , FL/ L_{off} , FL/ M_{off} , FL/ H_{off} . The outputs of the pressure sensors were recorded at the

beginning and at the end of each trial. A questionnaire seeking opinions on the offloading device was administered to the participants upon the completion of all five trials at a session.

- **2-h Walking Trials** (two sessions) — Metabolic and cognitive task responses were recorded and subjective ratings were elicited during a 2-h period of treadmill walking at a speed of $1.34 \text{ m}\cdot\text{s}^{-1}$ ($3 \text{ mi}\cdot\text{h}^{-1}$) on a 0% grade. There were two sessions of prolonged treadmill walking. At one session, the participant was tested in the FL condition and, at the other, testing was conducted in the FL/H_{off} condition. The outputs of the pressure sensors were recorded at the beginning and at the end of the walking trials. Isometric and isokinetic strength testing was also conducted before and after the 2-h trials. A questionnaire seeking opinions on the load distribution device was administered to the participants upon the completion of the walking periods.

Due to scheduling conflicts and early withdrawal from testing, complete data on all 17 participants were not obtained for any single test activity. Also, the one woman who volunteered for the study participated only in the cervical FRR evaluation. Further, because of equipment malfunctions during the 10-min walking trials activity, some measurements were not collected on all Soldiers who did participate in this activity. In addition, the study-specific questionnaire was administered to only 6 men. Table 2 is a presentation of summary statistics for the demographics of the participants in the different test activities. The body measurements included in the table were made following the procedures used by Hotzman et al. (2011).

Table 2. Demographics of Participants

Statistic	Variable							
	Age (years)	Nude Body Wt. (kg)	Stature (cm)	Waist Front Lgth. (cm)	Waist Back Lgth. (cm)	Waist Circum. (cm) ^a	Waist Ht. (cm) ^b	Cervicale Ht. (cm)
<i>Cervical FRR Evaluation (n = 1 woman + 12 men)</i>								
Mean	20.08	73.85	174.90	38.20	47.49	83.48	105.78	151.28
SD	2.84	7.19	6.53	2.41	2.26	5.58	4.46	5.69
<i>10-min Walking Trials, Metabolic Data (n = 14 men)</i>								
Mean	20.21	75.34	175.90	38.26	47.69	83.92	106.42	152.23
SD	2.94	5.74	5.78	2.09	2.18	5.70	3.87	4.94
<i>10-min Walking Trials, Biomechanical Data (n = 13 men)</i>								
Mean	20.38	75.70	175.97	38.32	47.63	83.76	105.51	152.35
SD	2.99	5.80	6.01	2.16	2.25	5.90	4.01	5.12
<i>10-min Walking Trials, EMG Data (n = 11 men)</i>								
Mean	20.64	76.25	177.23	38.61	48.11	84.80	107.01	153.01
SD	3.17	5.85	3.99	2.02	2.20	5.83	2.86	3.59
<i>2-h Walking Trials, Metabolic and Cognitive Data (n = 13 men)</i>								
Mean	20.38	74.65	174.99	38.02	47.58	83.79	105.65	151.15
SD	2.99	7.76	6.57	2.35	2.38	6.06	4.24	5.61
<i>2-h Walking Trials, Strength Data (n = 14 men)</i>								
Mean	20.21	74.56	175.41	37.99	47.58	83.84	106.11	151.67
SD	2.94	7.47	6.51	2.26	2.29	5.29	4.42	5.73
<i>Load Redistribution Questionnaire Data (n = 6 men)</i>								
Mean	22.50	78.71	179.53	39.62	48.57	85.60	108.05	154.70
SD	3.27	5.87	2.79	1.89	2.72	6.70	2.41	3.14

^aWaist circumference was taken 2 cm below the iliac crest.

^bWaist height was taken at omphalion.

2.3.2 Orientation Session

During the orientation session, participants completed a demographic questionnaire (Appendix A). Body measurements were taken, and the participants were fitted for the clothing and equipment to be used during testing. While the body measurements were made, the men wore PT shorts; the woman wore PT shorts, a bra, and a T-shirt.

The test protocol and test equipment were reviewed with the participants to ensure familiarity with the testing activities. The participants practiced walking at a speed of $1.34 \text{ m} \cdot \text{s}^{-1}$ ($3 \text{ mi} \cdot \text{h}^{-1}$) on a treadmill at both a 0% and a 9% grade. They walked for about 10 min at each grade in the NL condition and in the three conditions that entailed offloading (FL/L_{off}, FL/M_{off}, FL/H_{off}). Participants also carried out the isometric and isokinetic strength testing procedures and

performed the cognitive tasks. The cognitive tasks require minimal training. Participants were first familiarized with the tasks while standing in a stationary position. Then, during the treadmill walking familiarization with the grade and the load conditions, the cognitive tasks were performed for approximately 5 min of each 10-min treadmill familiarization period.

For familiarization with the isometric and isokinetic strength testing procedures, the strength measuring system (positioning chair and dynamometer) was positioned correctly for each muscle group that was to be tested on a participant. The axis alignment of the dynamometer shaft was aligned with a participant's anatomical axis of rotation. The settings were recorded and used for the testing sessions later in the study. Participants were instructed on the proper technique for each exercise and they performed practice trials at submaximal effort. Once they were comfortable performing the task, participants completed maximal effort (100%) trials.

2.3.3 Cervical FRR Evaluation

2.3.3.1 Equipment and Measurements

For the FRR evaluation, the participant performed an externally paced movement while muscle activity was recorded. The movement consisted of neck flexion to a fully flexed position, followed by a pause, and then neck extension back to the starting position. Wireless surface electrodes (Trigno™, Delsys, Inc., Natick, MA) were used to record muscle activity. Following the procedure employed by Lee et al. (2011), the electrodes were placed bilaterally over the muscle belly of the cervical erector spinae at the level of the 4th cervical vertebra (C4). Prior to electrode placement, any hair present was shaved and the skin was cleaned with abrasive pads and an alcohol wipe. The electrodes were secured with medical tape and the signal-to-noise ratio of a neck extension movement was visually inspected to ensure adequate site preparation and electrode placement. The EMG data were collected at 2000 Hz, demeaned, band pass filtered from 30 to 500 Hz using a 4th order, bi-directional Butterworth filter, and full wave rectified. A low-pass filter was applied with a cutoff frequency of 4 Hz to create a linear envelope. All EMG signal processing was performed using the Signal Processing Toolbox™ in MATLAB® (rel. R2014b, MathWorks, Natick, MA).

A cervical FRR was obtained for the right and the left sides of the body. It was calculated as the mean muscle activity during the middle 60% of the extension phase divided by the mean muscle activity during the middle 60% of the relaxation phase. The FRR was also calculated using the middle 2 s of the extension and the relaxation phases. No differences were found between calculating the FRR by using the EMG from the middle 60% versus the middle 2 s. The analyses of the FRR data were carried out on the middle 60% of the extension and the relaxation phases as the speed during this portion of the movement phase was typically constant and captured more of the EMG trace. Phase beginning and end times were visually determined using synchronized neck acceleration data.

2.3.3.2 Procedure

The cervical FRR testing required that the participant repeatedly perform a neck flexion-extension movement. The movement began and ended with the participant in an erect standing position, arms at the sides, and eyes facing forward. Movement execution was divided into three phases. Each phase was 5 s in duration and the pace was set by presenting prerecorded audio

cues to the participant. The phases were: 1) flexion — the participant lowered the head slowly to full flexion; 2) pause — the participant maintained full flexion; and 3) extension — the participant slowly lifted the head and returned to the original erect position. Before test data were acquired, the participant practiced performing the movement at the pace set by the audio cues.

Each participant was tested in each of the six load conditions. The NL condition was tested first and the participant was exposed to the remaining five conditions in a random order. A new random sequence of the five conditions was established for each participant.

Preparatory activities included putting the electrodes and the pressure sensor pads in place and identifying the anatomical landmarks underlying the pads through palpation. After testing of the NL condition had been completed, the participant donned the IOTV and the other components of the FL (Table 1), but not the DWD. The participant stood for 10 s, during which the baseline FL pressure data were recorded. The baseline pressure data at the shoulders were used to calculate a mean pressure at the tops of the shoulders. The mean was used during that session to obtain the settings for the shoulder pressure to be implemented during that session when the load condition to be tested entailed shoulder offloading (FL/L_{off}, FL/M_{off}, FL/H_{off}).

After recording of baseline pressure at the shoulders, the participant was completely outfitted in the components of the next load condition to be tested. If the load condition included wear of the DWD, the device was put in place. For the three conditions that involved offloading the shoulders (FL/L_{off}, FL/M_{off}, and FL/H_{off}), the device was adjusted by the investigators to set the proportion of the load resting on the tops of the shoulders based on the mean calculated from the baseline FL pressure readings. Next, pressure measurements were taken during a 10-s period of quiet standing, and then testing began.

Testing of a load condition consisted of performing the flexion-extension movement five times in succession. Separate mean FRRs were obtained for the right and the left sides of the body. The means were calculated over the second, third, and fourth trials and used as the participant's data for that load condition.

The five trials were followed by a rest break of approximately 5 min before the participant was prepared for testing of the next load condition. The duration of a participant's FRR evaluation session was approximately 2.5 h.

2.3.4 10-min Walking Trials

2.3.4.1 Equipment and Measurements

2.3.4.1.1 Metabolics. Metabolic measurements were recorded during treadmill walking trials using a Quark CPET metabolic measurement system (COSMED, Rome, Italy). The system records $\dot{V}O_2$ (mL·min⁻¹) and the rate of carbon dioxide production ($\dot{V}CO_2$; mL·min⁻¹) on a breath-by-breath basis. Also, the system calculates the respiratory exchange ratio (RER) as $\dot{V}CO_2$ divided by $\dot{V}O_2$. The user wears a lightweight mask that covers the oronasal area of the face. The mask has two inspiratory valves for reducing inspiratory resistance and to dry moisture produced during the effort. Seals of a hydro gel material are available for eliminating any possible air leakage. A bi-directional digital turbine, which ensures accuracy within a wide flow range, measures flow and volume and is connected by a flexible hose to the system. Prior to the

start of each participant's testing session, the metabolic measurement system was calibrated to known gas concentrations following manufacturer-supplied instructions.

The heart rate (HR) of the participants was monitored using a Vantage heart rate monitor (Polar USA, Lake Success, NY) that is integrated with the metabolic measurement system. The HR system includes a chest strap containing a transmitter that senses HR and sends information about it to the metabolic measurement unit. The HR is then interfaced with the computer software and information is stored for later analysis. Heart rate was recorded in $\text{beats}\cdot\text{min}^{-1}$.

2.3.4.1.2 Kinetics. A force plate treadmill, fabricated by AMTI (Watertown, MA), was used for the walking testing. The treadmill is comprised of two synchronized side-by-side belts located on a single platform. The treadmill belts are close together, with a gap of less than 10 mm (0.39 in.). The motors for the treadmill belts are synchronized and feedback controlled so that, if the speed of one belt changes, the other belt maintains an identical speed. The treadmill can attain speeds of up to $5.28 \text{ m}\cdot\text{s}^{-1}$ ($11.8 \text{ mi}\cdot\text{h}^{-1}$) and can be set at grades of $\pm 25\%$. Each belt is mounted over a force plate, which is capable of measuring GRF in three planes: the two coordinates of the center of pressure (CoP), and the moments about the vertical axis. The CoP is the point on the ground through which a resultant vertical force vector would act, if it was considered to have a single point of application. It is equal and opposite to a weighted average of the location of all downward forces acting on the ground. Each force plate in the treadmill provides six continuous voltage output signals corresponding to forces and torques in three orthogonal directions (x, y, z). For this study, the voltage outputs of the force plates were sampled at the rate of 1200 Hz, filtered with a low-pass Butterworth filter (cut-off frequency of 10 Hz), and converted to physical units (N) using manufacturer-supplied calibration factors. The digital values were stored in computer data files.

A number of kinetic variables were derived from the participants' force-time histories outputted from the force plate treadmill during walking, and the effects of the load conditions on these variables were determined. In analyzing locomotion, GRF is generally decomposed into three orthogonal components (Figure 8). The directions of the components are at right angles to each other: vertical (Z-axis), anteroposterior (X-axis), and mediolateral (Y-axis). By convention (Nigg, 1986), the vertical force is positive; the positive direction is upward, indicating that the force is exerted by the ground on the foot. The anteroposterior component is commonly referred to as the braking-propulsive component. It is the horizontal shear force exerted by the ground on the foot in the direction opposite locomotion (braking) or in the same direction as locomotion (propulsive). By convention (Nigg, 1986), braking force is expressed as a negative number and propulsive force as a positive number. The mediolateral component is horizontal shear force exerted by the ground on the foot toward (positive number) or away from (negative number) the midline of the body.

The patterns of force-time histories of walking strides differ among individuals. However, typical patterns associated with walking are graphed in Figure 8 for each component of the GRF. The abscissa in the graphs is percentage of stance time. Stance time is the elapsed time from initial contact of one foot with the ground (heel strike) until that same foot leaves the ground (toe off). In this study, a threshold value of 50 N was used to define heel strike and toe off.

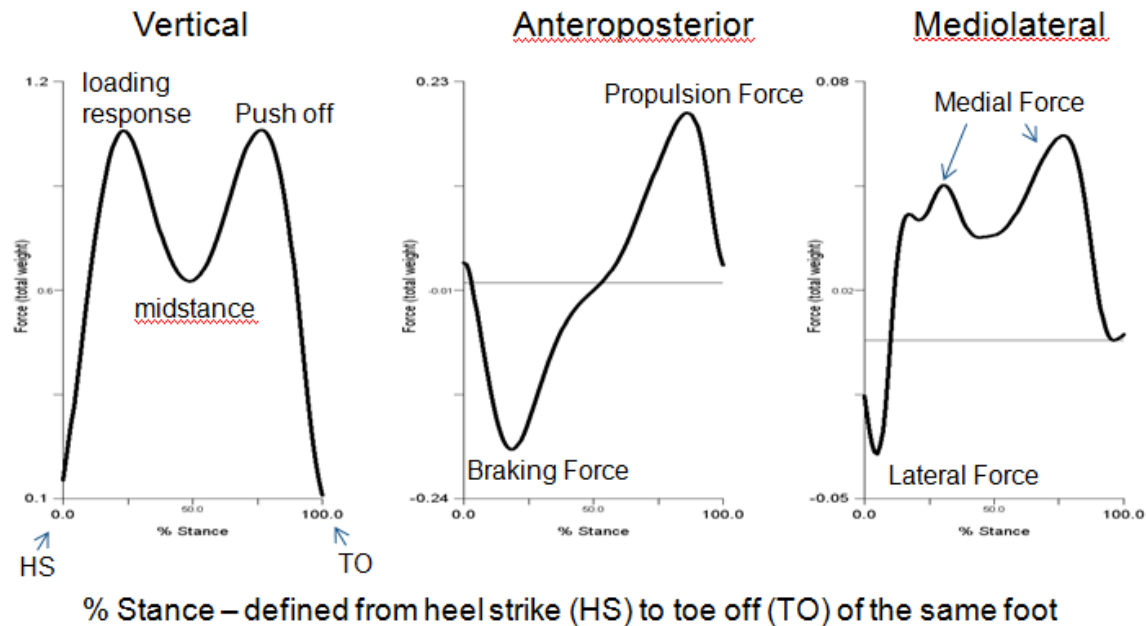


Figure 8. Example of three components of the GRF during walking on a level surface.

The vertical GRF component for walking shows two peaks, as illustrated in Figure 8. The first peak force (the loading response peak force) occurs early in the stride cycle, upon initial contact of the foot with the ground, indicating an upward acceleration of the body's mass as full weight bearing takes place. The midstance period of the gait cycle occurs after the first peak as the knee flexes and starts to extend again. The second peak force occurs late in the stride cycle as a result of the ankle plantarflexors causing push off of the foot from the ground. The force diminishes to zero as the opposite foot takes up the body weight. The anteroposterior component also tends to have two peaks (Figure 8). The first peak (braking force) is negative as a result of a backward horizontal frictional force between the foot and the ground. The second peak (propulsive force) occurs after midstance as muscle forces cause the foot to push back against the ground. The mediolateral GRF component tends to be relatively small. At contact of the foot with the ground, the force is in the lateral direction. During most of the rest of the stance phase, the force is in the medial direction (Figure 8).

Loading rate is the rate at which force is applied to the leg during heel strike. Loading rate in this context refers to the speed at which forces are applied to the CoP, which can change as a result of the external load applied to the body or the activity being performed. High loading rates have been associated with increased injury risk, including stress fractures in Soldiers (Knapik & Reynolds, 2012; Knapik et al., 2004).

One loading rate variable examined here was average loading rate. Average loading rate is calculated from the slope of the vertical GRF curve between the initial impact of the foot with the ground and the first vertical force peak (Figure 8). A second loading rate variable examined was instantaneous peak loading rate. This is the highest value achieved for the slope of the vertical GRF curve between the initial impact of the foot with the ground and the first vertical force peak (Figure 8).

In addition to the GRF components, hip, knee, and ankle joint moments in the sagittal plane were analyzed. Joint moments are the net effect of all muscle activity on a joint and describe the overall mechanical demands placed on those muscles due to movement of the joint. A net joint moment is the minimum moment required at a joint to obtain the observed kinematics or body movement. Larger joint moment values are generally considered unfavorable due to increased demand on the musculoskeletal system and the increased potential for injury (Knapik & Reynolds, 2012; Knapik et al., 2004).

2.3.4.1.3 Kinematics. Three-dimensional (3D) body motion was recorded by cameras as the participants walked on the treadmill. These data were used to analyze gait kinematics. Retroreflective markers, about 12 mm (0.5 in.) in diameter, were placed at selected locations on the participant's skin and clothing to expedite processing of the gait kinematics. Markers were placed bilaterally on the lateral and medial forefoot, lateral and medial malleolus, lateral and medial joint center of the knee, greater trochanter, ASIS and PSIS of the pelvis, lateral joint center of shoulder, the 7th cervical vertebra (C7), and the zygomatic processes of the head. Two clusters of three markers, which were attached to rigid plastic plates, were placed bilaterally on the heels and clusters of four markers were secured bilaterally on the lateral thigh and shank using double sided and athletic tape wrapped around the segment. After a calibration period of stationary standing, the ASIS and PSIS markers were removed. Tracking markers were placed on the ACH (four single markers) and the chest area of the IOTV (marker triad). In addition, calibration markers were created by digitizing pre-determined anatomical landmarks at the sternal notch, xiphoid process, iliac crest, and the 12th thoracic vertebra (T12).

Twelve Oqus cameras (Qualisys AB, Gothenburg, Sweden), operating at 120 Hz, were focused on the area of the treadmill to capture a participant's walking movements. The cameras were positioned on each side and anterior and posterior to the viewing area. This allowed the kinematics of the whole body to be defined in 3D space with 6° of freedom biomechanical movement analysis for each body segment. The outputs of the cameras and the force plates were collected through a single data acquisition system and were time-synchronized.

The recorded images were processed using dedicated hardware and software (Qualisys AB, Göteborg, Sweden) to produce files containing time histories of the 3D coordinates of each reflective marker. Marker trajectories were low-pass filtered with a 4th order Butterworth filter at a cut-off frequency of 10 Hz. Using the marker trajectories, seven segment (bilateral thigh, bilateral shank, bilateral feet, and torso), 6° of freedom models were generated for each participant using the Visual3D™ software program (C-motion, Inc., Germantown, MD), which allowed calculations of kinematic variables describing the participant's posture and the spatial and temporal characteristics of each participant's gait.

Sagittal plane trunk, hip, knee, and ankle angles were calculated to describe the participant's posture. The maximum value, minimum value, and ROM over a stride were computed for each of the four body angles. A graphical definition of each angle is presented in Figure 9. The trunk angle is a measure of forward lean of the torso. This angle was calculated with regard to the vertical. Higher trunk angle values denote greater forward lean and lower values indicate a more upright posture. The hip angle describes the angle formed by the thigh and the trunk. Higher hip angle values indicate greater flexion. The knee angle is formed by the thigh and the shank.

Higher values denote greater flexion at the knee. The ankle angle is formed by the shank and the foot. Positive values indicate foot dorsiflexion and negative values indicate plantarflexion.

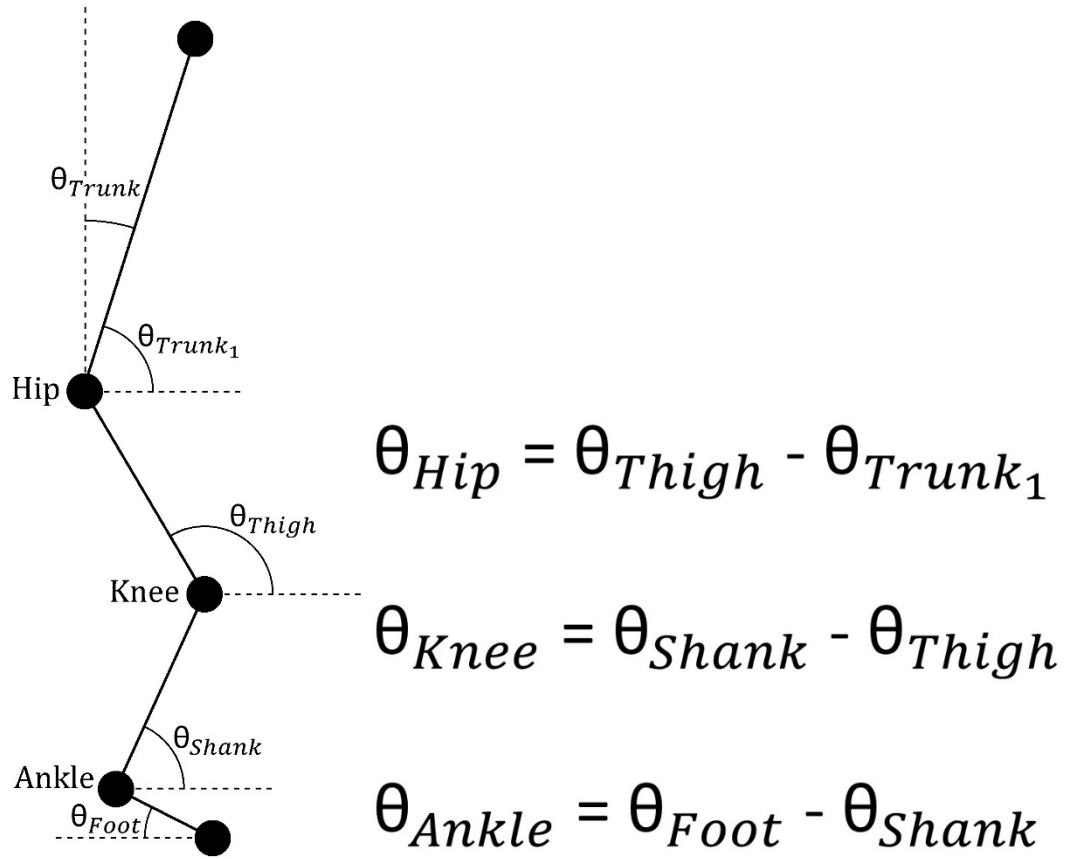


Figure 9. Definitions of trunk, knee, and ankle angles used for calculations of body posture.

The spatiotemporal gait variables that were calculated in the present study are listed and defined in Table 3. As indicated in the table, stance duration, swing duration, and double support duration for a stride were expressed as percentages of time to complete the stride.

Table 3. Definition of Spatiotemporal Variables

Variable	Definition
Stride length (m)	The linear distance from the point of heel strike of one foot with the ground to the point of the next heel contact of the same foot with the ground.
Stride width (m)	The medial-lateral distance between the right and the left heels as measured at the time of heel strike of each foot.
Stride time (s)	The time from heel strike of one foot with the ground to the time of the next heel strike of the same foot. Stride time is also commonly referred to as cycle time.
Stance duration (% stride time)	The time from heel strike of one foot with the ground to the time of toe-off of the same foot from the ground. It is expressed here as a percentage of stride time.
Swing duration (% stride time)	The time from toe-off of one foot from the ground until heel strike of the same foot with the ground. It is expressed here as a percentage of stride time.
Double support duration (% stride time)	The time that both feet are in contact with the ground. It is also referred to as double stance. Double support duration is expressed here as a percentage of stride time.

2.3.4.1.4 Muscle activity. Evaluation of the muscle activity was accomplished through surface EMG. To capture the muscle activity, electrodes were placed on the surface of the skin above the muscle group(s) of interest. The electrodes measure the algebraic summation of all motor unit action potentials transmitted along nearby muscle fibers as muscle contraction occurs. The intensity of the contraction is controlled by the frequency of nerve impulses and innervation of the muscle fibers (Florimond, 2010). In this study, muscle activity was collected using a Trigno™ wireless system (Delsys, Inc., Natick, MA). Electrodes were placed unilaterally on the following muscles of the participant's dominant side: vastus medialis, biceps femoris, and medial gastrocnemius. The electrodes could not be placed on shoulder or back muscles due to the placement of the pressure sensor pads. Before electrode placement, the application sites were prepared by removing the top layer of dead skin, oil, and hair with razors, abrasive pads, and alcohol wipes to ensure low impedance. After the electrodes had been secured to the skin with medical tape, the signal-to-noise ratios of static contractions were visually inspected to ensure adequate site preparation and electrode placement.

The EMG data were collected at 2400 Hz. The signals were systematically post-processed with custom MATLAB scripts (rel. R2014b, MathWorks, Natick, MA) using the following steps: 1) de-trend by removing the DC offset; 2) bandpass between 6 and 500 Hz using a 2nd-order Butterworth filter; 3) rectify; 4) create a linear envelope using a time-centered moving root mean square (RMS) with a 100-ms window length; 5) set an activation threshold at +2 *SD* above the mean of the resting muscle EMG signal; 6) determine muscle onset and offset timings by locating the intersections of the activation threshold and the RMS signal; 7) perform a spectral analysis on the raw EMG signal between each onset and offset timing; and 8) average each dependent variable for each muscle burst.

To prepare a participant's activity data from a muscle group for analysis, means were calculated for RMS peak amplitude and burst duration. Additionally, median spectral frequency and the log of the 5th order spectral index of muscle fatigue ($\log FI_{nsm5}$) were calculated using raw EMG signals. The log of the ratio between spectral moments of order -1 and order 5 defined $\log FI_{nsm5}$:

$$\log FI_{nsm5} = \log_{10} \left(\frac{\int_{f_1}^{f_2} f^{-1} \cdot PS(f) \cdot df}{\int_{f_1}^{f_2} f^5 \cdot PS(f) \cdot df} \right) \quad \text{Equation 1}$$

The component $PS(f)$ represents the EMG power-frequency spectrum as a function of frequency f , and f_1 and f_2 are the low and the high cutoff frequencies of the bandpass filter. This spectral index was proposed by Dimitrov et al. (2006). It has been found to be more sensitive as a metric to assess peripheral muscle fatigue during dynamic contractions than traditional indices, such as amplitude and spectral frequency parameters (González-Izal et al., 2010). Larger values of $\log FI_{nsm5}$ are taken to indicate higher levels of muscle fatigue.

2.3.4.1.5 Participants' ratings and questionnaire responses. Toward the end of treadmill walking trials, the 15-category RPE scale (Borg, 1970, 1982) was administered to assess the perceived exertion associated with the walking (Appendix B). The RPSD (Corlett & Bishop, 1976) was administered immediately upon the termination of treadmill walking trials. In the RPSD questionnaire, the respondent uses a 5-point scale to rate the level of pain, soreness, discomfort, or restriction being experienced on specific parts of the front and the back of the body (Appendix C).

A study-specific questionnaire, the Load Redistribution Questionnaire (Appendix D), was administered at the end of each of the two sessions comprised of 10-min walking trials. It sought to obtain participants' opinions regarding the load conditions under test and the acceptability of the load distribution device concept.

2.3.4.2 Procedure

Participants attended two sessions of testing, which were held on separate days. Each session lasted about 3.5 h. The main activities at each session consisted of five, 10-min trials of treadmill walking at a speed of $1.34 \text{ m} \cdot \text{s}^{-1}$ ($3 \text{ mi} \cdot \text{h}^{-1}$). At one session the treadmill grade was set at 0% and the grade was 9% at the other session. The order in which participants were exposed to the two grade conditions was randomly determined. Approximately half of the participants were tested on the 0% grade at the first session and on the 9% grade at the second session. The remaining participants were exposed to the treadmill grades in the opposite order.

Each participant carried out the five trials comprising a session and a different load condition was tested in each trial. The five conditions tested were: FL, FL/N_{off}, FL/L_{off}, FL/M_{off}, and FL/H_{off}. The order of testing of the load conditions was randomly determined for each participant. A new random sequence was generated for each participant at each test session.

The same procedures were followed at the two test sessions. The participant was outfitted in boots, spandex shorts, and a shirt. The participant completed the RPE (Appendix B) and the RPSD (Appendix C) while at rest. The chest strap of the HR monitor and the mask of the Quark CPET system were put in place. Seated, resting metabolic measurements were recorded for 2 min followed by standing, resting measurements recorded for 2 min. The mask was removed and the surface electrodes were taped in place on the skin. The participant then walked on the treadmill for a 5-min warm-up period. The retroreflective markers for motion capture were put in place and the participant stood upright on the treadmill in a stationary position while 5 s of kinematic data were recorded for calibration purposes. The PSIS and ASIS markers were removed.

Next, the pressure sensor pads were taped in place and the anatomical landmarks underlying the pads were identified through palpation. The participant donned the IOTV and the other FL components (Table 1), but not the load distribution device, and stood for about 10 s while the baseline FL pressures were recorded. The mean pressure at the tops of the shoulders obtained from the baseline FL readings was used to calculate the settings for the shoulder pressure to be implemented during that session when the load condition to be tested entailed shoulder offloading (FL/L_{off}, FL/M_{off}, FL/H_{off}).

The participant was then completely outfitted in the components of the first load condition to be tested. If the load condition included wear of the load distribution device, the device was put in place. For the three conditions that involved offloading the shoulders (FL/L_{off}, FL/M_{off}, and FL/H_{off}), the DWD was adjusted by the investigators to set the proportion of the load resting on the tops of the shoulders based on the mean calculated from the baseline FL pressure readings. Next, pressure measurements were taken during a 10-s period of quiet standing. The 10-min trial of continuous walking was then initiated, either at the 0% or the 9% grade. The participant carried the simulated weapon in both hands in front of the body (the ready position) throughout the trial.

After approximately 5 min of the walking trial had elapsed, time-synchronized force plate, camera, and EMG outputs were recorded for 30 s. At about 6 min into the trial, the mask was placed on the participant for approximately 2 min and metabolic data were captured, along with HR. After the mask was removed, the participant's RPE (Appendix B) was recorded. The treadmill was then stopped and pressure measurements were recorded for 10 s while the participant stood in a stationary position on the treadmill. The participant was then seated and completed the RPSD (Appendix C). This activity was followed by a 10-min rest break before the next trial began. Once outfitted in the load condition to be tested next, including adjustment of the DWD to the proper pressure, if required, a set of pressure measurements was taken for 10 s while the participant stood quietly and the 10 min of treadmill walking then began. After the fifth, and last, trial of a session, the questionnaire eliciting participants' opinions on the load distribution device (Appendix D) was administered.

In preparation for statistical analysis of the time-synchronized outputs of the force plates, motion capture cameras, and EMG, 10 successive strides, 5 initiated with a right foot contact and 5 with a left foot contact, were selected from each participant's data for a trial. Using the Visual3D software program, each dependent measure was calculated for each stride and a mean was obtained over the 10 strides for each measure. The GRF data were expressed as the measured force (N) normalized to the participant's body mass ($\text{N}\cdot\text{kg}^{-1}$) and to the participant's total mass ($\text{N}\cdot\text{kg}^{-1}$). Total mass was calculated as body mass plus the mass of all items worn or carried on the body.

The metabolic and the HR data recorded were also processed for analysis. The breath-by-breath $\dot{V}\text{O}_2$ and $\dot{V}\text{CO}_2$ measurements were averaged over 20-s increments for the 2-min gas collection period. These data were then ensemble-averaged for the 2-min period to obtain absolute values ($\text{mL}\cdot\text{min}^{-1}$). In addition, the $\dot{V}\text{O}_2$ data were scaled to the body mass of the participant ($\text{mL}\cdot\text{kg}^{-1}\cdot\text{min}^{-1}$). The HR data were processed by obtaining a mean over the 2-min recording period.

2.3.5 2-h Walking Trials

2.3.5.1 Equipment and Measurements

2.3.5.1.1 Metabolics. The Quark CPET, the metabolic measurement system used during the 10-min walking trials, was also used for the testing that entailed 2 h of treadmill walking. The $\dot{V}\text{O}_2$ and the $\dot{V}\text{CO}_2$ were recorded on a breath-by-breath basis and RER was calculated by the system. Prior to the start of testing of each participant, the metabolic measurement system was calibrated to known gas concentrations following manufacturer-supplied instructions. The Polar Vantage heart rate monitor was also worn again by the participants and HR was recorded in $\text{beats}\cdot\text{min}^{-1}$.

2.3.5.1.2 Cognitive tasks. Two cognitive tests were administered at regular intervals throughout the 2-h march. One was an auditory go/no-go response inhibition task and the other was a visual target detection task. For the auditory task, participants wore in-ear headphones with an auditory line to a laptop computer. The headphones presented participants with 500-ms clips of recorded gunfire sounds from an M-4 carbine or an AK-47 assault rifle. There was a randomized interstimulus interval between the gunfire sounds of 1500 to 1800 ms. Participants held a response device in their dominant hand. They were instructed to press the button on the response device as quickly as possible when hearing AK-47 fire (the go stimulus) and to withhold from responding when hearing M-4 fire (the no-go stimulus). The M-4 and the AK-47 sounds were chosen to emulate a common friend/foe (respectively) determination that Soldiers must make.

Each administration of the go/no-go task required 5 min to complete and consisted of two blocks of trials. One block was comprised of 80% go trials (68 trials of AK-47 gunfire) and 20% no-go trials (17 trials of M-4 gunfire). These trials were presented in randomized order with no more than two no-go trials in a row. The second block was comprised of go trials only (45 trials of AK-47 gunfire) in order to determine uninhibited reaction time. Participants were informed that there would not be any no-go trials presented in this block.

A number of variables were calculated from a participant's responses on each block of trials during a single, 5-min administration of the go/no-go test. The measures calculated from the

responses were reaction time, proportion of hits, proportion of false alarms, discriminability index (d'), and response criterion (c). Reaction time was quantified as the time taken to respond to the gunfire sound from the start of the presentation of the sound. Reaction times were computed for go trials contained within the go/no-go block of trials and for the block of trials with only go trials. The proportion of hits on AK-47 gunfire was obtained for the first block of trials. It was calculated from the number of correct hits (responded to AK-47 gunfire sounds) divided by the possible number of hits on the go trials (68 trials of AK-47 gunfire). The proportion of false alarms was also obtained for the first block of trials. This was calculated by dividing the number of incorrect hits (responded to M-4 gunfire sounds) by the total number of no-go trials (17 trials of M-4 gunfire).

The discriminability index (d'), a dimensionless value, was calculated for the go/no-go task data for the trials within the go/no-go block (Stanislaw & Todorov, 1999). Higher positive values reflect a higher proportion of hits compared with false alarms, whereas negative values reflect a higher proportion of false alarms compared with hits. The d' is calculated as follows:

$$d' = z(hits) - z(false\ alarms) \quad \text{Equation 2}$$

The components $z(hits)$ and $z(false\ alarms)$ are the z scores that correspond to the hit and the false alarm rates, respectively.

The c measure reflects the response strategy adopted by the participant. The response strategy has been referred to as an internal state that determines the participant's threshold for responding "yes" that the target stimulus is present or "no" that the target stimulus is not present (Stanislaw & Todorov, 1999). If participants adopt a liberal criterion, they respond "yes," regardless of the stimulus presented. This will yield a high hit rate, but also a high false alarm rate. Similarly, if participants adopt a conservative criterion, the response button will rarely be activated, resulting in a low hit rate and a low false alarm rate. The value of c is calculated as follows:

$$c = -.5[z(hits) + z(false\ alarms)] \quad \text{Equation 3}$$

Negative values of c signify a bias toward responding "yes" that the target stimulus is present. Positive c values signify a conservative bias. The closer a c value is to 0, the better the performance of the participant is in terms of maximizing the probability of a hit and minimizing the probability of a false alarm.

The second cognitive task used in this study was a visual target detection test that involved attending to a scene projected on television screens and responding when a person was detected in the scene. This task measures visual attention and was previously found to be unaffected by fatigue from load carriage and prolonged walking (Eddy et al., 2015). This task taps lower-level cognitive processes related to attention and vigilance.

The static scene was projected onto three, 2-m (80-in.) LED televisions, controlled by laptop computers. The scene was created to resemble one that a Soldier might encounter during dismounted operations (Figure 10). The televisions were on moveable stands and were positioned approximately 4.6 m (15 ft) in front of, to the right side, and to the left side of the participant (approximating 60° horizontal and 12° vertical field of view). One administration of this test required 5 min to complete and was comprised of the presentation of 30 targets, with

each target being presented for 2 s. There was a randomized interstimulus interval between target presentations of 4 to 16 s.



Figure 10. Urban Middle Eastern scene presented in the visual target detection test.

The targets were local nationals displayed one at a time in the scene. Target locations were evenly distributed among the three screen locations (10 targets per screen location). Targets appeared only in physically possible locations (e.g., no targets were placed in the sky) and no two targets appeared in the same location during a single block of trials. Participants held a response device in their dominant hand. They were instructed to press the button on the response device as quickly as possible when a target appeared. For the first 30 s of each 5-min task administration period, a fixation cross was centered on the middle television screen. To ensure that participants were ready and were attending to the screen, participants were instructed to focus on the cross. The variables calculated from the participants' responses were the number of correct responses and the latency to respond to a target. Latency was recorded as the time from target presentation to the time the participant actuated the response button. Participants had 2 s to respond to the target.

2.3.5.1.3 Isometric and isokinetic muscle strength. Strength measurements of the trunk, shoulder, and knee extensor and flexor muscles were made with a Biodex system (Model 900-860, Biodex Medical Systems, Shirley, NY) before and immediately after the 2 h of treadmill walking. The participant's settings determined during the orientation session were applied to adjust the system and range limits were set to ensure that the participant stayed within the allowable range of motion for the specific joint being tested.

Muscle groups were always tested in the same order. A participant first carried out trunk isokinetic testing at two velocities: $20^{\circ}\cdot\text{s}^{-1}$ and $60^{\circ}\cdot\text{s}^{-1}$. At $20^{\circ}\cdot\text{s}^{-1}$, one set of five maximal dynamic contractions was performed; for testing at $60^{\circ}\cdot\text{s}^{-1}$, there was one set of 21 maximal dynamic contractions. The participant started in an upright seated posture, perpendicular to the floor. Range of motion was restricted to 45° flexion from the starting posture to prevent hyperextension or hyperflexion. The axis of the dynamometer was aligned with the axis through the participant's ASIS. The participant was stabilized with waist, thigh, and foot straps to restrict motion to trunk flexion and extension.

Shoulder isokinetic testing followed trunk testing and it was also performed at two velocities: $60^{\circ}\cdot\text{s}^{-1}$ and $180^{\circ}\cdot\text{s}^{-1}$. For shoulder isokinetic testing at $60^{\circ}\cdot\text{s}^{-1}$, participants performed one set of five maximal dynamic contractions; for testing at $180^{\circ}\cdot\text{s}^{-1}$, there was one set of 21 maximal dynamic contractions. Range of motion was set at 0° (arm by the side of the body) and 180° (arm

above the head) to prevent hyperextension or hyperflexion. The axis of the dynamometer was aligned with the axis through the participant's acromion. The participant was stabilized with shoulder, waist, and thigh straps to restrict motion to shoulder flexion and extension.

The knee was the focus of the last of the strength testing. Isometric and isokinetic tests were conducted. A participant first performed the MVC isometric knee extensor test consisting of three repetitions of a 3- to 5-s MVC of the knee extensors. The knee was fixed at 90° flexion (Wilson & Murphy, 1996). For knee isokinetic testing, participants performed at the velocities of 60°·s⁻¹ and 180°·s⁻¹. For testing at 60°·s⁻¹, participants performed one set of five maximal dynamic contractions. For testing at 180°·s⁻¹, participants performed one set of 21 maximal dynamic contractions. Range of motion limits were set at 70° flexion and 0° (full extension) to prevent hyperextension and hyperflexion. For both isometric and isokinetic testing, the axis of the dynamometer was aligned with the axis through the participant's lateral femoral condyle. The participant was stabilized with shoulder, waist, and thigh straps to restrict motion to knee flexion and extension.

The torques produced during the isokinetic tests were recorded. Peak torque (N·m) was defined as the highest torque value measured during all contractions at each test velocity and indicates the maximum strength capability of the muscles involved. Total work performed (N·m) and average power (W) were also calculated for the isokinetic tests and used for analysis of each muscle group tested. Total work is the sum of work for every repetition performed and represents the capability of muscles to maintain torque over the course of all repetitions. Average power is the amount of total work divided by the time to complete the total work. Average power provides a measure of work rate intensity. For the isometric knee extension testing, the amount of force (N) exerted during the MVC was recorded.

2.3.5.1.4 Participants' ratings and questionnaire responses. The 15-category RPE scale (Appendix B; Borg, 1970, 1982) was administered at 10-min intervals throughout the 2-h march and the RPSD (Appendix C; Corlett & Bishop, 1976) was administered immediately upon march completion. A study-specific questionnaire, the Load Redistribution Questionnaire (Appendix D), was completed as the final activity of a testing session.

2.3.5.2 Procedure

Testing during prolonged walking required that participants attend two sessions, which were held on separate days. The duration of each session was about 3.5 h. At each session, participants engaged in 2 h of continuous treadmill walking while performing the cognitive tasks and executed the muscle strength tests before and after the bout of treadmill walking. The force plate treadmill used for the 10-min walking trials was used for this testing as well. However, force plate outputs were not recorded and kinetic data were not captured during the 2-h marches. For all testing, the treadmill was set at a 0% grade and a speed of 1.34 m·s⁻¹ (3 mi·h⁻¹). Therefore, the total distance walked by the participants over the 2-h period was 9.65 km (6.00 mi). At one of the two sessions, participants completed all testing in the FL condition. The FL/H_{off} load condition was used at the other session. The order of testing of the load conditions was randomly determined for each participant. Approximately half the participants were tested in the FL condition at the first session and in the FL/H_{off} condition at the second session. The remaining participants were exposed to the load conditions in the opposite order.

The same procedures were followed at the two test sessions. The participant was outfitted in boots, spandex shorts, and a shirt. The session started with the participant completing the RPE (Appendix B) and the RPSD (Appendix C) while at rest. The chest strap of the HR monitor and the mask of the Quark CPET system were put in place. Seated, resting measurements were recorded for 2 min followed by stranding, resting measurements recorded for 2 min. Pre-march muscle strength testing of the trunk, shoulder, and knee was then accomplished using the Biodex system. Before testing each muscle group, participants performed three submaximal (50% effort), full range contractions at a given test velocity to warm up the muscles. A period of 3 min of rest was provided between testing of the muscle groups and a period of 2 min of rest was provided between velocity conditions for a muscle group. For the isometric knee extension testing, there was a period of 2 min of rest between MVCs.

Upon completion of the muscle strength testing, the pressure sensor pads were taped in place at the shoulders and the hips and the anatomical landmarks underlying the pads were identified through palpation. The participant donned the IOTV and the other FL components (Table 1), but not the load distribution device, and stood for about 10 s while the baseline FL pressures were recorded. The mean pressure at the tops of the shoulders obtained from the baseline FL readings was used to calculate the setting for the shoulder pressure to be implemented during that session if the FL/H_{off} load condition was to be tested.

The participant was then completely outfitted in the components of the load to be tested at that session. For testing of the FL/H_{off} load condition, the DWD was put in place and was adjusted by the investigators to set the proportion of the load resting on the tops of the shoulders (70 to 90% of the baseline FL pressure) based on the mean calculated from the baseline FL pressure readings. Next, pressure measurements were taken during a 10-s period of quiet standing. The 2-h trial of continuous walking was then initiated.

A timeline of the activities that occurred over the course of the 2-h march is presented in Figure 11. As indicated in the figure, the auditory go/no-go task, which required 5 min to administer, was scheduled on six occasions over the 2-h march. The participant first performed the task at 5 min into the march and repeated the task at 20-min intervals. There were five administrations of the visual target detection test (Figure 11). Each iteration of the test required 5 min. The participant performed the target detection test for the first time after walking for 15 min and then at 20-min intervals (Figure 11). Beginning at 10 min into the march and then at 10-min intervals through 115 min of marching, metabolic, HR, pressure sensor, and RPE data were collected. A final period of collection of these measures occurred from 115 to 120 min. For collection of metabolic data, the mask was placed on the participant for approximately 2 min. The $\dot{V}O_2$ and the $\dot{V}CO_2$ were later averaged over 20-s increments for the 2-min gas collection period. These data were then ensemble-averaged for the 2-min period to obtain the absolute values ($mL \cdot min^{-1}$). The $\dot{V}O_2$ data were also scaled to the body mass of the participant ($mL \cdot kg^{-1} \cdot min^{-1}$) and to total mass ($mL \cdot kg^{-1} \cdot min^{-1}$). After the mask was removed, the participant's RPE (Appendix B) was recorded. This was followed by recording of measurements from the pressure pads for 10 s. The participant carried the simulated M-4 in the ready position throughout the trial, except when performing the cognitive tests. During these times, the participant held the response device in the dominant hand while cradling the weapon against the body.

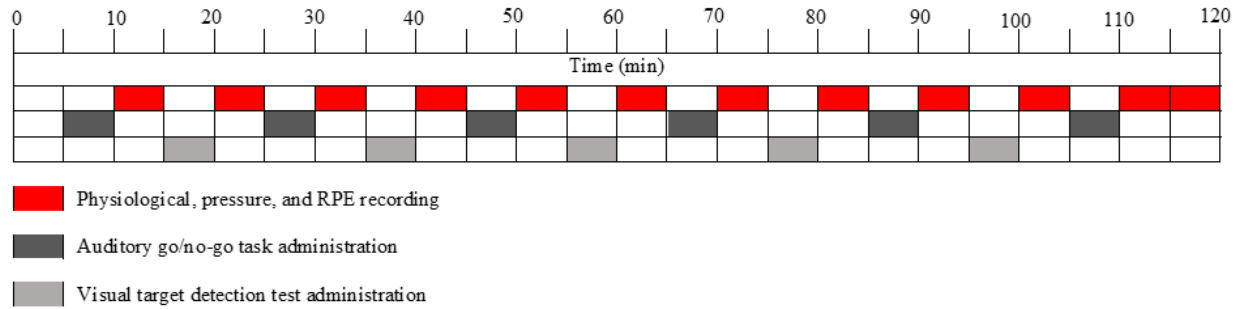


Figure 11. Overview of timing of data collections (in min) for performance evaluation during 2 h of treadmill walking.

At the time of each pressure measurement capture period, the top of the shoulder pressure was evaluated. If the offloading appeared to have fallen below the 70-90% offloading range, an adjustment of the participant's equipment was made to increase the offloading percentage while the participant continued to walk on the treadmill. In some instances, the treadmill was stopped temporarily to make the adjustment. The stoppage time was typically less than 1 min, and never exceeded 2 min.

The final capture of metabolic, HR, pressure, and RPE data ended at the 120-min mark (Figure 11). The RPSD (Appendix C) was then administered and the treadmill was stopped. With the participant standing in a stationary position on the treadmill, 10 s of pressure data were captured. All equipment was removed and the participant immediately executed the post-march muscle strength testing of the trunk, shoulder, and knee. Post-march strength testing did not include warm-up trials of submaximal contractions. Upon completion of the strength testing, participants completed the study-specific questionnaire (Appendix D) and the session ended.

2.4 Statistical Analysis

Descriptive statistics were obtained for pressure measurement data to illustrate differences among the load conditions in sensor outputs. The pressure measurements examined included the sensor outputs recorded immediately prior to the beginning of trials for each of the study activities and, for the 10-min and the 2-h walking trials, the outputs of the sensors upon trial completion were also examined. For most other measures taken in the study, statistical analyses in the form of analyses of variance (ANOVAs) were completed using SPSS Statistics ver. 21.0 (IBM, Inc., Armonk, NY). An effect was considered statistically significant if the likelihood of its occurrence by chance was $p < .05$. For sets of data that did not meet the sphericity assumption when Mauchly's test of sphericity was used, the Greenhouse-Geisser adjustment was applied to the degrees of freedom. When post hoc tests were undertaken, the Bonferroni method was used to make adjustments to significance level for multiple comparisons.

2.4.1 Cervical FRR Evaluation

The raw data inputted into the analysis of the cervical FRR were the mean muscle activity during the middle 60% of the extension phase divided by the mean muscle activity during the middle 60% of the relaxation phase. A mean was obtained for each side of the body from the second, third, and fourth trials of the five trials performed. These means were submitted to a two-way repeated measures ANOVA with six levels of the load condition variable (NL, FL, FL/N_{off}, FL/L_{off}, FL/M_{off}, FL/H_{off}) and two levels of the body side variable (Right, Left).

2.4.2 10-min Walking Trials

To analyze the effects of load condition and treadmill grade on data acquired during the 10-min walking trials, separate two-way repeated measures ANOVAs were carried out on the metabolic, kinetic, kinematic, EMG, and RPE measures. There were five levels of the load condition variable (FL, FL/N_{off}, FL/L_{off}, FL/M_{off}, FL/H_{off}) and two levels of the grade variable (0%, 9%). For the RPSD data, the non-parametric Cochran Q test was applied to contrast the five load conditions (FL, FL/N_{off}, FL/L_{off}, FL/M_{off}, FL/H_{off}) with regard to ratings the participants gave to the front and the back of the body. For treatment of the RPSD data, each of the ratings on the 5-point scale was assigned a numeric value, with the values ranging from 0 (*none*) to 4 (*extreme pain, soreness, discomfort, or restriction*).

2.4.3 2-h Walking Trials

The effects of load condition and elapsed time during the 2-h march were analyzed by applying separate two-way repeated measures ANOVAs to the metabolic, cognitive, and RPE data from the marches. There were two levels of the load condition variable (FL, FL/H_{off}) and 12 levels of the elapsed time variable (5 to 120 min in 10-min increments). Additional analyses for the cognitive tests included a trend analysis by testing for linear, quadratic, and cubic curve estimates via polynomial contrasts. In the case of a significant interaction, the same ANOVA with contrasts was conducted within conditions of interest to test for linear, quadratic, and cubic trends.

For the dependent measures from the isometric and isokinetic strength tests administered before and after the 2-h walking trials, the data acquired after trial completion were subtracted from the readings taken before the trial was initiated. Separate one-way repeated measures ANOVAs for the dependent measures of the different muscle groups were applied to the differences obtained. There were two levels of the load condition variable (FL, FL/H_{off}).

For the RPSD data, the non-parametric Cochran Q test was applied to contrast the two load conditions (FL, FL/H_{off}) with regard to ratings the participants gave to the front and the back of the body. Each of the ratings on the 5-point scale was assigned a numeric value, with the values ranging from 0 (*none*) to 4 (*extreme pain, soreness, discomfort, or restriction*).

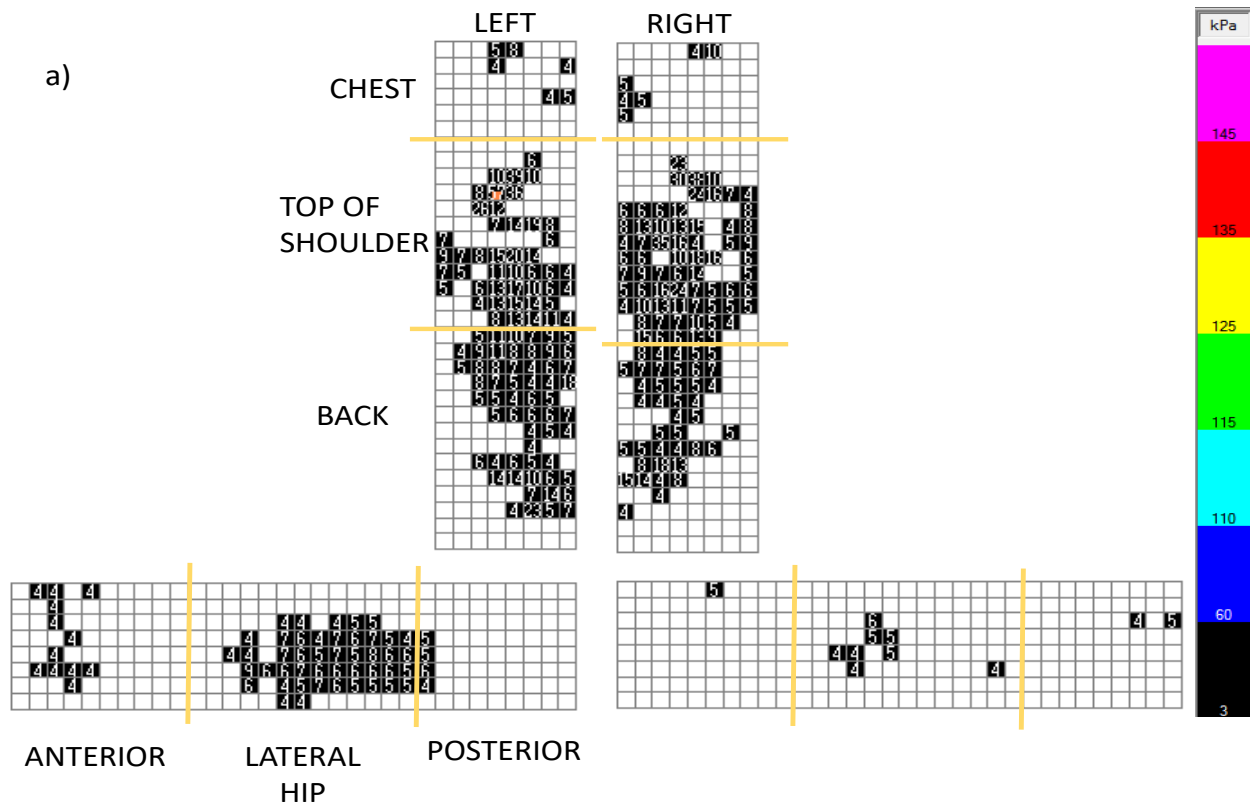
2.4.4 Participants' Questionnaire Responses

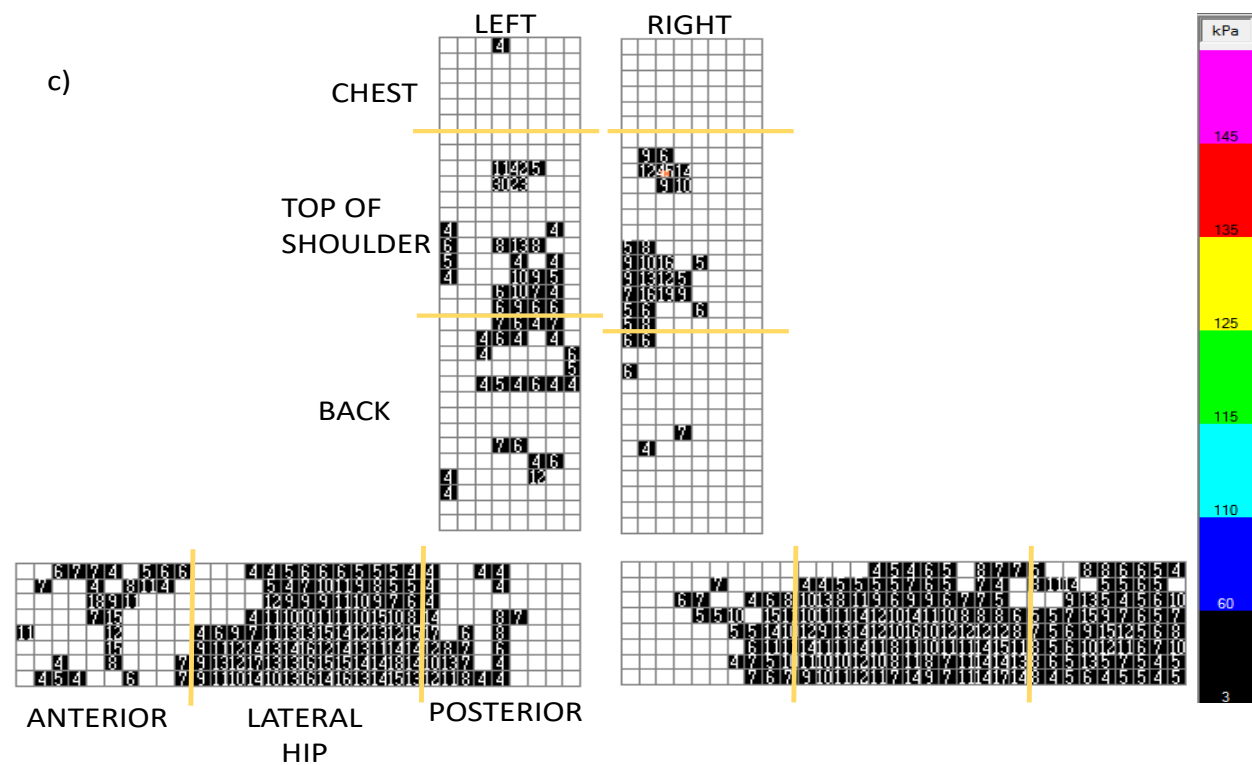
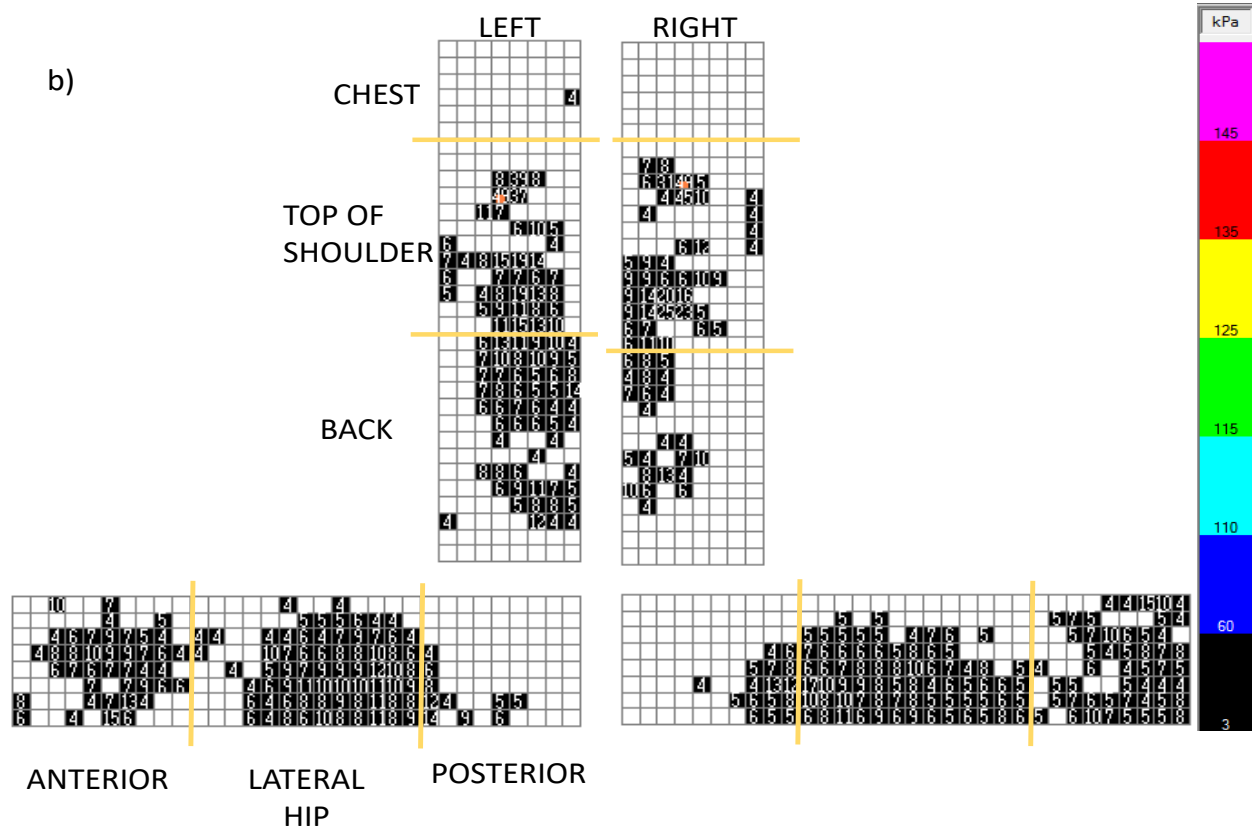
For the Load Redistribution Questionnaire (Appendix D), descriptive statistics, such as frequency of response and medians, were obtained and participants' comments were summarized.

3 RESULTS

3.1 Pressure Measurements

Figure 12 contains exemplar outputs of the pressure sensor pads in the shoulder and the hip regions for the FL, FL/L_{off}, FL/M_{off}, and FL/H_{off} load conditions. The displays for the FL/L_{off}, FL/M_{off}, and FL/H_{off} conditions illustrate the differences in the pressure distribution patterns at the shoulders and the hips as the pressure on the top of the shoulder regions was adjusted to achieve sensor outputs that were reduced by 10 to 30% (FL/L_{off}), 40 to 60% (FL/M_{off}), and 70 to 90% (FL/H_{off}) relative to the baseline FL pressure reading. As shown in Figure 12, increases in offloading at the shoulders (i.e., reduced pressure) were associated with increased pressure at the hips.





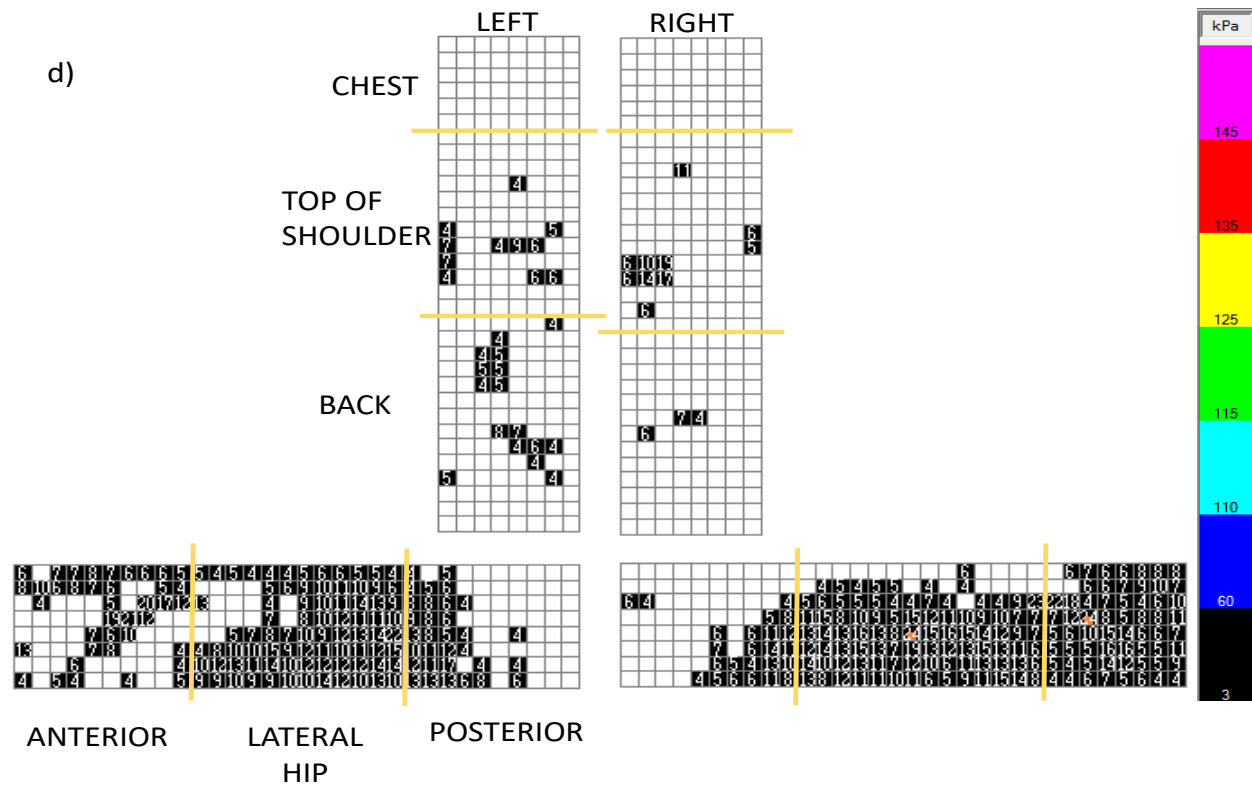


Figure 12. Exemplar displays of pressure sensor outputs for the following load conditions: a) FL; b) FL/L_{off}; c) FL/M_{off}; and FL/H_{off}.

The pressure sensor outputs were treated to obtain means calculated over the data of the study participants. Figure 13 is a presentation of mean pressures in each region of the pressure sensor pads for five load conditions (FL, FL/N_{off}, FL/L_{off}, FL/M_{off}, and FL/H_{off}). The means were obtained from the pressure readings captured immediately before the initiation of each trial of the study, when the participants had been completely outfitted in the load condition to be tested and the targeted amount of offloading had been set, if required. Figure 13 shows that the mean pressures on the right and the left sides of the body were highly similar for a given load condition. Further, as illustrated in Figure 12, Figure 13 shows the increase in pressure that occurred at the hips, particularly the lateral regions, as the amount of offloading at the tops of the shoulders was increased.

Additional pressure data are presented in Figure 14. The figure displays the mean percentage offloading at the tops of the right and the left shoulders combined for four load conditions (FL/N_{off}, FL/L_{off}, FL/M_{off}, and FL/H_{off}). The means were calculated over the pressure readings for the participants and separate means were obtained for the various study activities.

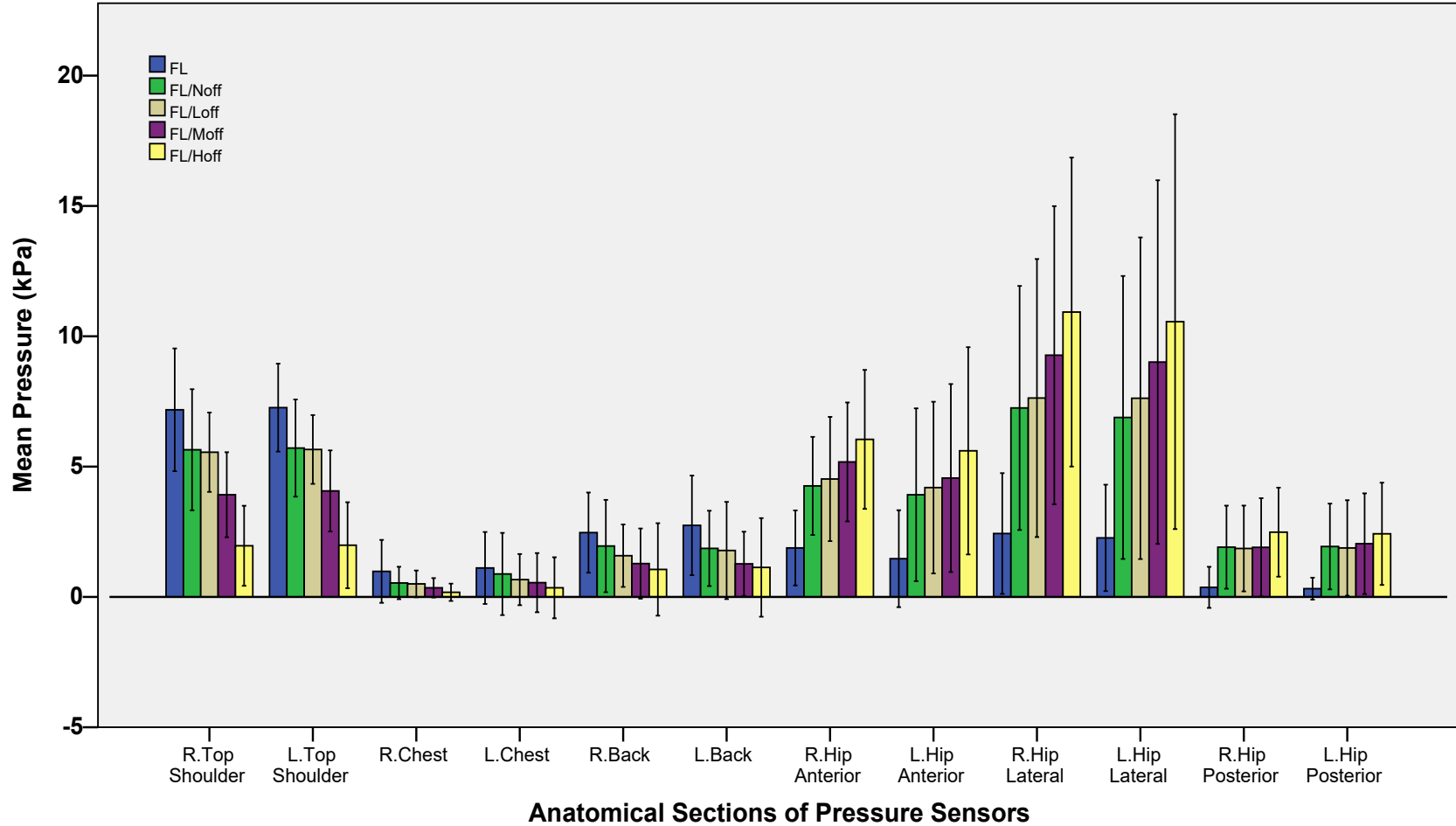


Figure 13. Mean pressure measurements for each region of the right and the left shoulder and hip pads under five load conditions. The pressure data were captured immediately before the start of each trial of the study, after participants had been outfitted for the trial and the amount of offloading set, if required. The means were calculated over participants and over trials of the test activities. Error bars indicate ± 1 SD.

The data in Figure 14 were acquired during the period of stationary standing that immediately preceded the initiation of a trial. At that time, the participants were wearing the gear for the load condition to be tested and adjustments had been completed to set the targeted amount of offloading, if required. The values in Figure 14 are expressed as percentages of reduction in pressure relative to the baseline FL pressure, the pressure measured at the tops of the shoulders when the FL components were being worn during preparations before initiation of a trial. The data in the figure indicate that the settings for each of the three load conditions that entailed adjustment of the load distribution device to offload the shoulders were highly similar for each test activity and that the percentages of offloading for each of these conditions were within the ranges established (FL/L_{off}: 10 to 30%; FL/M_{off}: 40 to 60%; and FL/H_{off}: 70 to 90%). Further, the variances associated with these three load conditions were smaller than the variance for the FL/N_{off} condition, which entailed wearing the components of the DWD with the offloading capability disengaged (Figure 14).

It was expected that the pressure at the tops of the shoulders when the FL/N_{off} condition was used would approximate the pressure with the FL condition. As indicated in Figure 14, this was not the case. The mean pressures obtained with the FL/N_{off} condition were similar to those recorded for the FL/L_{off} condition.

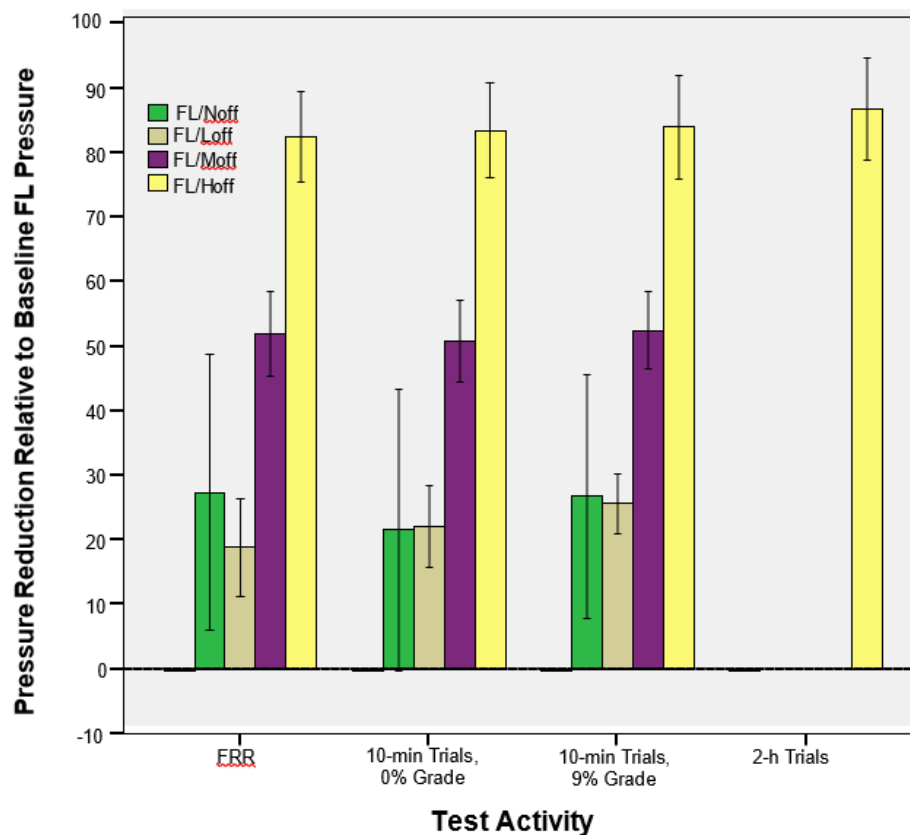


Figure 14. Means for pressure at the tops of the right and the left shoulders combined immediately prior to trial initiation for four load conditions. Values are expressed as percentage reduction in pressure relative to the baseline FL pressure, which was the pressure measured at the tops of the shoulders when the FL components were being worn prior to initiation of a trial. The means are presented separately for each of the main study activities. Error bars indicate ± 1 SD.

Some post-trial pressure data are presented in Figure 15. These data are mean values that were calculated over the pressure readings for the participants upon trial completion. The values are expressed as percentages of pressure reduction relative to the baseline FL pressure, the pressure measured at the tops of the shoulders when the FL components were being worn before initiation of a trial. It is this FL pressure reading that dictated the pre-trial settings for the three load conditions that entailed adjustment of the load distribution device to reduce top of shoulder pressure. The post-trial data for the offloading conditions (FL/L_{off}, the FL/M_{off}, and the FL/H_{off}) show less of a reduction in pressure relative to the pre-trial FL condition than the pre-trial data do (Figure 14). The mean percentages of post-trial pressure reduction relative to the pre-trial FL pressures remained within the specified range for the FL/L_{off} condition. The percentages at the end of a trial were less than the minima established for both the FL/M_{off} and the FL/H_{off} conditions. However, the relationships among the conditions remained the same: relative to pressure for the pre-trial baseline FL condition, the FL/H_{off} condition reflected the greatest percentage reduction in pressure, followed by the FL/M_{off} condition, with the percentage of pressure reduction being lowest for the FL/L_{off} condition (Figure 15).

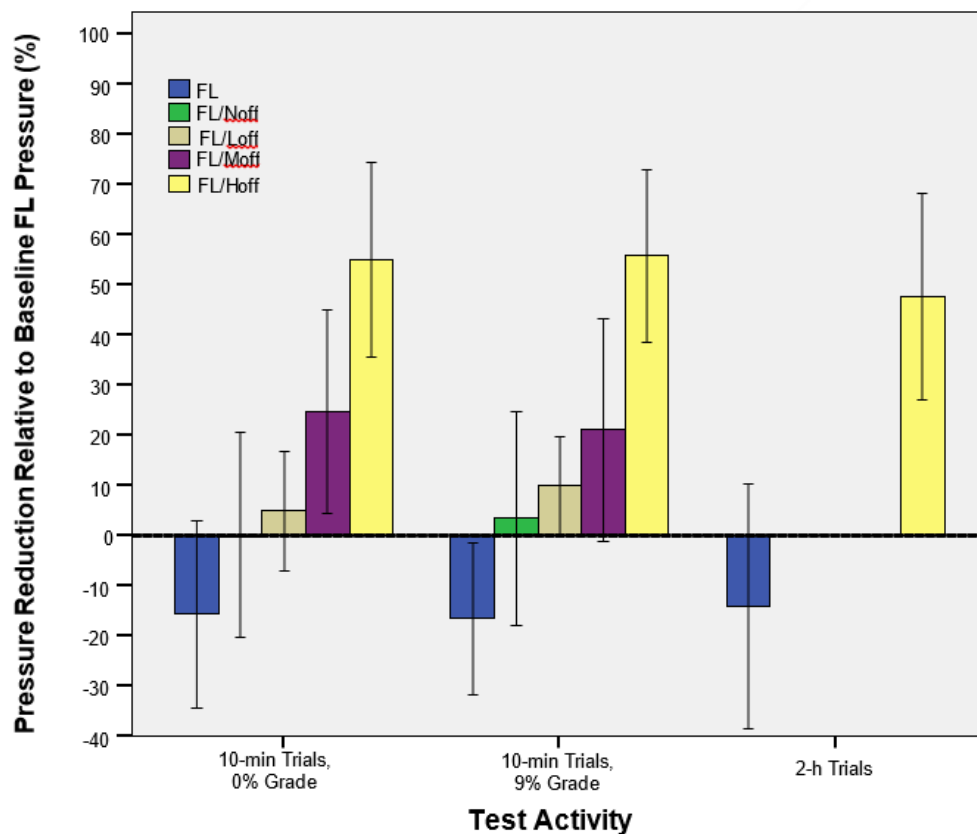


Figure 15. Means for pressure at the tops of the right and the left shoulders combined immediately after trial completion for five load conditions. Values are expressed as percentage reductions in pressure relative to the baseline FL pressure, which was measured at the tops of the shoulders when the FL components were being worn immediately prior to the initiation of a trial. The means are presented separately for the 10-min trials at each grade and for the 2-h trials. Error bars indicate ± 1 SD.

In addition to the post-trial data for the three load conditions that entailed offloading by use of the DWD, Figure 15 contains post-trial pressures for the FL and the FL/N_{off} conditions. Like the FL/L_{off}, the FL/M_{off}, and the FL/H_{off} conditions, the pressure reductions were less after than before a trial for the FL and the FL/N_{off} conditions (Figure 15).

Additional post-trial pressure data are presented in Figure 16. They are summary data on the pressure sensor outputs at the tops of the shoulders immediately upon completion of trials. For the test activities that consisted of 10-min walking trials and 2-h walking trials, the treadmill was stopped at the end of a trial period and the participant then stood in a stationary position on the treadmill for 10 s while pressure measurements were recorded. Post-trial pressures were not recorded for the FRR activity.

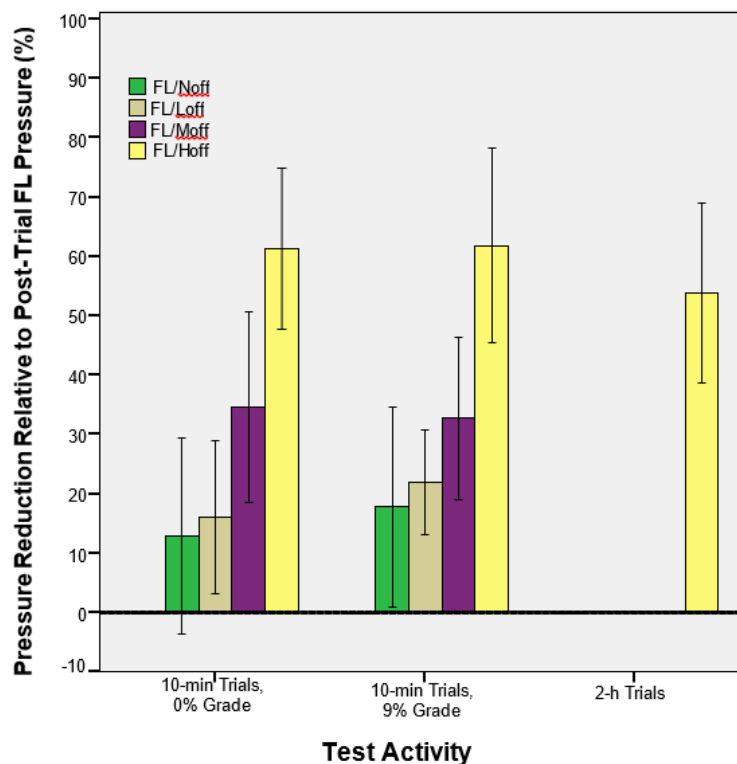


Figure 16. Means for pressure at the tops of the right and the left shoulders combined immediately after trial completion for four load conditions. Values are expressed as percentage reductions in pressure relative to the pressure measured at the tops of the shoulders with the FL condition upon trial completion. The means are presented separately for the 10-min trials at each grade and for the 2-h trials. Error bars indicate ± 1 SD.

The mean values in Figure 16 were calculated over the pressure readings for the participants and are expressed as percentages of pressure reduction relative to the pressure measured at the top of the shoulders for the FL condition upon trial completion. These post-trial pressure data are a means to assess whether the three load conditions in which top of shoulder pressures were set to specific levels prior to each trial (FL/L_{off}: 10 to 30%; FL/M_{off}: 40 to 60%; and FL/H_{off}: 70 to 90%) showed the same relationship to the FL condition when all pressure readings were obtained after the dynamic activity of walking had been carried out. As can be seen in Figure 16, the mean percentage of pressure reduction relative to the post-trial FL pressures remained within the specified range for the FL/L_{off} condition. However, the percentages at the end of a trial were less

than the minima established for the FL/M_{off} and the FL/H_{off} conditions. Although there were differences in the percentages before and after a trial, the relationships among the conditions did not change: the FL/H_{off} condition reflected the greatest percentage reduction in pressure, followed by the FL/M_{off} condition, with the percentages being lowest for the FL/L_{off} condition.

3.2 Cervical FRR Evaluation

Typical EMG and acceleration traces for the flexion, relaxation, and extension phases of the FRR movement are in Figure 17. The traces from both the middle 60% of each movement phase and from the middle 2 s are identified in the figure.

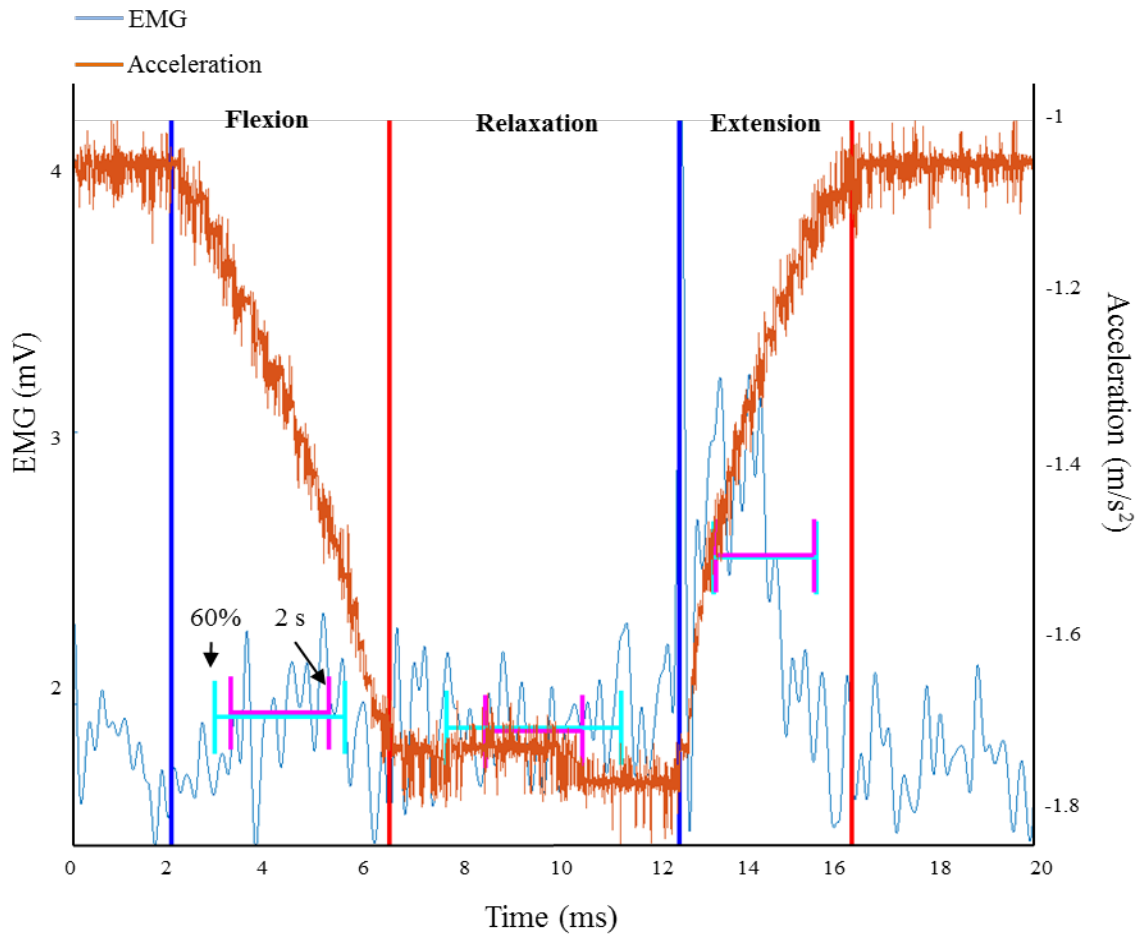


Figure 17. Typical EMG and acceleration traces captured during the flexion-extension-relaxation motion.

Mean FRRs, calculated using muscle activity for the middle 60% of the extension phase divided by activity for the middle 60% of the relaxation phase, are provided in Table 4 for each load condition and body side. The ANOVA performed on the FRR data did not yield a significant interaction between the load condition and the body side variables, $F(1.26, 15.18) = 0.99, p > .35$. The means in Table 4 for the NL and the FL conditions are somewhat higher than the means for the remaining load conditions. Also, the mean for the right side of the body is higher than the mean for the left side. However, the main effects of load condition and of body side were not significant ($F_s < 2.00, p_s > .22$).

Table 4. Means (SD) of the Cervical FRR for Each Load Condition and Side of the Body ($n = 13$)

Variable	Load Condition						Body Side	
	NL	FL	FL/N _{off}	FL/L _{off}	FL/M _{off}	FL/H _{off}	Right	Left
FRR	1.52 (0.45)	1.52 (0.49)	1.49 (0.58)	1.48 (0.60)	1.45 (0.63)	1.44 (0.57)	1.52 (0.53)	1.44 (0.49)

3.3 10-min Walking Trials

The results of the ANOVAs performed on the metabolic, biomechanical, EMG, and RPE data collected during the 10-min trials of treadmill walking at $1.34 \text{ m} \cdot \text{s}^{-1}$ ($3.0 \text{ mi} \cdot \text{h}^{-1}$) are reported in this section. The data for the load condition by grade interactions are presented in those instances in which the interaction was found to be significant ($p < .05$). Means and *SDs* are presented in tables for each of five levels of the load condition variable (FL, FL/N_{off}, FL/L_{off}, FL/M_{off}, FL/H_{off}) and for each level of the treadmill grade variable (0%, 9%). Means for a given load condition were computed across both treadmill grades and means for a given treadmill grade were computed across the five load conditions. Instances in which there was a significant main effect of load condition or of grade ($p < .05$) are noted in the tables. Because treadmill grade was not the focus of this evaluation, the text does not address the results in instances in which the grade main effect was significant. Results are also presented in this section for the nonparametric statistical analyses carried out on the RPSD ratings given by the participants at the conclusion of each trial.

3.3.1 Metabolics

Summary statistics for the metabolic dependent measures are presented in Table 5. The ANOVAs for these measures did not yield any significant interactions (all F s < 1.40 , p s $> .28$). A significant effect of load condition was limited to three related measures, the absolute value of $\dot{V}\text{O}_2$ [$F(4, 52) = 5.42$, $p < .001$, $\eta_p^2 = .294$], $\dot{V}\text{O}_2$ scaled to body mass [$F(4, 52) = 7.21$, $p < .001$, $\eta_p^2 = .289$], and the absolute value of $\dot{V}\text{CO}_2$ [$F(4, 52) = 5.25$, $p < .001$, $\eta_p^2 = .288$]. For these measures, post hoc tests revealed significantly higher values for the FL/H_{off} than for the FL condition (Table 5). There were no other significant differences between load conditions on these measures.

Table 5. Means (SD) of the Metabolic Variables for Each Load Condition and Treadmill Grade During 10-min Walking Trials at 1.34 m·s⁻¹ (n = 14)

Metabolic Variable	Load Condition					Treadmill Grade	
	FL	FL/N _{off}	FL/L _{off}	FL/M _{off}	FL/H _{off}	0%	9%
$\dot{V}O_2$ (mL·min ⁻¹) ^{a,b}	2520.70 (326.55)	2560.72 (366.41)	2588.44 (336.88)	2577.17 (363.90)	2624.59 (353.33)	1852.57 (539.95)	3296.08 (214.00)
$\dot{V}O_2$ normalized to body mass (mL·kg ⁻¹ ·min ⁻¹) ^{a,b}	33.38 (2.64)	33.82 (3.34)	34.21 (3.05)	34.03 (3.20)	34.66 (3.00)	24.33 (5.48)	43.67 (1.95)
$\dot{V}CO_2$ (mL·min ⁻¹) ^{a,b}	2219.43 (297.78)	2254.22 (315.50)	2279.12 (350.97)	2283.10 (351.11)	2337.38 (304.01)	1567.45 (502.80)	2981.85 (234.60)
RER (dimensionless) ^b	0.874 (0.028)	0.872 (0.033)	0.871 (0.037)	0.875 (0.033)	0.883 (0.033)	0.845 (0.032)	0.905 (0.041)
HR (beats·min ⁻¹) ^b	148.17 (14.01)	148.82 (14.33)	149.07 (12.22)	148.97 (14.14)	150.22 (13.49)	122.75 (18.26)	175.35 (13.49)

^aSignificant main effect of load condition, $p < .001$. ^bSignificant main effect of treadmill grade, $p < .001$ or better.

3.3.2 Kinetics

Summary statistics for the GRF variables are presented in Tables 6 and 7. The GRF variables are expressed in body weight (BW) in Table 6 and in total weight (TW) in Table 7. Total weight is body weight plus the weight of all items worn or carried on the body. The ANOVA results for these variables normalized to BW did not yield any significant main effects of load condition (Table 6; all F s < 2.11, p s > .09). It was also the case for the ANOVA results for the GRF variables normalized to TW that no significant main effects of load condition were obtained (Table 7; all F s < 2.11, p s > .09). However, the analysis of 2nd peak vertical force normalized to BW revealed a significant interaction between load condition and treadmill grade, $F(4, 48) = 5.47$, $p < .001$, $\eta_p^2 = .313$. The cell means are displayed in Figure 18. A significant interaction was also obtained for 2nd peak vertical force normalized to TW, $F(4, 48) = 5.42$, $p < .001$, $\eta_p^2 = .311$. The cell means for this interaction are presented in Figure 19.

Table 6. Means (SD) of the GRF Variables Normalized to Body Weight for Each Load Condition and Treadmill Grade During Walking Trials at $1.34 \text{ m}\cdot\text{s}^{-1}$ ($n = 13$)

GRF Variable	Load Condition					Treadmill Grade	
	FL	FL/N _{off}	FL/L _{off}	FL/M _{off}	FL/H _{off}	0%	9%
1st Peak Vertical	1.59 (0.09)	1.60 (0.10)	1.59 (0.10)	1.62 (0.02)	1.60 (0.09)	1.60 (0.08)	1.60 (0.10)
2nd Peak Vertical^{a,b}	1.60 (0.08)	1.58 (0.06)	1.61 (0.08)	1.60 (0.07)	1.60 (0.09)	1.56 (0.07)	1.64 (0.09)
Peak Mid-stance^a	0.81 (0.09)	0.81 (0.09)	0.83 (0.08)	0.83 (0.08)	0.83 (0.06)	0.89 (0.04)	0.75 (0.12)
Peak Braking	-0.26 (0.04)	-0.27 (0.04)	-0.27 (0.04)	-0.27 (0.04)	-0.27 (0.04)	-0.27 (0.03)	-0.26 (0.04)
Peak Propulsive^a	0.28 (0.04)	0.28 (0.03)	0.28 (0.03)	0.28 (0.03)	0.28 (0.03)	0.30 (0.03)	0.27 (0.03)
1st Peak Medial	0.10 (0.01)	0.10 (0.02)	0.11 (0.02)	0.10 (0.02)	0.10 (0.01)	0.10 (0.01)	0.10 (0.02)
2nd Peak Medial	0.11 (0.03)	0.12 (0.03)	0.11 (0.03)	0.12 (0.03)	0.11 (0.03)	0.12 (0.03)	0.11 (0.04)
Peak Lateral	-0.08 (0.01)	-0.08 (0.02)	-0.08 (0.01)	-0.08 (0.02)	-0.08 (0.01)	-0.08 (0.01)	-0.09 (0.02)

^aSignificant main effect of treadmill grade, $p < .003$ or better. ^bSignificant load condition by treadmill grade interaction, $p < .001$.

Table 7. Means (SD) of the GRF Variables Normalized to Total Weight for Each Load Condition and Treadmill Grade During 10-min Walking Trials at 1.34 m·s⁻¹ (n = 13)

GRF Variable	Load Condition					Treadmill Grade	
	FL	FL/N _{off}	FL/L _{off}	FL/M _{off}	FL/H _{off}	0%	9%
1st Peak Vertical	1.14 (0.06)	1.15 (0.06)	1.14 (0.06)	1.16 (0.05)	1.15 (0.05)	1.15 (0.05)	1.15 (0.06)
2nd Peak Vertical^{a,b}	1.14 (0.05)	1.14 (0.05)	1.16 (0.05)	1.15 (0.05)	1.15 (0.06)	1.12 (0.04)	1.18 (0.06)
Peak Midstance^a	0.58 (0.06)	0.58 (0.05)	0.59 (0.06)	0.60 (0.06)	0.60 (0.06)	0.64 (0.03)	0.54 (0.09)
Peak Braking	-0.19 (0.03)	-0.19 (0.03)	-0.19 (0.03)	-0.20 (0.03)	-0.20 (0.03)	-0.20 (0.02)	-0.19 (0.03)
Peak Propulsive^a	0.20 (0.03)	0.20 (0.02)	0.20 (0.02)	0.20 (0.02)	0.20 (0.03)	0.21 (0.03)	0.19 (0.02)
1st Peak Medial	0.08 (0.01)	0.07 (0.01)	0.08 (0.01)	0.08 (0.01)	0.07 (0.01)	0.08 (0.01)	0.07 (0.01)
2nd Peak Medial	0.08 (0.02)	0.08 (0.02)	0.08 (0.02)	0.08 (0.02)	0.08 (0.02)	0.08 (0.02)	0.08 (0.03)
Peak Lateral	-0.06 (0.01)	-0.06 (0.01)	-0.06 (0.01)	-0.06 (0.01)	-0.06 (0.01)	-0.06 (0.01)	-0.06 (0.01)

^aSignificant main effect of treadmill grade, $p < .003$ or better. ^bSignificant load condition by treadmill grade interaction, $p < .001$.

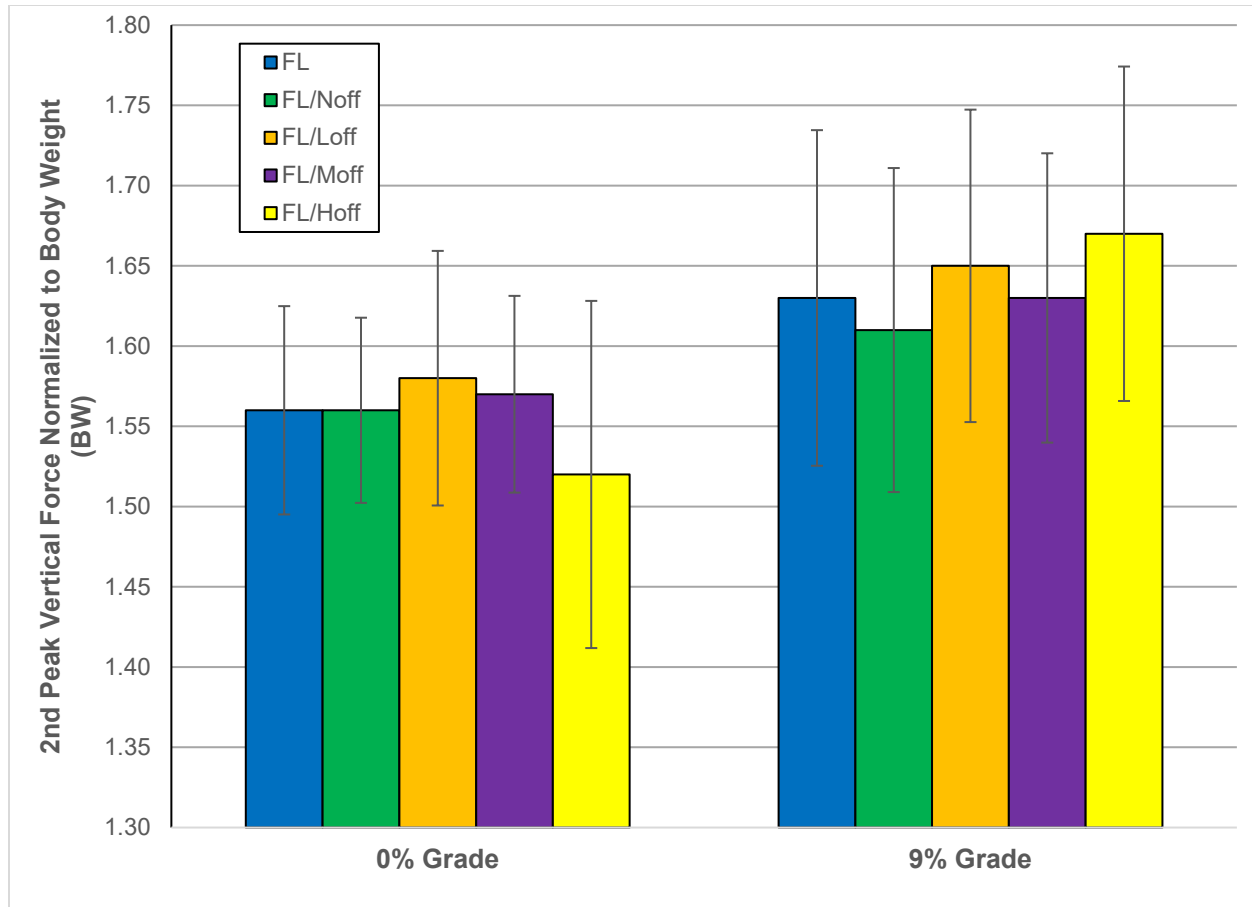


Figure 18. Means of 2nd peak vertical force normalized to body weight (BW) for each load condition during the 10-min walking trials at a speed of $1.34 \text{ m}\cdot\text{s}^{-1}$ with treadmill grades set at 0% and at 9% ($n = 13$). Error bars indicate ± 1 SD.

From the data presented in Figures 18 and 19, differences with respect to load condition and grade are observed. For example, at the 0% grade, the mean for the FL/H_{off} condition was lower than the means for the other load conditions, whereas, at the 9% grade, the FL/H_{off} condition had a higher mean value than the other load conditions (Figures 18 and 19). Student t-tests (with a Bonferroni adjustment factor of 5) of each load condition were performed with respect to treadmill grade. Significant differences ($p < .05$) were found for FL, FL/M_{off} and FL/H_{off} between the 0% and 9% treadmill grades. One-way ANOVAs (Bonferroni adjustment) were also performed between load conditions for each treadmill grade. No significant differences were found ($p > .05$); however, the FL/H_{off} condition was observed to be the load condition that was near significance.

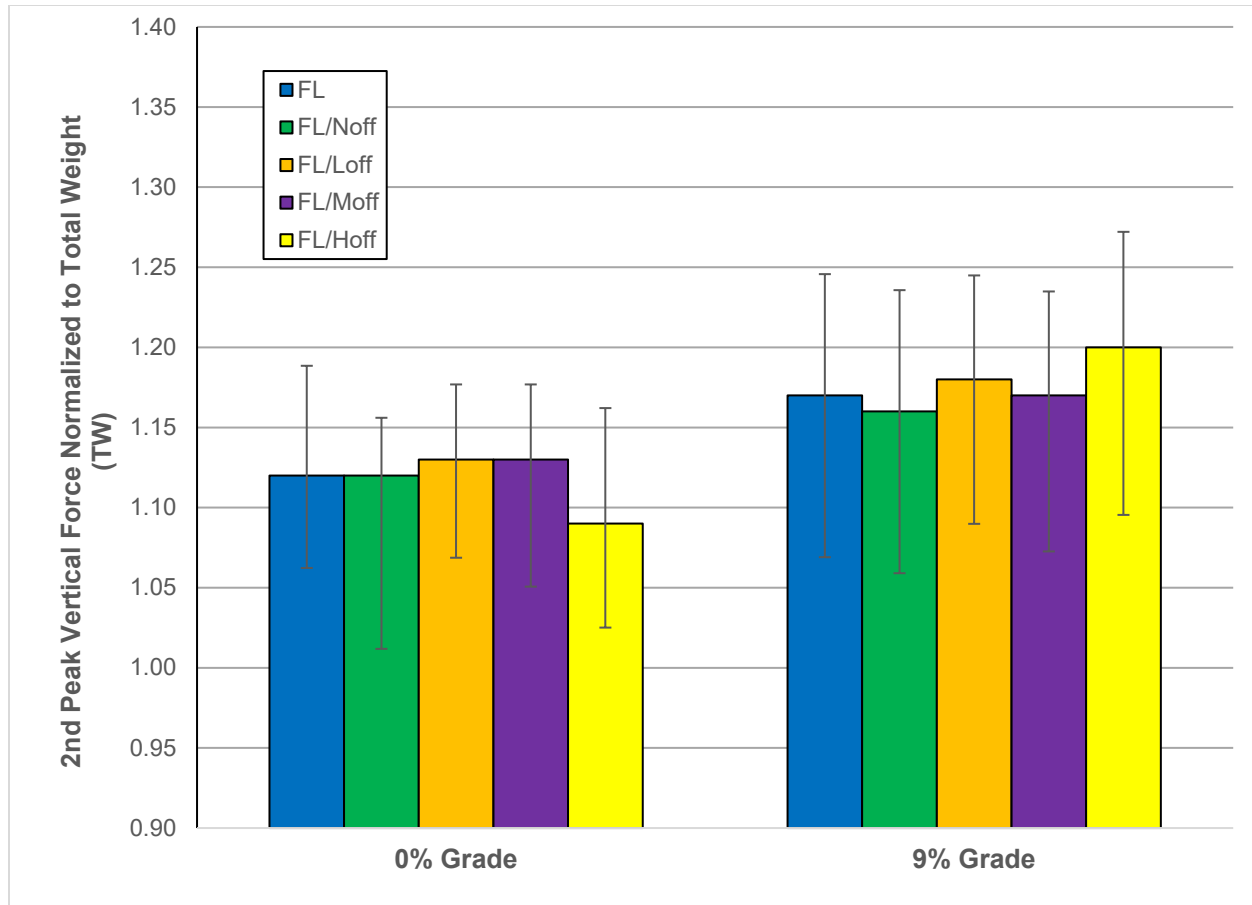


Figure 19. Means of 2nd peak vertical force normalized to total weight (TW) for each load condition during the 10-min walking trials at a speed of $1.34 \text{ m}\cdot\text{s}^{-1}$ with treadmill grade set at 0% and at 9% ($n = 13$). Error bars indicate ± 1 SD.

The means and *SDs* for the loading rate variables normalized to body weight and normalized to total weight are presented in Tables 8 and 9, respectively. The ANOVAs performed on the loading rate measures did not yield significant interactions between load condition and treadmill grade ($F_s < 0.80$, $p_s > .73$) or significant main effects of load condition ($F_s < 1.43$, $p_s > .24$).

Table 8. Means (SD) of the Mean and Instantaneous Loading Rates Normalized to Body Weight ($\text{BW}\cdot\text{s}^{-1}$) for Each Load Condition and Treadmill Grade During 10-min Walking Trials at $1.34 \text{ m}\cdot\text{s}^{-1}$ ($n = 13$)

Loading Rate Variable	Load Condition					Treadmill Grade	
	FL	FL/N _{off}	FL/L _{off}	FL/M _{off}	FL/H _{off}	0%	9%
Mean Loading Rate ^a	9.09 (0.78)	9.08 (0.80)	9.08 (0.76)	9.23 (0.81)	9.09 (0.77)	8.74 (0.63)	9.49 (1.12)
Instantaneous Peak Loading Rate ^a	19.43 (2.53)	20.08 (3.28)	20.12 (3.08)	20.50 (3.77)	20.29 (3.08)	18.51 (1.82)	21.66 (4.50)

^aSignificant main effect of treadmill grade, $p < .03$ or better.

Table 9. Means (SD) of the Mean and Instantaneous Loading Rates Normalized to Total Weight ($TW \cdot s^{-1}$) for Each Load Condition and Treadmill Grade During Walking Trials at $1.34 \text{ m} \cdot s^{-1}$ ($n = 13$)

Loading Rate Variable	Load Condition					Treadmill Grade	
	FL	FL/N _{off}	FL/L _{off}	FL/M _{off}	FL/H _{off}	0%	9%
Mean Loading Rate ^a	6.52 (0.53)	6.52 (0.55)	6.51 (0.55)	6.62 (0.56)	6.52 (0.53)	6.27 (0.45)	6.81 (0.77)
Instantaneous Peak Loading Rate ^a	13.94 (1.77)	14.40 (2.26)	14.44 (2.16)	14.70 (2.62)	14.55 (2.10)	13.28 (1.26)	15.53 (3.14)

^aSignificant main effect of treadmill grade, $p < .03$ or better.

Table 10 displays the means and *SDs* for the joint moments of the hip, knee, and ankle normalized to body mass. There were no significant interactions found in the ANOVAs performed on these measures (all F s < 2.82 , p s $> .12$). However, the ANOVA for one variable, minimum hip moment, did yield a significant main effect of load condition, $F(4, 48) = 3.47$, $p < .014$, $\eta_p^2 = .224$. Post hoc tests did not reveal significant differences between the load conditions on the minimum hip moment variable. The significant main effect of load condition does suggest a difference between the extreme data points. The largest mean negative value was for the FL/H_{off} condition and the smallest mean negative value was obtained for the FL condition (Table 10).

Table 10. Means (SD) of Maximum and Minimum Joint Moments ($N \cdot m \cdot kg^{-1}$) of the Hip, Knee, and Ankle for Each Load Condition and Treadmill Grade During 10-min Walking Trials at $1.34 \text{ m} \cdot s^{-1}$ ($n = 13$)

Joint Moment Variable	Load Condition					Treadmill Grade	
	FL	FL/N _{off}	FL/L _{off}	FL/M _{off}	FL/H _{off}	0%	9%
Maximum Hip Moment	0.78 (0.23)	0.76 (0.23)	0.79 (0.23)	0.75 (0.22)	0.75 (0.24)	0.76 (0.18)	0.77 (0.32)
Minimum Hip Moment ^{a,b}	-1.36 (0.06)	-1.41 (0.18)	-1.41 (0.22)	-1.42 (0.23)	-1.43 (0.21)	-1.17 (0.04)	-1.64 (0.07)
Maximum Knee Moment ^b	0.53 (0.11)	0.58 (0.13)	0.55 (0.06)	0.56 (0.09)	0.57 (0.09)	0.53 (0.08)	0.59 (0.11)
Minimum Knee Moment ^b	-0.90 (0.28)	-0.94 (0.27)	-0.92 (0.25)	-0.95 (0.27)	-0.92 (0.29)	-0.82 (0.24)	-1.04 (0.32)
Maximum Ankle Moment ^b	1.58 (0.06)	1.53 (0.09)	1.61 (0.06)	1.57 (0.07)	1.58 (0.09)	1.50 (0.09)	1.65 (0.05)
Minimum Ankle Moment ^b	-0.18 (0.04)	-0.18 (0.04)	-0.18 (0.04)	-0.18 (0.03)	-0.18 (0.04)	-0.23 (0.05)	-0.13 (0.04)

^aSignificant main effect of load condition, $p < .02$. ^bSignificant main effect of treadmill grade, $p < .03$ or better.

3.3.3 Kinematics

The means and *SDs* for the trunk, hip, knee, and ankle angle variables are in Table 11. The ANOVAs performed on these body angle variables did not yield any significant interactions (all F s < 1.50 , p s $> .22$) or significant main effects of load condition (all F s < 1.37 , p s $> .27$).

Table 11. Mean (SD) of the Body Angle Variables (degrees) for Each Load Condition and Treadmill Grade During 10-min Walking Trials at 1.34 m·s⁻¹ (n = 13)

Body Angle Variable	Load Condition					Treadmill Grade	
	FL	FL/N _{off}	FL/L _{off}	FL/M _{off}	FL/H _{off}	0%	9%
<i>Trunk</i>							
Maximum Angle ^a	-3.35 (2.86)	-3.87 (2.69)	-3.54 (2.94)	-3.39 (2.57)	-4.45 (3.68)	-0.61 (2.34)	-6.84 (3.57)
Minimum Angle ^a	-8.72 (3.17)	-8.72 (3.03)	-8.53 (3.30)	-8.33 (2.76)	-9.18 (3.97)	-4.69 (2.66)	-12.70 (3.62)
ROM ^a	5.37 (1.94)	4.85 (1.28)	4.99 (1.59)	4.94 (1.39)	4.73 (1.61)	4.08 (1.26)	5.87 (1.76)
<i>Hip</i>							
Maximum Angle ^a	50.70 (5.31)	51.24 (4.87)	50.36 (5.47)	50.26 (4.54)	52.14 (6.69)	40.62 (4.56)	61.26 (5.97)
Minimum Angle ^a	-2.36 (4.47)	-2.80 (5.06)	-3.56 (4.88)	-3.04 (4.91)	-1.71 (7.04)	-6.06 (4.74)	0.76 (5.82)
ROM ^a	53.06 (4.47)	54.04 (4.07)	53.71 (3.99)	53.29 (3.89)	53.85 (4.52)	46.68 (4.25)	60.50 (4.39)
<i>Knee</i>							
Maximum Angle ^a	71.35 (4.84)	70.71 (5.56)	69.55 (4.73)	69.98 (4.76)	70.37 (6.37)	71.42 (4.95)	69.37 (5.47)
Minimum Angle	0.88 (4.17)	0.42 (3.99)	-0.65 (3.48)	0.38 (4.12)	0.35 (5.03)	0.06 (3.90)	0.50 (4.38)
ROM ^a	70.47 (3.30)	70.29 (3.46)	70.20 (3.41)	69.60 (3.42)	70.02 (3.97)	71.36 (4.56)	68.87 (4.56)
<i>Ankle</i>							
Maximum Angle ^a	16.73 (3.13)	16.16 (2.75)	15.68 (2.81)	15.86 (2.50)	17.67 (7.47)	14.18 (2.73)	18.65 (3.55)
Minimum Angle ^a	-13.27 (3.26)	-13.46 (3.37)	-14.27 (4.03)	-14.43 (3.27)	-13.01 (1.93)	-14.58 (2.72)	-12.79 (2.71)
ROM ^a	30.00 (3.58)	29.61 (3.47)	29.95 (3.41)	30.30 (3.48)	30.68 (6.06)	28.77 (3.22)	31.45 (4.66)

^aSignificant main effect of treadmill grade, $p < .001$.

The means and SDs for the spatiotemporal measures are in Table 12. The ANOVAs carried out on these variables did not yield any significant interactions between load condition and grade (all F s < 0.94, p s > .46) or significant main effects of load condition (all F s < 1.82, p s > .18).

Table 12. Means (SD) of the Spatiotemporal Gait Variables for Each Load Condition and Treadmill Grade During 10-min Walking Trials at $1.34 \text{ m}\cdot\text{s}^{-1}$ ($n = 13$)

Gait Variable	Load Condition					Treadmill Grade	
	FL	FL/N _{off}	FL/L _{off}	FL/M _{off}	FL/H _{off}	0%	9%
Stride Length (m)	1.04 (0.05)	1.04 (0.04)	1.04 (0.05)	1.03 (0.04)	1.03 (0.04)	1.04 (0.04)	1.04 (0.05)
Stride Width (m)	0.18 (0.02)	0.17 (0.02)	0.18 (0.02)	0.17 (0.03)	0.17 (0.02)	0.18 (0.02)	0.17 (0.02)
Stride Time (s)	1.06 (0.05)	1.06 (0.04)	1.06 (0.05)	1.06 (0.04)	1.06 (0.04)	1.06 (0.04)	1.06 (0.05)
Stance Duration (% stride time) ^a	64.64 (0.92)	64.32 (1.45)	64.90 (0.94)	64.86 (0.92)	64.64 (1.16)	64.12 (1.07)	65.22 (1.11)
Swing Duration (% stride time) ^a	35.36 (0.93)	35.68 (1.45)	35.10 (0.94)	35.14 (0.92)	35.36 (1.16)	35.88 (1.07)	34.78 (1.11)
Double Support Duration (% stride time) ^a	28.91 (1.28)	28.78 (2.21)	29.28 (1.47)	29.21 (1.54)	29.03 (1.59)	28.10 (1.65)	29.98 (1.82)

^aSignificant main effect of treadmill grade, $p < .004$ or better.

3.3.4 Muscle Activity

The results of the separate ANOVAs performed on the EMG data for the vastus medialis, the biceps femoris, and the medial gastrocnemius muscle groups are reported in Tables 13 through 15, respectively.

Table 13. Means (SD) of the Vastus Medialis EMG Variables for Each Load Condition and Treadmill Grade During 10-min Walking Trials at $1.34 \text{ m}\cdot\text{s}^{-1}$ ($n = 11$)

Vastus Medialis Variable	Load Condition					Treadmill Grade	
	FL	FL/N _{off}	FL/L _{off}	FL/M _{off}	FL/H _{off}	0%	9%
Peak Amplitude (V) ^a	0.104 (0.052)	0.108 (0.054)	0.110 (0.054)	0.111 (0.064)	0.113 (0.054)	0.058 (0.024)	0.161 (0.092)
Burst Duration (ms) ^a	0.283 (0.052)	0.296 (0.058)	0.306 (0.069)	0.299 (0.060)	0.307 (0.057)	0.275 (0.063)	0.321 (0.058)
Median Spectral Frequency (Hz)	80 (17)	83 (18)	81 (18)	82 (18)	82 (17)	86 (20)	76 (21)
Log 5th Order Spectral Index (ratio) ^a	-12.896 (0.372)	-12.897 (0.328)	-12.891 (0.343)	-12.894 (0.316)	-12.888 (0.347)	-13.109 (0.372)	-12.677 (0.414)

^aSignificant main effect of treadmill grade, $p < .01$ or better.

Table 14. Means (SD) of the Biceps Femoris EMG Variables for Each Load Condition and Treadmill Grade During 10-min Walking Trials at 1.34 m·s⁻¹ (n = 11)

Biceps Femoris Variable	Load Condition					Treadmill Grade	
	FL	FL/N _{off}	FL/L _{off}	FL/M _{off}	FL/H _{off}	0%	9%
Peak Amplitude (V) ^{a,b}	0.045 (0.014)	0.044 (0.014)	0.048 (0.014)	0.044 (0.014)	0.050 (0.013)	0.036 (0.013)	0.057 (0.016)
Burst Duration (ms)	0.378 (0.071)	0.366 (0.066)	0.388 (0.104)	0.379 (0.094)	0.371 (0.120)	0.337 (0.087)	0.416 (0.107)
Median Spectral Frequency (Hz)	74 (15)	75 (11)	72 (12)	71 (13)	66 (18)	72 (21)	72 (9)
Log 5th Order Spectral Index (ratio) ^a	-13.191 (0.246)	-13.205 (0.172)	-13.136 (0.199)	-13.169 (0.190)	-13.003 (0.332)	-13.203 (0.385)	-13.078 (0.122)

^aSignificant main effect of load condition, $p < .05$ or better. ^bSignificant main effect of treadmill grade, $p < .001$.

Table 15. Means (SD) of the Medial Gastrocnemius EMG Variables for Each Load Condition and Treadmill Grade During 10-min Walking Trials at 1.34 m·s⁻¹ (n = 11)

Gastrocnemius Variable	Load Condition					Treadmill Grade	
	FL	FL/N _{off}	FL/L _{off}	FL/M _{off}	FL/H _{off}	0%	9%
Peak Amplitude (V) ^a	0.143 (0.039)	0.144 (0.040)	0.148 (0.043)	0.144 (0.042)	0.151 (0.044)	0.107 (0.040)	0.185 (0.057)
Burst Duration (ms)	0.347 (0.070)	0.341 (0.043)	0.349 (0.058)	0.352 (0.045)	0.338 (0.063)	0.349 (0.043)	0.342 (0.070)
Median Spectral Frequency (Hz) ^a	86 (22)	88 (19)	86 (17)	88 (19)	86 (18)	96 (25)	77 (16)
Log 5th Order Spectral Index (ratio) ^a	-13.266 (0.318)	-13.297 (0.252)	-13.288 (0.265)	-13.278 (0.272)	-13.275 (0.269)	-13.433 (0.319)	-13.129 (0.313)

^aSignificant main effect of treadmill grade, $p < .02$ or better.

None of the ANOVAs yielded a significant interaction between load condition and grade (all F s < 2.87 , $ps > .48$). Further, the biceps femoris was the only muscle group where a significant main effect due to load condition was found (Table 14). For this muscle group, load condition had a significant effect on peak amplitude, $F(4, 40) = 3.53$, $p < .015$, $\eta_p^2 = .261$, and on logFI_{ns5}, $F(4, 40) = 3.45$, $p < .05$, $\eta_p^2 = .256$. For both these variables, post hoc tests did not reveal significant differences between the load conditions. However, the significant main effect does suggest a difference between the lowest and the highest values. For peak amplitude, the lowest mean value was for the FL/N_{off} and the FL/M_{off} conditions and the highest was for the FL/H_{off} condition. For the logFI_{ns5} variable, the lowest (most negative) value was associated with the FL/N_{off} condition and the highest (least negative) value with the FL/H_{off} condition (Table 14).

3.3.5 Participants' Ratings

The summary data for the RPE are in Table 16. The ANOVA performed on the RPE yielded no significant main effect of load condition, $F(4, 36) = 0.247, p = .910$, and the interaction of load condition and grade was not significant, $F(4, 36) = 0.295, p = .879$. The values of the means for the load conditions were highly similar and corresponded to a rating of *light exertion* (Table 16).

Table 16. Means (SD) of the RPE Variable for Each Load Condition and Treadmill Grade During 10-min Walking Trials at 1.34 m·s⁻¹ (n = 10)

Variable	Load Condition					Treadmill Grade	
	FL	FL/N _{off}	FL/L _{off}	FL/M _{off}	FL/H _{off}	0%	9%
RPE ^a	11.25 (1.57)	11.20 (1.63)	11.05 (1.48)	11.05 (1.36)	11.15 (1.23)	9.20 (1.81)	13.08 (1.76)

^aSignificant main effect of treadmill grade, $p < .001$.

On the five-point scale of the RPSD, there were some ratings of 1 or 2 (*slight or moderate pain, soreness, discomfort, or restriction*), but the majority of ratings given were 0 (*no pain, soreness, discomfort, or restriction*). The number of participants who gave a rating of greater than 0 to a section of the body was counted for each load condition at each grade. These counts are presented in Figure 20 for the 0% grade and in Figure 21 for the 9% grade. The figures indicate that there were more participants assigning ratings greater than 0 at the 9% grade than at the 0% grade.

Cochran Q tests were carried out to analyze for differences among the load conditions in the RPSD ratings given. The data for the two grades were treated separately, as were the data for the front and the back of the body. For each load condition, counts were made of the number of participants who assigned a rating greater than 0 (i.e., a rating of at least *slight pain, soreness, discomfort, or restriction*) to one or more sections on the front of the body. The same was done for the back of the body. None of the tests revealed significant differences among load conditions, $Q(4) < 9.49, p > .05$, indicating that the likelihood of a rating exceeding 0 was the same for all five load conditions.

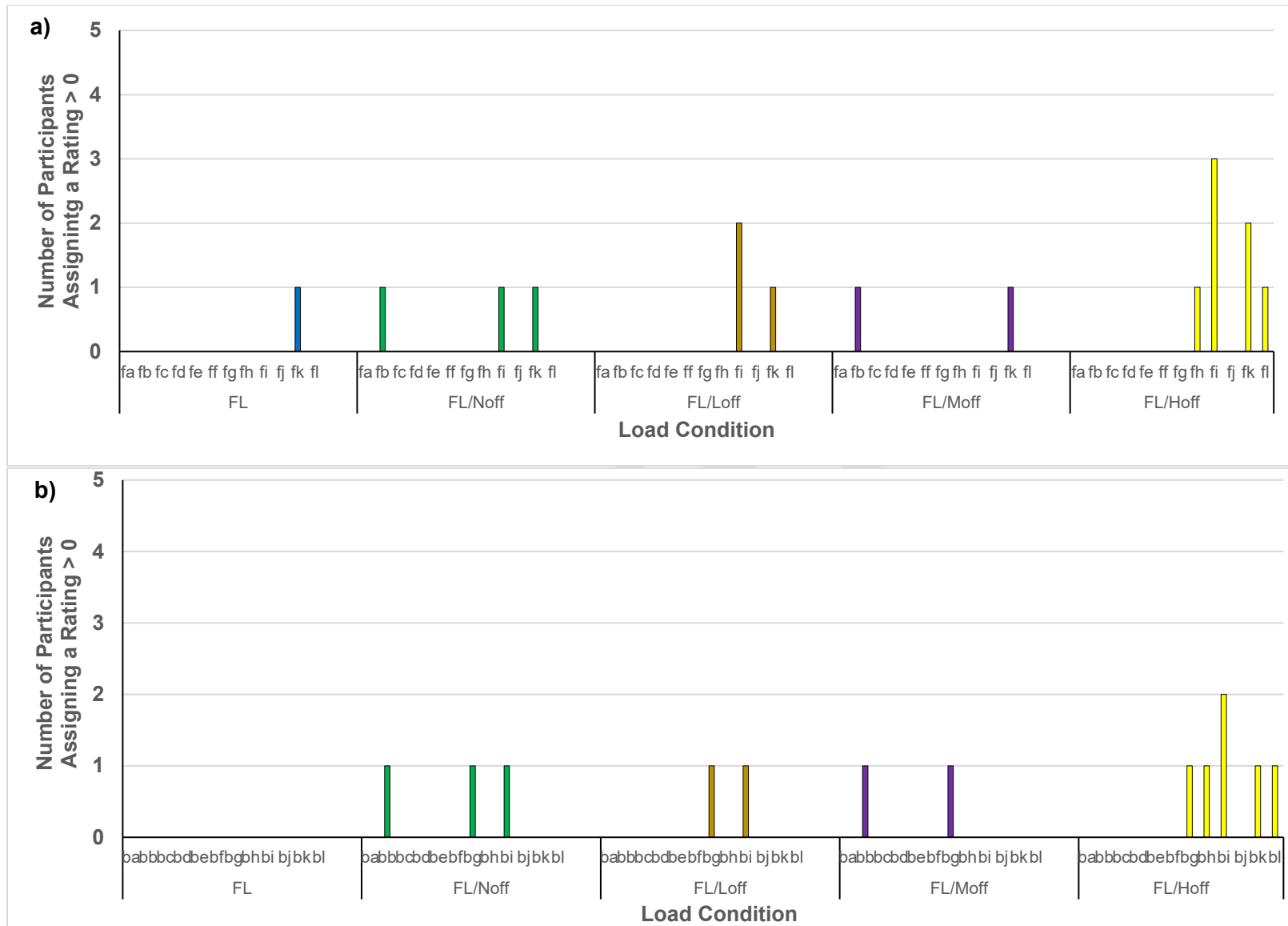


Figure 20. Count of participants ($n = 14$) assigning a rating greater than 0 (no pain, soreness, discomfort, or restriction) on the RPSD to each load condition after 10-min walking trials at 0% grade: a) front and b) back of body. Body sections are identified in Appendix C.

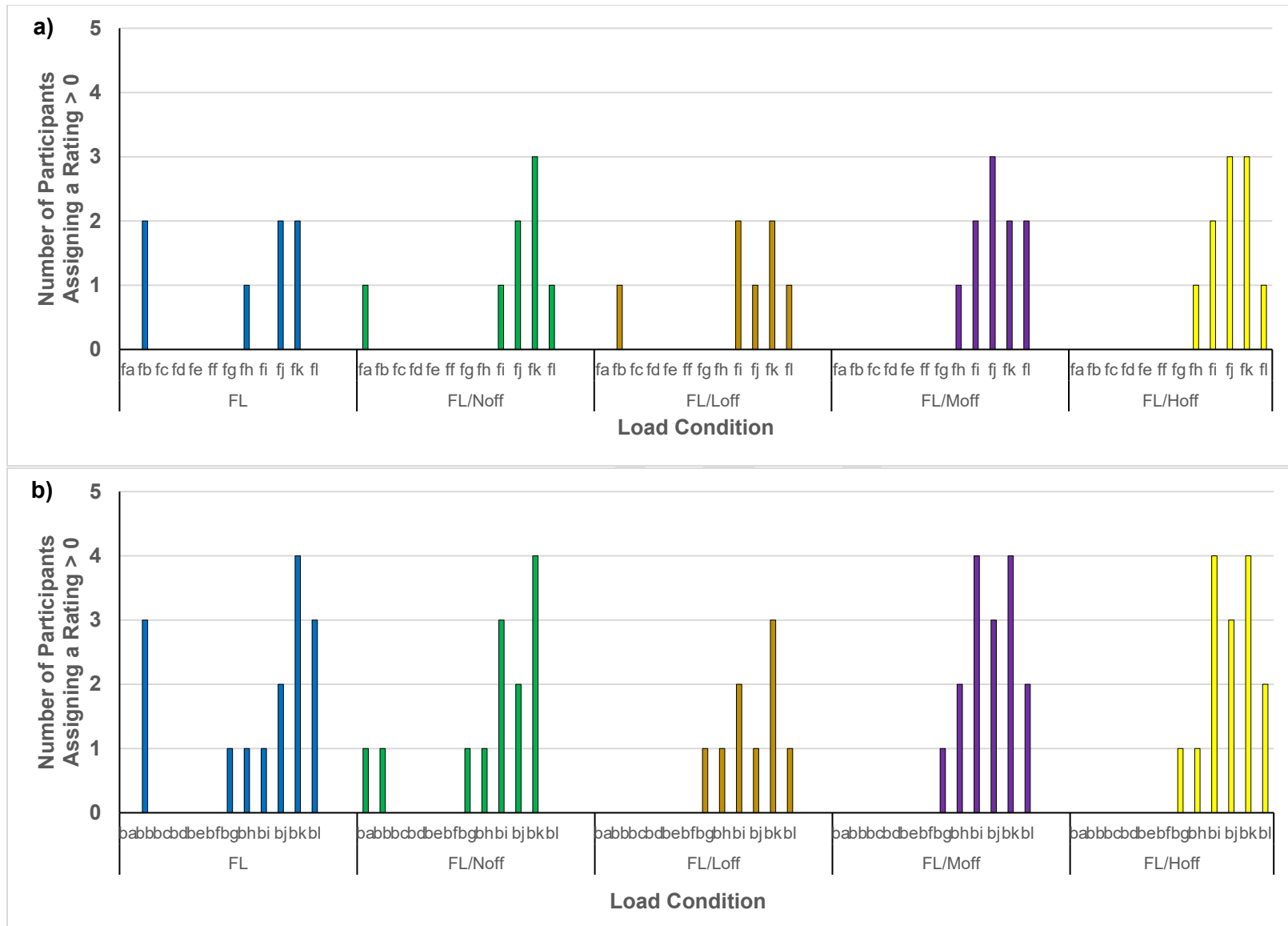


Figure 21. Count of participants ($n = 14$) assigning a rating greater than 0 (no pain, soreness, discomfort, or restriction) on the RPSD to each load condition after 10-min walking trials at 9% grade: a) front and b) back of body. Body sections are identified in Appendix C.

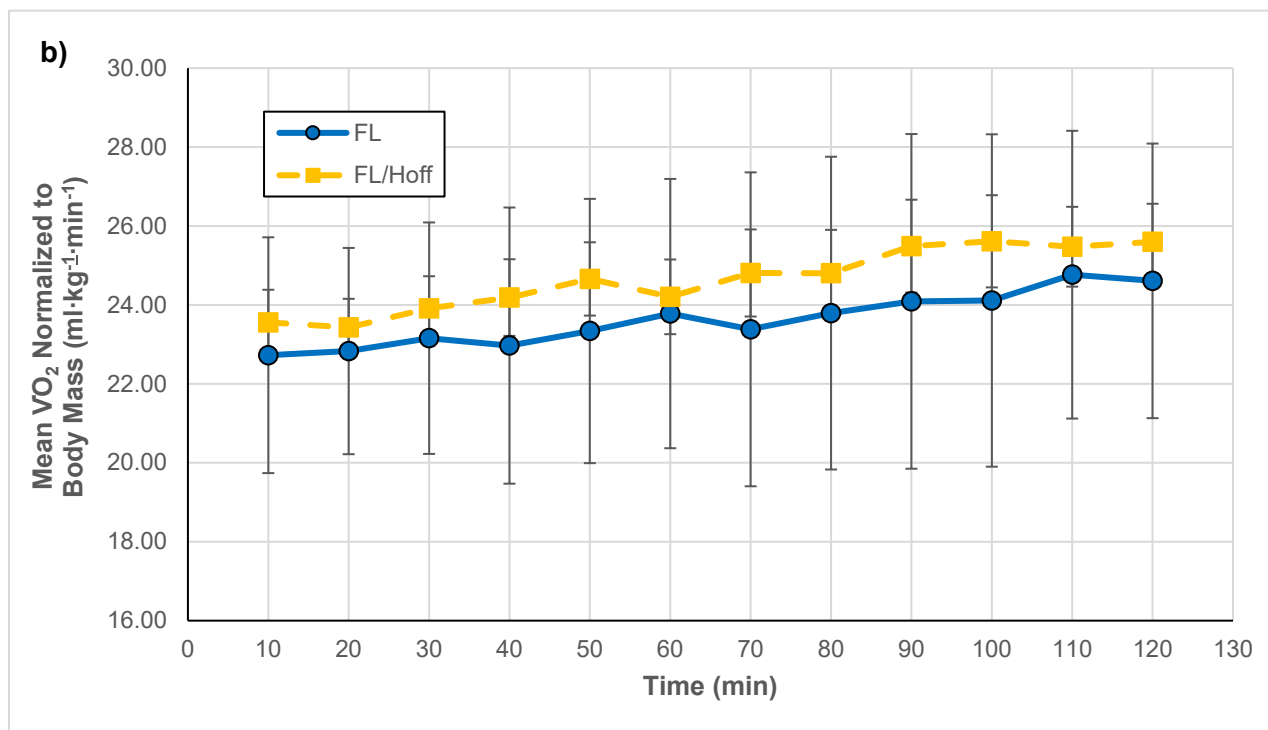
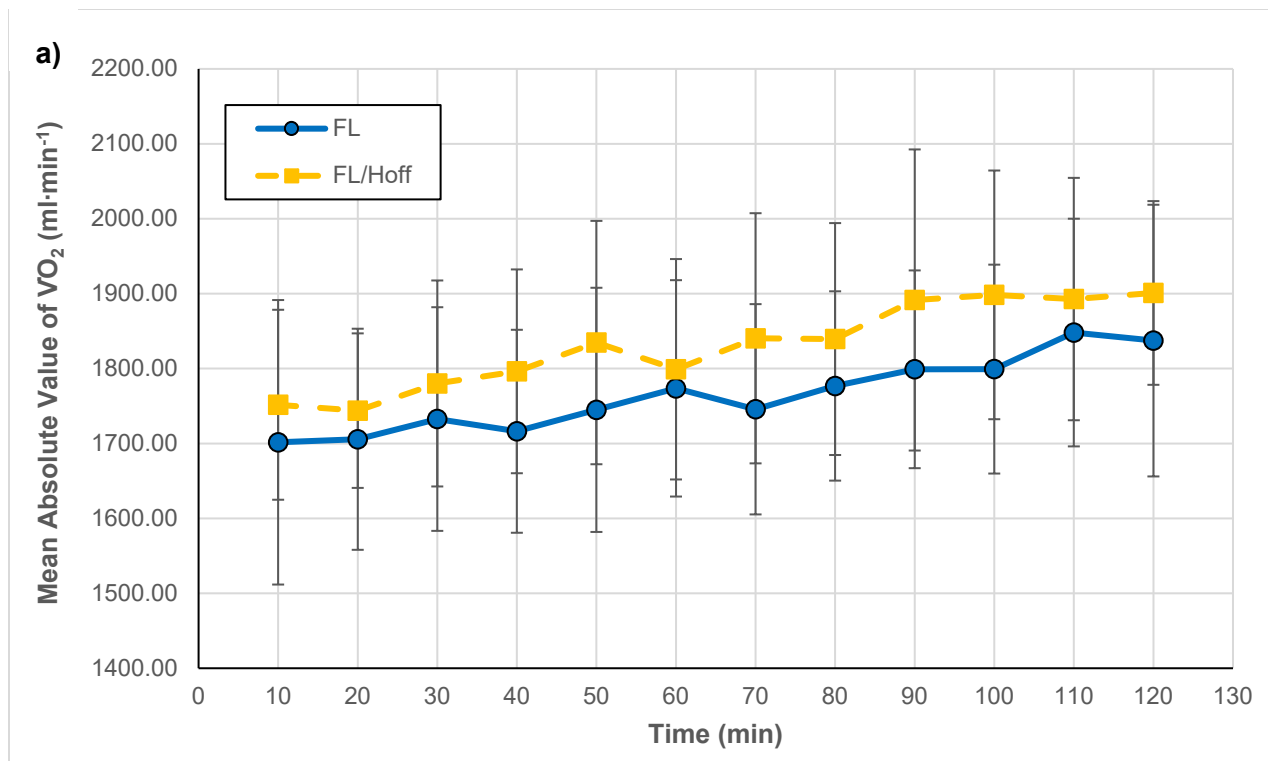
3.4 2-h Walking Trials

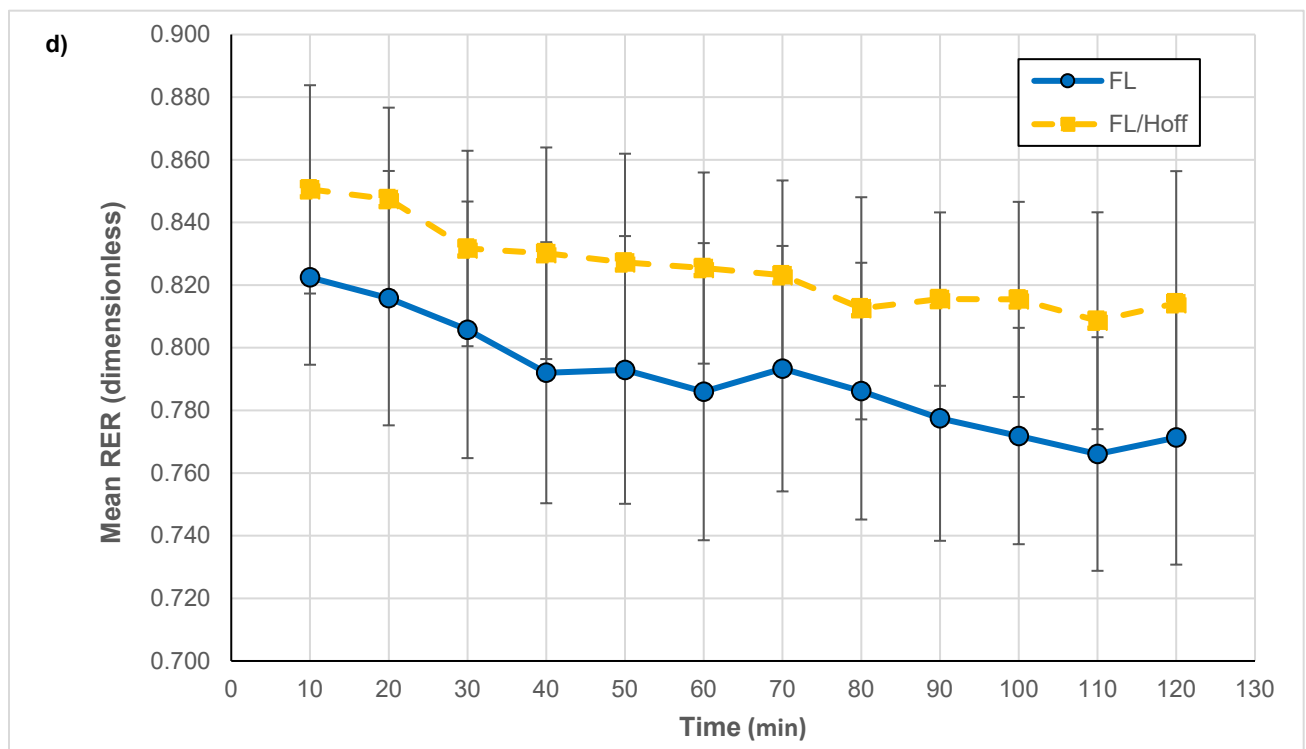
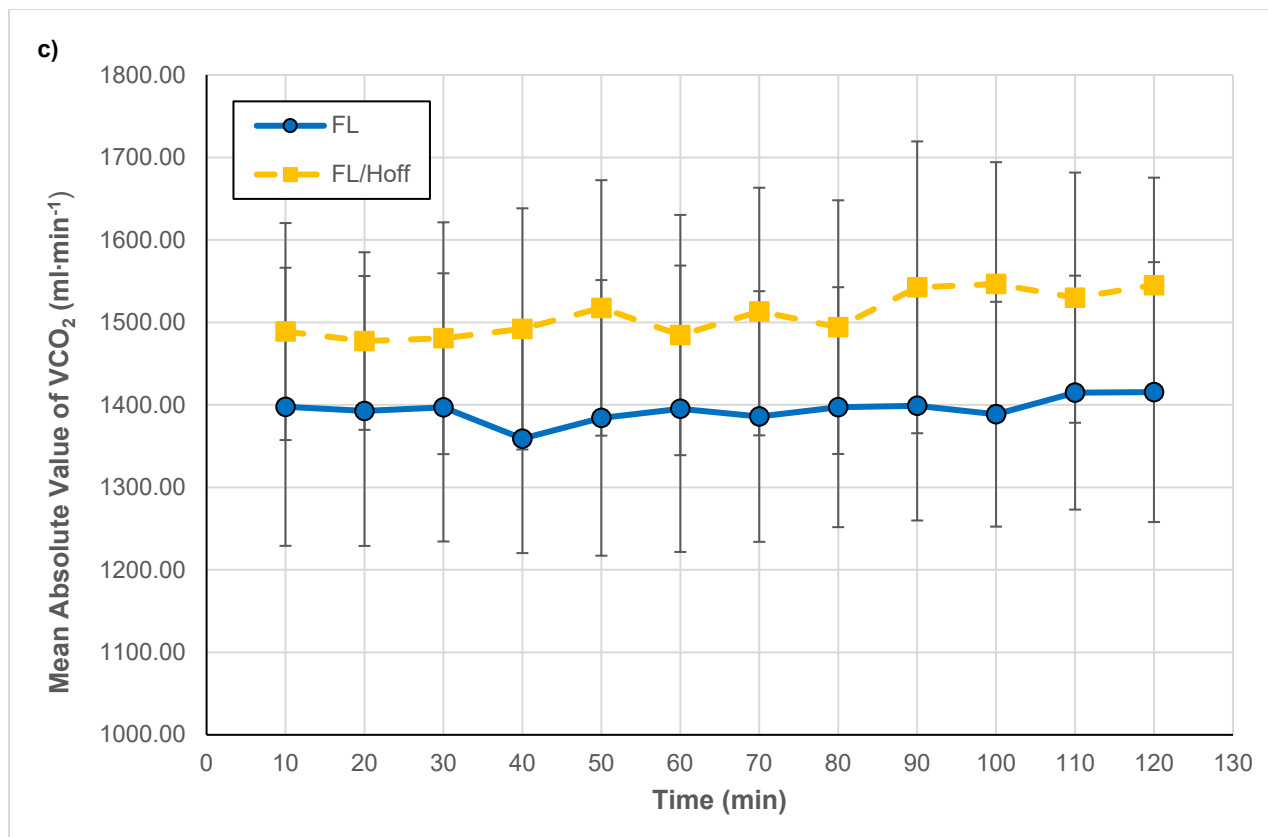
The results of the ANOVAs performed on the metabolic, cognitive task, and RPE responses recorded during the 2 h of treadmill walking on a level grade at $1.34 \text{ m}\cdot\text{s}^{-1}$ ($3.0 \text{ mi}\cdot\text{h}^{-1}$) in each of two load conditions (FL, FL/H_{off}) are presented in this section. Results are also included for the nonparametric statistical analyses carried out on the RPSD ratings given by the participants at the conclusion of each 2-h trial. In addition, the findings from the strength testing conducted before and after each walking trial are presented here.

3.4.1 Metabolics

The ANOVAs performed on the metabolic measures yielded a significant main effect of load condition on the absolute value of $\dot{V}\text{CO}_2$, $F(1, 12) = 8.62$, $p < .012$, $\eta_p^2 = .418$, and on RER, $F(1, 12) = 10.15$, $p = .008$, $\eta_p^2 = .458$. The $\dot{V}\text{CO}_2$ values for the FL/H_{off} condition were significantly greater than those for the FL condition ($M_{\text{FL}} = 1393.90 \text{ mL}\cdot\text{min}^{-1}$, $SD_{\text{FL}} = 140.88$; $M_{\text{FL/Hoff}} = 1509.40 \text{ mL}\cdot\text{min}^{-1}$, $SD_{\text{FL/Hoff}} = 130.29$). Similarly, there were significantly higher RER values for the FL/H_{off} condition compared with those for the FL condition ($M_{\text{FL}} = 0.790$, $SD_{\text{FL}} = 0.004$; $M_{\text{FL/Hoff}} = 0.825$, $SD_{\text{FL/Hoff}} = 0.003$). Load condition did not have a significant effect on the absolute value of $\dot{V}\text{O}_2$, on $\dot{V}\text{O}_2$ normalized to body mass, or on HR (all F s < 2.75 , p s $> .13$). Elapsed time had a significant effect on the absolute value of $\dot{V}\text{O}_2$, $F(3.55, 42.61) = 12.78$, $p < .000$, $\eta_p^2 = .516$, $\dot{V}\text{O}_2$ normalized to body mass, $F(3.59, 43.07) = 12.21$, $p < .000$, $\eta_p^2 = .504$, RER, $F(3.21, 38.49) = 15.95$, $p < .000$, $\eta_p^2 = .571$, and HR, $F(2.15, 25.83) = 23.26$, $p < .000$, $\eta_p^2 = .660$, but the effect of time on $\dot{V}\text{CO}_2$ was not significant, $F(3.74, 44.85) = 1.58$, $p > .05$, $\eta_p^2 = .116$.

There were no significant interactions between load condition and elapsed time on any of the metabolic measures (all F s < 1.48 , p s $> .15$). However, plots of the means for each load condition, calculated at 10-min intervals for the 2-h trial, are presented in Figure 22 for completeness.





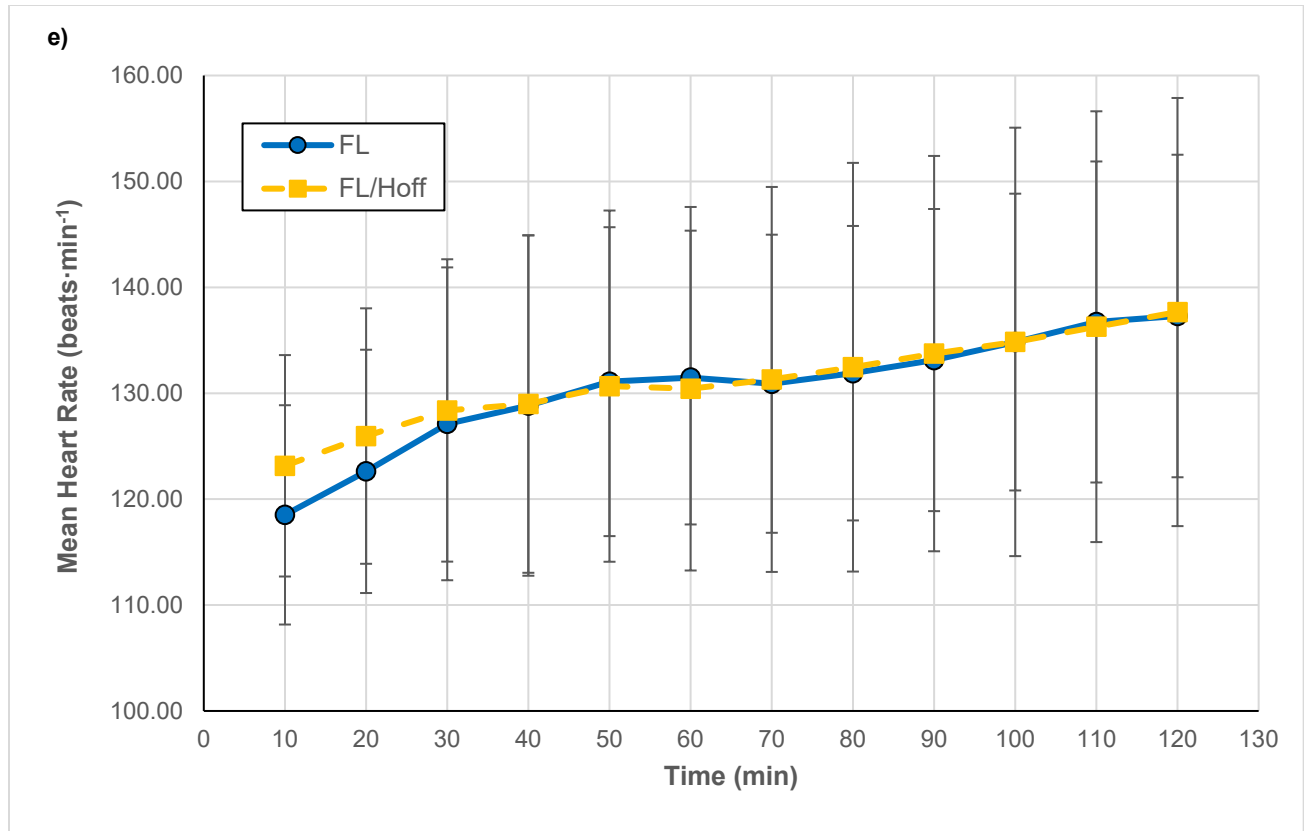


Figure 22. Means ($n = 13$) of the metabolic variables for the load conditions over time during the 2-h walking trials at $1.34 \text{ m}\cdot\text{s}^{-1}$ and 0% grade: a) absolute value of $\dot{V}\text{O}_2$; b) $\dot{V}\text{O}_2$ normalized to body mass; c) absolute value of $\dot{V}\text{CO}_2$; d) RER; and e) HR. Error bars indicate $\pm 1 \text{ SD}$.

3.4.2 Cognitive Tasks

3.4.2.1 Auditory Go/No-Go Response Inhibition Test

The discriminability index (d') did not yield a significant main effect due to load condition. Regardless of load condition, performance decreased across the six time blocks, as indicated by a significant linear main effect of elapsed time, $F(1, 12) = 8.84$, $p = .012$, $\eta_p^2 = .424$. None of the Bonferroni corrected (critical $p < .0033$), post hoc pairwise comparisons reached significance. However, examination of the means revealed that the elapsed time main effect was driven by a decrease in performance over time. In addition, load condition and elapsed time did not significantly interact, $F(5, 60) = 2.10$, $p = .077$, $\eta_p^2 = .149$.

For the response criterion measure (c), there was no significant main effect of load condition or of elapsed time, and the interaction was not significant. However, there was a quadratic trend toward worse performance over time and then a slight increase in performance near the end of the 2-h trial, $F(1, 12) = 3.98$, $p = .069$, $\eta_p^2 = .249$. This trend reflected a bias toward responding “yes” (i.e., the target stimulus is present) more so later in the trial than earlier, with slightly less of a bias at the end of the trial.

The analysis examining the proportion of hits did not find any significant effects of load condition or of elapsed time and the interactions between these variables did not achieve significance (all F s < 2.00, ps > .18). Therefore, it appears the effect of elapsed time observed on the d' scores was driven by the proportion of false alarms, rather than the hit rate. This is supported by findings from the analysis of the false alarms. There was a significantly higher proportion of false alarms later during the trial as evidenced by a linear main effect of time, $F(1, 13) = 11.62, p = .005, \eta_p^2 = .472$. Corrected comparisons (critical $p = .0033$) revealed overall worse performance at 45 and 85 min into the trial compared with performance after 5 min of walking, $ps < .002, M_{5min} = .08, SD_{5min} = .07; M_{45min} = .15, SD_{45min} = .11; M_{65min} = .19, SD_{65min} = .15$. None of the other corrected comparisons reached significance (all other $ps > .09$).

In addition to these main effects on the proportion of false alarms, there was a quadratic interaction between load condition and elapsed time, $F(5, 45) = 2.56, p = .041, \eta_p^2 = .220$. To further quantify this quadratic trend, the effect of load condition on the proportion of false alarms over time was examined separately for the two load conditions. For the FL/H_{off} load condition, there was a linear main effect of elapsed time, $F(1, 13) = 6.31, p = .026, \eta_p^2 = .327$. The means indicate that this linear main effect reflected an overall increase in false alarm rates as the trial progressed (Figure 23). However, none of the follow-up comparisons survived the correction for multiple comparisons (critical $p < .0033$). For the FL condition, there were linear, $F(1, 13) = 8.99, p = .009, \eta_p^2 = .380$, and quadratic, $F(1, 13) = 6.95, p = .019, \eta_p^2 = .320$, main effects of elapsed time on the proportion of false alarms (Figure 23). Corrected pair-wise comparisons (critical $p < .0033$) revealed the linear main effect for the FL condition was driven by differences between performance at 5 min compared to performance at 65 min and 85 min of walking, $ps < .002, M_{5min} = .07, SD_{5min} = .08; M_{65min} = .195, SD_{65min} = .15; M_{85min} = .21, SD_{85min} = .16$. The means for the two load conditions over the trial are presented in Figure 23.

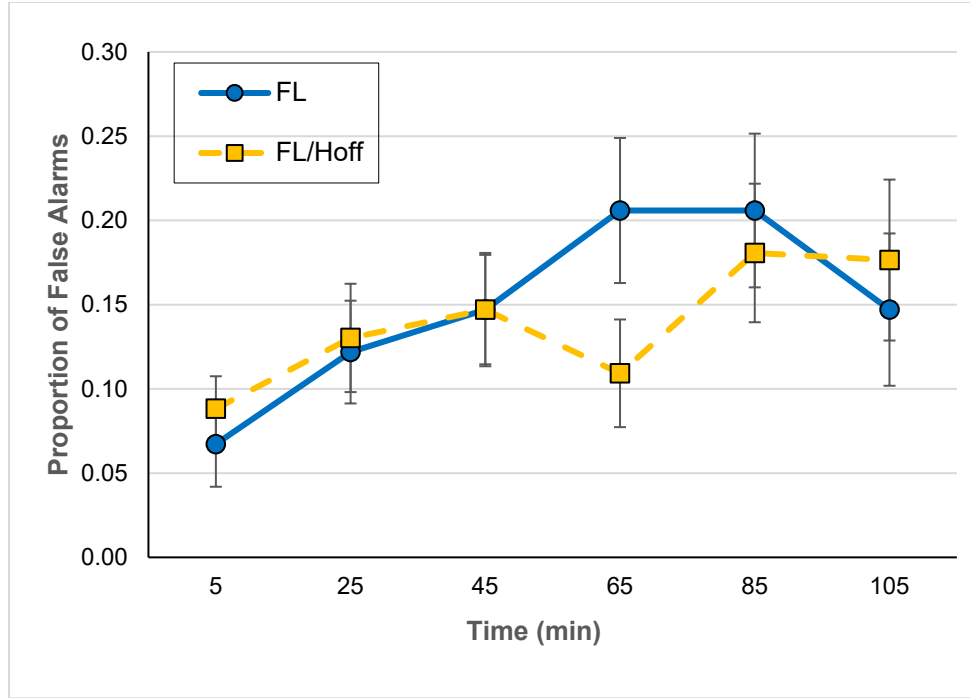


Figure 23. Means for the proportion of false alarms over time on the auditory go/no-go task for the load conditions during the 2-h walking trials at 1.34 m·s⁻¹ and 0% grade. Error bars indicate ± 1 SD.

Investigation of reaction time included comparing reaction times on the trial blocks containing both go and no-go trials with reaction times on the blocks containing all-go trials. There was a significant main effect of trial type, $F(1, 12) = 99.83$, $p < .001$, $\eta_p^2 = .890$, with reaction times for trials in the all-go blocks being faster than times for the trials in the blocks with go and no-go trials intermixed: $M_{\text{all-go}} = 385.35$ ms, $SD_{\text{all-go}} = 74.9$; $M_{\text{go/no-go}} = 499.3$ ms, $SD_{\text{go/no-go}} = 84.03$. However, trial type did not interact with load condition or elapsed time (all F s < 1.00 , p s $> .40$). When comparing reaction times for the go/no-go trial blocks by load condition and elapsed time, there was a significant main effect of time, $F(5, 60) = 3.54$, $p = .007$, $\eta_p^2 = .230$, but no significant main effect of load condition or a significant interaction of load and time (all F s < 1.00 , all p s $> .40$). Post-hoc corrected comparisons (critical $p < .0033$) revealed no significant differences in pairwise comparisons over elapsed time. However, an examination of the means revealed that reaction times became faster over the course of the trial.

3.4.2.2 Visual Target Detection Test

Analysis of the participants' accuracy on the target detection test indicated that performance improved over time, as demonstrated by a significant main effect of elapsed time, $F(4, 48) = 6.64$, $p < .001$, $\eta_p^2 = .356$, $M_{15\text{min}} = 69\%$, $SD_{15\text{min}} = 6.85\%$; $M_{35\text{min}} = 73.5\%$, $SD_{35\text{min}} = 6.85\%$; $M_{55\text{min}} = 75.8\%$, $SD_{55\text{min}} = 6.13\%$; $M_{75\text{min}} = 75.1\%$, $SD_{75\text{min}} = 5.05\%$; $M_{95\text{min}} = 77.8\%$, $SD_{95\text{min}} = 6.49\%$. Specifically, accuracy was higher at 75 and 95 min of the 2-h walking trial compared with 15 min into the trial (all p 's $< .005$) as revealed by Bonferroni corrected comparisons (critical $p < .005$). There was no significant main effect of load condition or significant interaction between load condition and elapsed time (all F s < 0.60 , p s $> .55$).

Analysis of reaction time for detecting targets revealed that there were no significant main effects of load condition or of elapsed time (all F s < 1.40, all p s > .20). In addition, there was not a significant interaction between load and elapsed time (F < 1.00, p > .47).

3.4.3 Isometric and Isokinetic Muscle Strength

The muscle strength data analyzed were the readings recorded after completion of the 2-h walking trial subtracted from the readings recorded prior to trial initiation. Negative values indicate that participants' strength readings achieved after the trial were higher than those achieved before the trial began.

On the isometric test of the knee joint, the means for both the FL and the FL/H_{off} conditions had negative values. Thus, the forces achieved after completion of a trial were generally greater than those achieved before the trial was undertaken. This was the case for 10 of the 14 participants when they were tested in the FL condition and for nine of the participants when the FL/H_{off} condition was being tested. The mean difference between the pre-trial and the post-trial values was greater for the FL condition than for the FL/H_{off}: $M_{FL} = -35.76$ N, $SD_{FL} = 43.06$, $M_{FL/H_{off}} = -11.14$ N, $SD_{FL/H_{off}} = 41.46$. However, the ANOVA performed on the data for the isometric test of the knee joint did not reveal a significant effect of load condition, $F(1, 13) = 3.29$, $p = .09$.

Summary statistics for the isokinetic strength tests of the trunk, the shoulder, and the knee are in Table 17. The ANOVAs performed on the isokinetic test data revealed two instances in which the effect of load condition was significant and both instances were in testing of the trunk. For trunk flexion at $20^{\circ} \cdot s^{-1}$, the total work, $F(1, 13) = 8.54$, $p = .012$, $\eta_p^2 = .396$, and the average power, $F(1, 13) = 4.87$, $p = .046$, $\eta_p^2 = .273$, measures revealed significantly greater differences between the pre-trial and the post-trial values for the FL/H_{off} than for the FL condition. The means for both total work and average power were positive, indicating that pre-trial values were generally higher than post-trial values (Table 17).

Table 17. Mean (SD) Difference Between Pre- and Post-Trial Isometric Testing of Trunk, Shoulder, and Knee Flexion and Extension for Each Load Condition (n = 14)

Test	Total Work (N·m)		Average Power (W)		Peak Torque (N·m)	
	FL	FL/H _{off}	FL	FL/H _{off}	FL	FL/H _{off}
Trunk						
Flexion, 20°·s⁻¹	2.3** (48.4)	44.2 (38.2)	0.3* (4.3)	3.2 (3.6)	4.5 (40.2)	8.7 (29.7)
Extension, 20°·s⁻¹	25.2 (142.5)	25.2 (115.4)	2.0 (11.2)	2.6 (8.2)	14.9 (41.5)	7.9 (26.1)
Flexion, 60°·s⁻¹	33.6 (286.9)	88.9 (229.5)	1.1 (15.2)	4.4 (13.2)	3.4 (37.4)	4.2 (19.0)
Extension, 60°·s⁻¹	-107.9 (488.1)	110.7 (600.0)	-6.7 (24.0)	5.1 (29.6)	-2.6 (41.9)	11.6 (53.8)
Shoulder						
Flexion, 60°·s⁻¹	-37.8 (146.8)	20.9 (107.9)	-2.6 (9.4)	0.8 (6.1)	-6.7 (18.1)	1.0 (6.2)
Extension, 60°·s⁻¹	-5.2 (93.8)	5.9 (56.2)	-0.6 (6.2)	0.1 (3.5)	-1.8 (11.5)	-2.1 (6.4)
Flexion, 180°·s⁻¹	16.7 (273.5)	-29.5 (519.2)	-0.3 (11.4)	-1.8 (20.8)	0.8 (14.3)	-3.5 (8.0)
Extension, 180°·s⁻¹	20.1 (171.4)	18.7 (217.3)	0.4 (7.4)	-0.1 (9.2)	3.1 (5.3)	1.0 (8.0)
Knee						
Flexion, 60°·s⁻¹	-35.5 (110.8)	42.1 (154.0)	-5.0 (15.2)	3.2 (21.2)	-9.2 (17.5)	4.2 (24.6)
Extension, 60°·s⁻¹	-15.6 (164.6)	3.4 (144.9)	-4.8 (21.1)	-0.1 (27.8)	-14.2 (36.2)	2.5 (38.8)
Flexion, 180°·s⁻¹	-121.9 (256.9)	-56.6 (201.6)	-10.7 (19.1)	-6.5 (17.1)	-3.6 (9.6)	-6.3 (12.4)
Extension, 180°·s⁻¹	-268.2 (315.4)	-258.8 (460.4)	-22.8 (27.6)	-25.2 (42.4)	-9.1 (12.4)	-15.8 (17.4)

* $p = .046$. ** $p = .012$.

The findings for isokinetic trunk flexion at 20°·s⁻¹ were followed up to determine whether there were differences between the FL and the FL/H_{off} conditions in the pre-trial strength data. The post-trial data for the two conditions were also compared. Using t tests to examine total work, it was found that the pre-trial means for the two conditions differed significantly, $t(13) = 3.59$, $p < .01$. However, there was not a significant difference between the post-trial means, $t(13) = 0.26$, $p > .05$. The average power data were treated in the same manner and again t tests yielded a

significant difference between the FL and the FL/H_{off} conditions for the pre-trial testing, $t(13) = 3.48$, $p < .05$, but not for the post-trial testing, $t(13) = 0.35$, $p > .05$. The means for total work and for average power are in Figures 24 and 25, respectively. The data for the other strength tests were also analyzed using t tests to compare the two load conditions with regard to differences in pre-trial scores and also in post-trial scores. The isokinetic trunk flexion at $20^{\circ}\cdot s^{-1}$ was the only measure on which the two load conditions differed significantly.

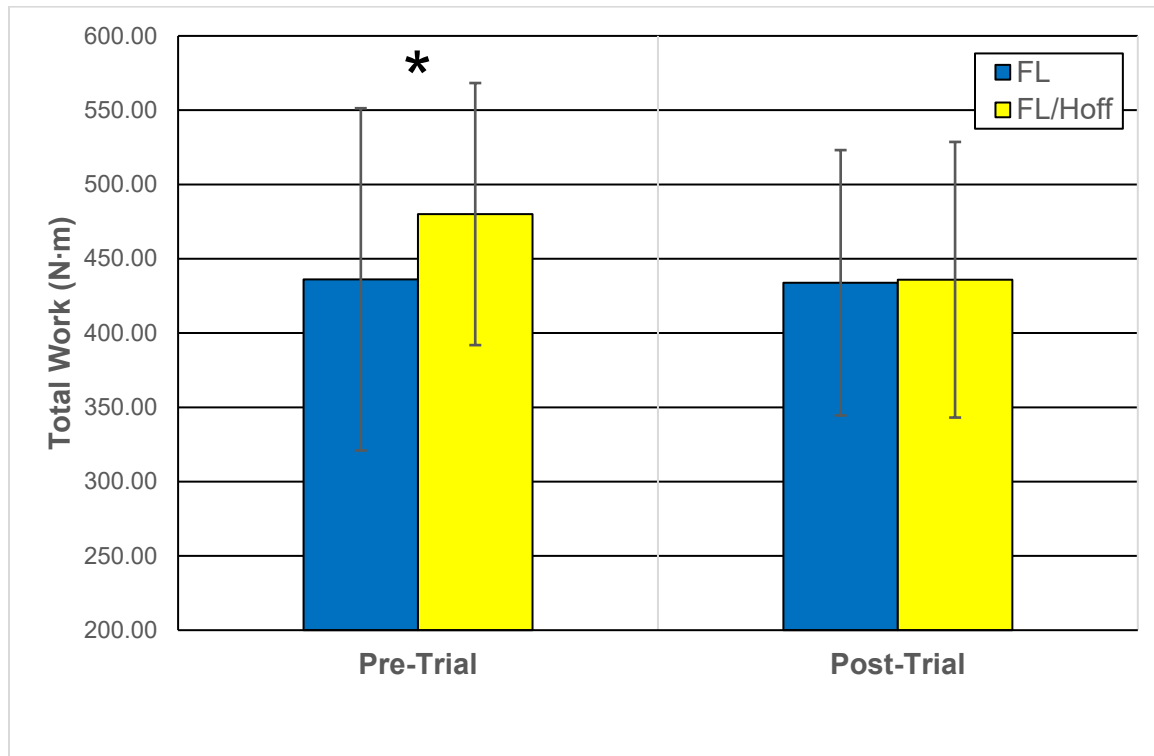


Figure 24. Pre-trial and post-trial mean values for total work obtained during testing of isokinetic trunk flexion at $20^{\circ}\cdot s^{-1}$ in two load conditions. The asterisk (*) indicates a significant difference between load conditions ($p < .01$). Error bars indicate ± 1 SD.

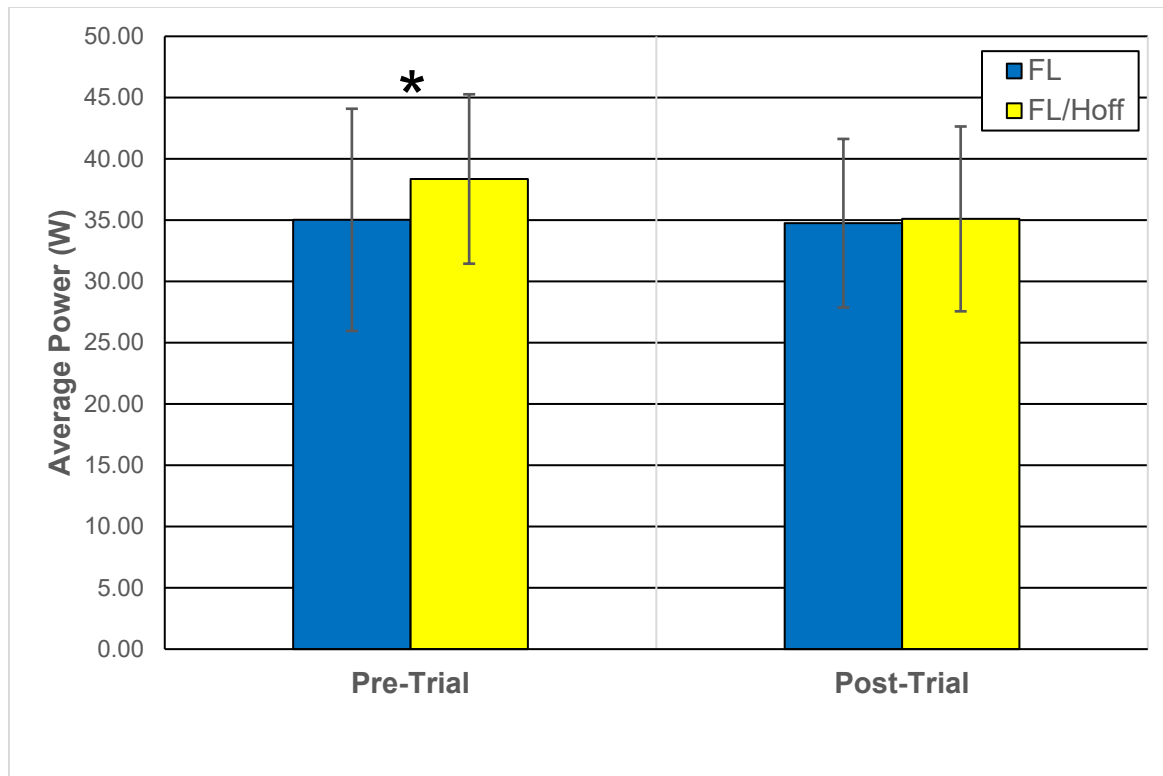


Figure 25. Pre-trial and post-trial mean values for average power obtained during testing of isokinetic trunk flexion at 20°s^{-1} in two load conditions. The asterisk (*) indicates a significant difference between load conditions ($p < .05$). Error bars indicate ± 1 SD.

3.4.4 Participants' Ratings

The ANOVA carried out on the RPE data did not yield a significant interaction between load condition and elapsed time on the 2-h trial, $F(12, 156) = 0.44, p > .05$. Further, the main effect of load condition was not significant, $F(1, 13) = 0.08, p > .05$. The mean ratings obtained during the trial, which are presented in Table 18, indicate the highly similar ratings for the FL and the FL/H_{off} conditions over the course of the trial. It can also be seen in Table 18 that the mean ratings increased gradually over the 2-h walking period from a rating of about 8 (*extremely light* to *very light exertion*) to a rating of approximately 11 (*light exertion*). This increase in ratings over the 2-h trial was significant, $F(1.66, 21.56) = 18.75, p = .000, \eta_p^2 = .006$.

The majority of ratings given on the five-point scale of the RPSD were 0 (*no pain, soreness, discomfort, or restriction*) and no rating exceeded 2 (*moderate pain, soreness, discomfort, or restriction*). The number of participants who gave a rating of greater than 0 to a section of the body was counted for each load condition. The counts are presented in Figure 26. The figure shows that a larger number of ratings greater than 0 were given to the tops of the shoulders, both at the front and at the back of the body, when the FL was worn than when the FL/H_{off} condition was used. There were also three ratings greater than 0 assigned to the back of the neck with the FL condition and no ratings exceeding 0 for that area with the FL/H_{off} condition. However, the FL/H_{off} condition elicited ratings greater than 0 in the front pelvic area from five participants, whereas none of the participants gave a rating above 0 to this area of the body when wearing the FL condition (Figure 26, Appendix C).

Table 18. Mean (SD) of the RPE Variable for Each Load Condition Over Time During the 2-h Walking Trials at 1.34 m·s⁻¹ and 0% Grade (n = 14)

Time (min)	Load Condition			
	FL		FL/H _{off}	
10	7.9	(1.8)	8.4	(1.7)
20	8.6	(2.1)	8.6	(1.8)
30	9.2	(1.9)	9.3	(1.8)
40	9.4	(2.3)	9.6	(2.0)
50	10.0	(2.6)	9.8	(2.1)
60	10.2	(2.4)	10.2	(2.2)
70	10.4	(2.3)	10.4	(2.3)
80	10.5	(2.3)	10.7	(2.5)
90	10.7	(2.6)	10.9	(2.7)
100	10.8	(2.5)	11.2	(2.6)
110	11.1	(2.4)	11.1	(2.9)
115	11.1	(2.3)	11.2	(3.1)
120	11.2	(2.5)	11.1	(3.1)

Cochran Q tests were done to analyze for differences between the FL and the FL/H_{off} conditions in the RPSD ratings. The data for the front and the back of the body were treated separately. For each load condition, counts were made of the number of participants who assigned a rating greater than 0 to at least one section on the front of the body. The same was done for the back of the body. A significant difference between load conditions was not obtained in the Q test performed on the data for the front of the body, $Q(1) = 0.67, p > .05$. Although, there was a significant finding for the Q test done on the data for the back of the body, $Q(1) = 4.00, p < .05$. This finding reflected that a significantly greater number of participants gave ratings exceeding 0 (i.e., a rating of at least *slight pain, soreness, discomfort, or restriction*) to the FL compared with the FL/H_{off} condition. When focusing on the shoulder area (section “i”) the FL condition was significantly higher than the FL/H_{off} $Q(1) = 7.00, p < .01$; however, when focusing on the pelvic region (section “b”) the FL/H_{off} condition was significantly higher than the FL $Q(1) = 5.00, p < .05$. This suggests a tradeoff in RPSD between the two regions when the load is redistributed from the shoulders to the hips.

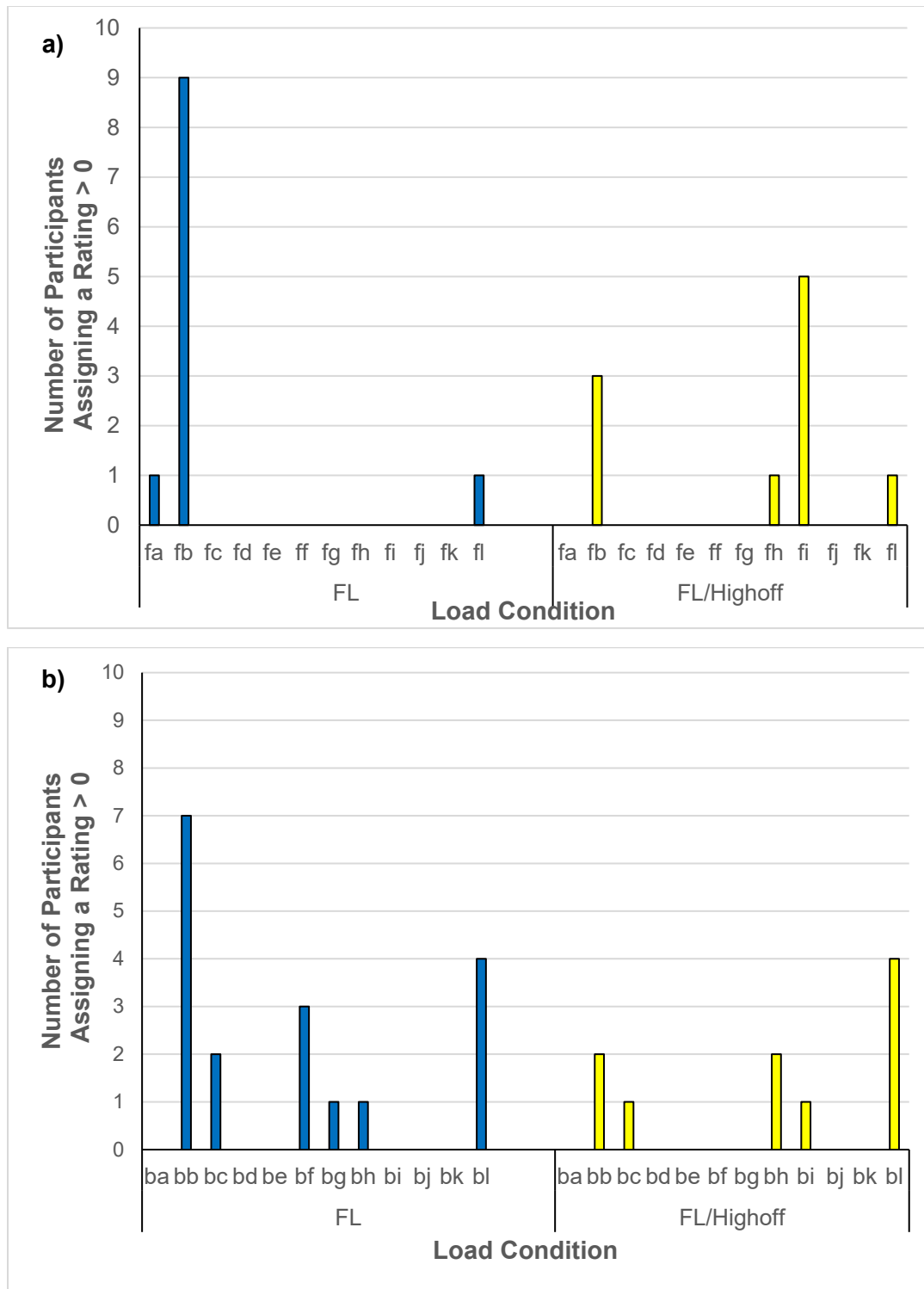


Figure 26. Count of participants ($n = 13$) assigning a rating greater than 0 (no pain, soreness, discomfort, or restriction) on the RPSD to each load condition after the 2-h walking trials: a) front and b) back of body. Body sections are identified in Appendix C.

3.5 Participants' Questionnaire Responses

On the study-specific questionnaire, the Load Redistribution Questionnaire (Appendix D), the participants were given an opportunity to address how well they liked the offloading conditions and the features of the load distribution device. The questionnaire was given to the participants after the 10-min walking trial sessions at 0% and at 9% grades. The questionnaire was administered for the third and last time after both 2-h marches had been completed. The results are presented here separately for each of the three administrations.

3.5.1 Like/Dislike of Load Distribution Device

Participants rated the load distribution device overall and the three levels of offloading (i.e., low, medium, high) on a 5-point scale (1 = *disliked very much*; 3 = *neutral*; 5 = *liked very much*). During the 2-h trials of treadmill walking, the participants were tested in the high offloading condition, but not in the low or the medium offloading conditions. However, the participants were asked to assign ratings to all three offloading conditions for this test activity. Frequency counts and median ratings are presented in Table 19. There were only two instances in which a participant assigned a rating lower than 3 (*neutral*). In both instances, a rating of 2 (*disliked*) was given in association with the 10-min walking trials at a 0% grade. Regardless of the testing activity or the amount of offloading, the majority of the participants' ratings were at the high end of the scale (4 = *liked*; 5 = *liked very much*), indicating a positive opinion of the load distribution device and the concept of offloading the shoulders. This is reflected in the median ratings, most of which were between 4.0 and 4.8 (*liked*) on the 5-point scale (Table 19).

In association with rating the extent of like/dislike, participants were asked to state what they liked most and least about the load distribution device. For all test activities, the participants responded that they most liked the offloading of the weight from the shoulders. After carrying out the 10-min walking trials at a 0% grade, one participant added that he liked the low offloading configuration and considered it to offer "an ideal balance" and another participant noted that the high offloading condition was "great", but the others were "inconvenient". In association with the 10-min walking trials at a 9% grade, two participants stated that the high offloading condition was best on the incline and another participant stated that the medium offloading condition was a good balance of the load between the shoulders and the hips.

Few participants listed any aspects of the load distribution device when asked to identify what they liked least. After completion of the 10-min walking trials at a 9% grade, one participant did comment that he disliked the high offloading condition because the amount of weight transferred to the hips caused pressure in that region that was greater than what he usually experienced when marching with a load. Another participant commented negatively on the low offloading condition after completing the 10-min trials at a 9% grade. Three participants expressed dislike for the waist belt of the DWD after completing the 2-h walking trials. The complaint was that the belt slipped down below the waist during the long walking period. One of these participants also responded negatively to the pressure that the waist belt exerted in the hip region.

Table 19. Frequency Counts and Median Ratings for Questionnaire Responses Regarding Like/Dislike of Offloading Conditions ($n = 6$)

Rate How Much You Liked the Load Distribution Device:	10-min Walking Trials, 0% Grade						10-min Walking Trials, 9% Grade						2-h Walking Trials					
	Frequency					Mdn	Frequency					Mdn	Frequency					Mdn
	1	2	3	4	5		1	2	3	4	5		1	2	3	4	5	
All offloading configurations	--	--	1	2	3	4.5	--	--	1	4	1	4.0	--	--	--	3	3	4.5
LOW offloading	--	1	2	2	1	3.5	--	--	--	5	1	4.1	--	--	3	2	1	3.5
MEDIUM offloading	--	1	--	1	4	4.8	--	--	3	1	2	3.5	--	--	3	--	3	4.0
HIGH offloading	--	--	1	2	3	4.5	--	--	--	5	1	4.1	--	--	1	3	2	4.2

Note. Rating scale: 1 = disliked very much; 2 = disliked; 3 = neutral; 4 = liked; 5 = liked very much.

Two questions entailed the rating of design features of the load distribution device on a 5-point scale (1 = *disliked very much*; 3 = *neutral*; 5 = *liked very much*). In one question, participants rated the desirability of a capability that was not available during testing. That is, the capability to adjust the amount of offloading while on the move. The frequency counts and the median ratings for the responses to this question are presented in Table 20. The participants rated this feature at a 3 (*neutral*) or higher and the medians were 3.8 (*neutral*) to 4.2 (*liked*), indicating that participants judged that an adjustment feature that could be used while underway to change the level of offloading would be a positive attribute. The second question was focused on rating the like/dislike of the waist belt of the load distribution device, a component of the device that some participants cited as being the feature of the device that they liked least. The results for this question are in Table 20. With the exception of a rating of 3 (*neutral*) given by one participant, all ratings were 4s (*liked*) or 5s (*liked very much*). Relatedly, the medians were positive ranging from 4.1 to 4.5.

3.5.2 Impact of Load Distribution Device on Movement and Acceptability of the Device for Military Use

The participants used a 5-point scale (1 = *strongly disagree*; 3 = *neutral*; 5 = *strongly agree*) to rate whether the load distribution device had a negative impact on movement during treadmill walking. Table 21 contains the frequency counts and medians for this question. The majority of responses were ratings of 1 (*strongly disagree*) or 2 (*disagree*), indicating that the device did not interfere with movement in the participants' opinions. The medians reflect these ratings, with the median values ranging from 1.5 to 2.0. There were two instances in which a rating of 3 (*neutral*) was assigned. One neutral rating was given in association with the 10-min walking trials at a 0% grade and the other for the 10-min trials at a 9% grade (Table 21). The participants used the same 5-point scale to rate whether the waist belt of the load distribution device had a negative effect on treadmill walking movement. All responses to this question were 1s (*strongly disagree*) or 2s (*disagree*). Reflecting these ratings, the medians were low, at 1.7 to 1.8 (Table 21).

A number of yes/no questions were posed to the participants that included topics related to use of the DWD during military field operations. The participants' responses to the questions are summarized in Table 22. All participants responded in the affirmative to questions regarding the likelihood that use of the DWD would improve comfort and performance during missions. With the exception of one participant's responses, the opinion was that the DWD would not pose safety hazards (Table 22). All participants agreed that the DWD would not introduce a noise or a visual signature that might increase risk of detection in the field.

Table 20. Frequency Counts and Median Ratings for Questionnaire Responses Regarding Like/Dislike of Load Distribution Device Components (n = 5-6)

Question:	10-min Walking Trials, 0% Grade						10-min Walking Trials, 9% Grade						2-hr Walking Trials					
	Frequency					Mdn	Frequency					Mdn	Frequency					Mdn
	1	2	3	4	5		1	2	3	4	5		1	2	3	4	5	
Rate how much you would like capability to adjust the amount of offloading while you are on the move.	--	--	2	2	1	3.8	--	--	2	3	1	3.8	--	--	1	3	2	4.2
Rate the waist belt of the load distribution device.	--	--	--	4	1	4.1	--	--	1	2	3	4.5	--	--	--	4	2	4.2

Note. Rating scale: 1 = Disliked very much; 2 = Disliked; 3 = Neutral; 4 = Liked; 5 = Liked very much.

Table 21. Frequency Counts and Median Ratings for Questionnaire Responses Regarding Impact of Load Distribution Device on Movement (n = 5-6)

Question:	10-min Walking Trials, 0% Grade						10-min Walking Trials, 9% Grade						2-hr Walking Trials					
	Frequency					Mdn	Frequency					Mdn	Frequency					Mdn
	1	2	3	4	5		1	2	3	4	5		1	2	3	4	5	
Did the load distribution device (as a whole) negatively impact your ability to move?	2	2	1	--	--	2.0	3	2	1	--	--	1.5	1	5	--	--	--	1.9
Did the waist belt of the load distribution device negatively impact your ability to move?	2	3	--	--	--	1.7	2	4	--	--	--	1.8	2	4	--	--	--	1.8

Note. Rating scale: 1 = Strongly disagree; 2 = Disagree; 3 = Neutral; 4 = Agree; 5 = Strongly agree.

Participants were also asked whether the DWD reduced the load evenly across the shoulders, chest and back (Table 22). This question referred to the distribution of weight equally on the three body areas, as opposed to placing greater weight on one or more of the body areas. In responding upon completion of the 10-min treadmill walking session at a 0% grade, one participant indicated that the load relief was uneven, reducing the weight felt on the shoulders only. Aside from this exception, all responses were in the affirmative that the load was evenly distributed across the shoulders, chest and back. In another related question, participants responded as to whether the DWD reduced the load evenly across the hips and the pelvis. This question pertained to whether the DWD reduced the weight equally on the front of the body in the pelvic region and on the lower back. In association with the 2-h treadmill walking sessions, one participant responded that the load was reduced on the lower back, but not on the front of body. All other responses were in the affirmative, indicating that the participants felt that the load distribution device distributed the weight equally on the front and the back of the body in the pelvic area.

Table 22. Counts of Responses to Yes/No Questions Regarding Load Distribution Device and Offloading (n = 6)

Question:	10-min Walking Trials, 0% Grade		10-min Walking Trials, 9% Grade		2-hr Walking Trials	
	Yes	No	Yes	No	Yes	No
Did load distribution device reduce load evenly across shoulders/chest/back?	5	1	6	--	6	--
Did load distribution device reduce load evenly across hips/pelvis?	6	--	6	--	5	1
Would offloading capability improve your comfort carrying heavy loads?	6	--	6	--	6	--
Would offloading capability improve mobility/performance during a mission?	6	--	6	--	6	--
Does any aspect of load distribution device create safety/health hazard?	1	5	1	5	--	6
Does any aspect of load distribution device create a signature that would increase your detection or distraction?	--	6	--	6	--	6

3.5.3 Participants' Additional Observations and Suggestions for Improvement of the Load Distribution Device

At each administration of the questionnaire, participants were encouraged to add comments in the form of observations regarding the load distribution device and improvements that they would like to see made in the device. The participants' comments, which are presented in Table 23, were few in number. Several recommendations addressed the need to improve the load distribution device waist belt, specifically the buckle and the padding. Other recommendations regarding the waist belt addressed the need to ensure that the belt stayed in place and did not slip down on the torso. Participants also mentioned that the load distribution device should be able to be donned and adjusted by the user, without assistance.

Table 23. Participants' Observations and Suggestions for the Load Distribution Device

10-min Walking Trials, 0% Grade
Improve the buckle on the front of the load distribution device waist belt for easier/better adjustment of belt
10-min Walking Trials, 9% Grade
Improve the buckle on the front of the load distribution device waist belt for easier/better adjustment of belt
Incorporate the capability to adjust the amount of offloading while on the move
Load distribution device is uncomfortable in the hip area, particularly in the high offloading condition. Do not know how this might be improved
Increase the padding on the front of the waist belt for comfort
Make sure the load distribution device can be donned and adjusted by the user, without assistance
2-h Walking Trials
Improve the buckle on the front of the load distribution device waist belt for easier/better adjustment of belt
Prevent the waist belt from slipping down
Make sure the load distribution device can be donned and adjusted by the user, without assistance
The load distribution device was great in preventing the fatigue that usually sets in when carrying a rucksack load on a march. Walking on the treadmill for 2 h without the load distribution device resulted in the build-up of fatigue over time. Walking with the load distribution device required less effort

4 DISCUSSION

4.1 Pressure Measurements

In the current study, the pressure measurements taken in the shoulder areas on participants wearing the FL and the load distribution device, the DWD, were used primarily to adjust the DWD to three predetermined ranges of pressure reduction relative to the shoulder pressure recorded when the FL was used without the DWD. In pilot testing (Carboni et al., 2014), it was established that these levels of offloading were feasible and encompassed from the lowest to the highest settings of pressure reduction that could be achieved with the DWD (low: $FL/L_{off} = 10$ to 30% reduction in shoulder pressure relative to the baseline FL; medium: $FL/M_{off} = 40$ to 60% reduction in shoulder pressure relative to the baseline FL; and high: $FL/H_{off} = 70$ to 90% reduction in shoulder pressure relative to the baseline FL).

The baseline FL pressures at the tops of the shoulders were taken over a 10-s period while the participant was in a stationary standing position. Similarly, pressure readings for the three shoulder offloading levels were obtained during periods of quiet standing. Shoulder pressure readings taken immediately before the start of a trial of testing indicated that the settings of the offloading conditions were accomplished successfully and that the variances in shoulder pressure measurements across participants for these three conditions were minimized.

The pressure readings taken during a 10-s period of quiet standing, immediately upon completion of the 10-min and of the 2-h treadmill walking trials, showed that changes had occurred over the course of the trials. Relative to the baseline FL shoulder pressure readings, the FL/L_{off} condition was at about a 5% reduction, the FL/M_{off} condition at about a 20% reduction, and the FL/H_{off} condition at about a 50% reduction. Thus, for each offloading condition, the amount of pressure reduction relative to the baseline FL pressure had decreased by the end of a trial and was below the pre-established range.

The changes in pressure are understandable, given the dynamic nature of the walking activity. However, they potentially compromised the validity of the pressure ranges used insofar as the three conditions that involved offloading of the shoulders using the load distribution device were not tested at their selected, predetermined levels throughout the entire duration of the treadmill walking trials. While it is unknown how quickly this shift occurred, there are positive study findings related to the offloading conditions. For one, the relationship among these three conditions, relative to the baseline FL shoulder pressure, did not change: the lowest to highest pressure reductions at the end of the trials were, in order, FL/L_{off} , FL/M_{off} , and FL/H_{off} . In addition, the top of shoulder pressure of the FL condition itself changed over the treadmill walking trials: the post-trial FL shoulder pressures were greater than the pre-trial, baseline FL shoulder pressures. Calculation of top of shoulder pressures for the three offloading conditions as a percentage reduction relative to the post-trial FL shoulder pressures indicated that the FL/L_{off} condition was at about a 15% reduction, the FL/M_{off} condition at about a 30% reduction, and the FL/H_{off} condition at about a 60% reduction. The FL/L_{off} condition was within the range of pressure reduction specified for that condition, whereas the two other offloading conditions were below the minima established. However, the ordering of the three conditions, from lowest to highest pressure reductions, did not change and the percentages of offloading were closer to the pre-established ranges when contrasted with the post-trial FL top of shoulder pressures than

when expressed relative to the pre-trial, baseline FL pressures. Although shoulder pressure reductions for the three offloading conditions were not maintained within their respective ranges throughout the durations of the walking trials, the findings indicate that the conditions, as tested, were likely sufficient to serve the purpose of the current study.

The concept of use of the load distribution device is to offload the shoulders and to transfer the load from the shoulders to the pelvis, a body area thought to be better structured than the shoulders to bear a heavy load. Successful load transfer in the current study was dependent upon the design and the fit of the DWD waist belt. The pressure sensor data indicated that, with increases in the level of shoulder offloading, there were increases in the pressure at the hips, signifying transfer of the load. This was most evident in the lateral hip regions. Examination of the means for the pressure readings taken during quiet standing before trial initiation revealed that the highest mean pressure readings obtained for the right and the left lateral hip regions occurred with the FL/H_{off} condition. The mean pressures were approximately 13 kPa. The next highest means, at approximately 8 kPa, were for the lateral hip regions with the FL/M_{off} condition.

The maximum average skin contact pressure recommended by Stevenson et al. (2004) for areas of the body exclusive of the shoulder and the lumbar regions was 45 kPa, a value well above the mean pressures obtained for the pelvic region in the current study. However, the pressure data obtained for the pelvis in the current study were recorded during periods of quiet standing — the pressures during periods of activity are expected to be higher.

The highest top of shoulder mean pressure readings in the current study were approximately 7 kPa and occurred with the FL condition. This value was also below the 10 kPa suggested by Holewijn (1990) and the 20 kPa suggested by Stevenson et al. (2004) for the maximum skin contact pressures in the shoulder region. However, as is the case for the pelvic area, the pressures in the shoulder region during periods of activity are not known. Also, the pressure readings were means calculated from all sensors in each of a number of anatomical regions of the sensor pads. One or more sensors in a given region could have exceeded the maximum contact pressures recommended by Stevenson et al. (2004) and by Holewijn (1990). Higher pressures are particularly likely to have occurred in skin areas overlying bony structures, such as the clavicle (Hadid et al., 2012).

The FL/N_{off} condition was included as one of the load conditions tested in this study in order to acquire data on the participants when they were outfitted with the DWD, just as they were in the three offloading conditions, but without the DWD being engaged. For the FL/N_{off} condition, the spine bar was not inserted in the waist belt and the investigators did not make any adjustments to offload the shoulders. It was expected that, under this condition, top of shoulder pressure would be similar to the pressure with the FL condition. However, this was not the case. Relative to the baseline FL shoulder pressure readings, the FL/N_{off} condition showed mean pressure reductions of about 20%. The variances were large, suggesting that this condition was not dynamically stable. Visual observations indicated that, for some participants, the bottom edge of the armor vest rested on the DWD waist belt, resulting in the waist belt supporting some of the load of the vest. The extent to which this occurred seemed to vary among the participants, depending on a participant's torso length and the size of vest worn.

4.2 Cervical FRR Evaluation

The only study activity that included testing of a condition in which the armor vest, the TAP, and the hydration system were not used (i.e., the NL condition) was the cervical FRR evaluation. The FL, the FL/N_{off}, and the three offloading conditions (FL/L_{off}, FL/M_{off}, and FL/H_{off}) were also tested in this assessment. The NL condition was included to extend the range of weights represented among the load conditions in the current study. In the study in which they found that the cervical FRR decreased significantly as load mass increased, Lee et al. (2011) used loaded rucksacks averaging approximately 7 and 14 kg (15 and 31 lb), along with a condition in which a rucksack was not worn. With the NL condition weighing about 25 kg (55 lb) less than the other load conditions, the range of masses investigated in the current study exceeded the range tested by Lee et al. (2011).

Unlike the findings reported by Lee et al. (2011), there were no significant differences in cervical FRR among the load conditions tested in the current study. The mean FRR values for the NL and the FL conditions were approximately equal, and the mean values for the other load conditions were slightly higher, by 2 to 5%. Thus, there were no indications that adding an external load of about 25 kg (55 lb) to the body affected the cervical FRR. Therefore, the findings from the current study did not provide evidence to support the results of Lee et al. (2011) that cervical FRR decreases with increases in the mass of loads on the body. There was also no indication that use of a load distribution device affected the FRR.

The findings from the current study do not negate the results reported by Lee et al. (2011) regarding the relationship between cervical FRR values and the mass of external loads. The loaded backpacks used by Lee et al. (2011) may have influenced activation of the cervical erector spinae muscles differently than the external loads used in the current study, which were distributed about the torso. In addition, Lee et al. (2011) did not mention how long the backpacks were worn before the FRR test was performed. In the current study, testing was initiated immediately upon the donning of the clothing and equipment comprising the load condition being tested. It is possible that the load must be worn for some minimum amount of time if the FRR phenomenon is to be captured.

4.3 10-min and 2-h Walking Trials

In their evaluation of the physiological and kinematic effects of a prototype load distribution device for the USMC, Kelly et al. (2014) found few significant differences between the prototype and a standard armor vest without a load redistribution capability during a trial of approximately 20 min of treadmill walking. Heart rate, caloric expenditure, and trunk lean were not significantly affected. Lenton and his colleagues did not record physiological measures, but they investigated a number of kinetic and kinematic gait variables in 10-min trials of treadmill walking for their testing of five load distribution systems and the standard Australian Army vest without a load redistribution capability (Lenton, Bishop, Saxby, et al., 2018; Lenton et al., 2019). Their analyses did not reveal extensive differences among the systems tested. Similarly, there were a limited number of significant main effects of load condition in the statistical analyses performed on the dependent measures recorded during the walking trials in the current study. None of the analyses yielded significant differences between the FL and the FL/N_{off}, the FL/L_{off}, or the FL/M_{off} conditions. Further, significant differences were not obtained between the three

offloading conditions (i.e., FL/L_{off}, FL/M_{off}, and FL/H_{off}). However, there were instances in which the FL and the FL/H_{off} conditions differed significantly. Also, only a few of the analyses of the data from the current study revealed significant interactions involving the load condition variable.

The interactions between load condition and grade were not significant for any of the metabolic variables recorded during the 10-min walking trials. Thus, unlike the $\dot{V}O_2$ results reported by Liu (2007) for 10-min walking periods on 0% and 6% grades with a rucksack load of approximately 11.0 kg (24.2 lb), there were no indications that metabolic measures for the load conditions tested here were differentially affected by whether participants walked on the level or ascended a 9% grade.

Liu (2007) reported that, compared with high placement of the load in a rucksack, low placement of the load resulted in somewhat higher $\dot{V}O_2$ values when participants were walking on the 0% grade, although the effect of load placement was not significant. On the 6% grade, low placement of the load in the rucksack yielded significantly lower $\dot{V}O_2$ values compared with high placement. The fact that $\dot{V}O_2$ findings for the 10-min walking trials in the current study did not reflect those of Liu (2007) may be attributable to the differences between the two studies in the items worn by the participants. Participants in the Liu (2007) study did not wear an armor vest and they carried the weighted rucksack on their backs. With this configuration of the load, the center of mass of the body plus load system was displaced toward the wearer's back. The FL in the current study included the armor vest, the 3.0-kg (6.6-lb) hydration system located on the upper back, and a substantial weight, a 9.1-kg (20.1-lb) TAP, placed on the front of the body, at chest level. With this arrangement of items, it is likely that the center of mass of the body plus load system was located toward the front of the wearer's body. The differences in the locations of loads on the body may underlie the lack of differential effects of load location and grade of the walking surface on rate of oxygen consumption.

Researchers have reported that prolonged carrying of heavy loads can result in higher oxygen uptake late in a march compared with earlier in the march period (Epstein et al., 1988; Patton et al., 1991). Metabolic data from the 2-h treadmill walking trials carried out in the current study revealed similar changes over time. Elapsed time was found to have a significant main effect on the absolute value of $\dot{V}O_2$, $\dot{V}O_2$ normalized to body mass, and HR, with the values of each of these variables increasing over time. None of the analyses of the metabolic variables yielded a significant interaction between elapsed time and load condition. Thus, the metabolic measures taken over the 2 h of walking were not differentially affected by the load condition used.

With regard to metabolic findings that pertain to main effects of load condition, there were some effects of load condition found to be significant in the analyses of the 10-min and the 2-h trials of treadmill walking. In these instances, the load conditions that differed significantly were the FL and the FL/H_{off}.

The load conditions with the DWD (FL/N_{off}, FL/L_{off}, FL/M_{off} and FL/H_{off}) were heavier than the FL by about 1.13 kg (2.50 lb), the mass of the load distribution device. It is well established that energy consumption increases with increases in load mass (Beekley et al., 2007; Soule et al., 1978). For the 10-min walking trials, all load conditions that entailed wear of the load distribution device had higher values of $\dot{V}O_2$ and of $\dot{V}O_2$ normalized to body mass than the FL.

The mean values of these metabolic variables for the FL/N_{off}, the FL/L_{off}, and the FL/M_{off} conditions during the 10-min trials exceeded the means for the FL by about 2%, a nonsignificant difference. However, the means of $\dot{V}O_2$ and of $\dot{V}O_2$ normalized to body mass for the FL/H_{off} condition were greater than the means for the FL by about 4%, a difference that was statistically significant.

These relationships among the load conditions during the 10-min walking trials suggest that the significantly greater energy consumption with the FL/H_{off} compared with the FL condition may not be attributable to load mass alone, a possibility further supported by the heart rate results. Heart rate was not significantly affected by load condition: the mean values of heart rate for the three offloading conditions (i.e., FL/L_{off}, FL/M_{off}, and FL/H_{off}), as well as for the FL/N_{off} condition, were all within 1% of the mean FL value.

In addition to significantly higher values of $\dot{V}O_2$ and of $\dot{V}O_2$ normalized to body mass with the FL/H_{off} than with the FL condition, the 10-min walking trials yielded significantly higher $\dot{V}CO_2$ values for the FL/H_{off} than for the FL condition. The mean for the FL/H_{off} was about 5% higher than that for the FL. The means for the remaining load conditions, including the FL/N_{off}, exceeded the mean for the FL by about 2 to 3%, nonsignificant differences. Thus, although all conditions that included wear of the load distribution device had higher means than the FL in both oxygen consumed and carbon dioxide produced during the 10-min walking trials, the FL/H_{off} condition was the only one that was significantly higher than the FL on these measures.

Differences between the FL and the FL/H_{off} conditions were also found for the metabolic data from the 2-h walking trials. Again, $\dot{V}CO_2$ values were significantly higher with the FL/H_{off} than with the FL condition. The mean for the FL/H_{off} condition was higher by 8%. The RER values from the 2-h trials were significantly higher with the FL/H_{off} condition, as well. For the RER variable, the mean of the FL/H_{off} condition exceeded that of the FL condition by 4%. Although there were no significant differences between the FL/H_{off} and the FL conditions in the absolute value of $\dot{V}O_2$ or of $\dot{V}O_2$ normalized to body mass during the 2-h trials as there were during the 10-min trials, the means of these variables for the FL/H_{off} condition were higher, by about 4%, than the means for the FL. The differences in metabolic measurements for the 2-h trials were not reflected in the heart rate data; heart rates were very similar, with the mean for FL/H_{off} condition differing from that for the FL condition by less than 1%.

The findings from the 10-min and the 2-h walking trials of higher values for some metabolic variables when the FL/H_{off} was worn relative to values for the FL condition are not in consonance with results of studies of rucksack concepts presented by Holewijn (1990) and by Winsmann and Goldman (1976). These investigators contrasted rucksacks designed to suspend most of the load from the shoulders and equally weighted rucksacks with integral waist belts, designed to place most of the load on the hips. No differences in $\dot{V}O_2$ were found between the rucksack designs during walking. The rucksack concepts are not unlike the load conditions tested in the current study insofar as the load was suspended from the shoulders in the FL condition and distributed to the hips in the FL/L_{off}, the FL/M_{off}, and the FL/H_{off} conditions. In addition, although the participants in Holewijn's (1990) study carried relatively light rucksack loads of 5.4 or 10.4 kg (11.9 or 23.0 lb), a rucksack load of 30 kg (66 lb) was carried by the participants tested by Winsmann and Goldman (1976), a mass that approximated the external load of about 31 kg (68 lb) used in the current study.

Based on the results of the rucksack studies by Holewijn (1990) and by Winsmann and Goldman (1976), it would not be expected that the FL/H_{off} condition, or the other two offloading conditions (i.e., FL/L_{off} and FL/M_{off}), would yield higher values on some of the metabolic variables than the FL in the current study. The point can again be made that the FL configuration in the current study, which included body armor and a 9.1-kg (20.1-lb) TAP placed on the front of the body at chest level, presented a different load-carrying situation than those studied by Holewijn (1990) and by Winsmann and Goldman (1976) in which the load was located on the back. However, the question remains as to what extent the small difference in load mass of 1.13 kg (2.50 lb), which was attributable to the presence or absence of the load distribution device, contributed to the FL and the FL/H_{off} conditions being significantly different on some of the metabolic variables analyzed in the current study and to what extent characteristics of these two loads other than mass differentially affected the metabolic measures. Given that the FL/L_{off}, the FL/M_{off}, and the FL/H_{off} load conditions, as well as the FL/N_{off}, were equal in mass, but that the FL/H_{off} was the only one of these load conditions that differed significantly from the FL, it would seem that some element other than mass contributed to the differences in metabolics found between the FL and the FL/H_{off} conditions.

The results of analyses of the kinetic and kinematic variables do little to clarify the issue raised by findings from analyses of the metabolic variables. Research has shown that increases in load mass and differences in distributions of loads on the body can affect gait kinetics and kinematics (Birrell & Haslam, 2010; Harman et al., 2000; Johnson et al., 2001; Martin & Nelson, 1986; Park et al., 2011). However, Kelley et al. (2014) and Lenton et al. (2019) found few differences in kinetic and kinematic variables attributable to wearing or not wearing a load distribution device. Similarly, the analyses performed on the 10-min walking trial data in the current study did not yield significant differences between the FL and the FL/H_{off} conditions, or indeed between any of the load conditions, in body angles, spatiotemporal gait variables, or loading rates. However, there were indications that the FL/H_{off} affected 2nd peak vertical force and hip moment differently than the FL condition did.

The 2nd peak vertical force is the force exerted as the body propels itself and the load on the body into the next step. Generating the forces to move the body forward is an energy-intensive activity. On 2nd peak vertical force normalized to body weight and normalized to total weight recorded during the 10-min walking trials, there was a significant interaction between load condition and grade. The FL/H_{off}, FL and FL/M_{off} conditions were associated with lower 2nd peak force at the 0% grade and higher 2nd peak force at the 9% grade. However, the difference was the greatest for the FL/H_{off} condition, where 2nd peak force was about 10% greater at the 9% grade relative to the force at the 0% grade, whereas the FL and FL/M_{off} showed percentage differences that were about 4% greater at the 9% relative to the 0% grade. The FL/N_{off} and FL/L_{off} showed no differences between grade.

During push off into the next step, there is a moment that extends the hip in the sagittal plane of the body, with maximum hip extension occurring just prior to the foot pushing off the ground. Minimum hip moment is associated in time with maximum extension. Larger joint moment values are generally considered to be unfavorable due to an increased demand on the musculoskeletal system and the increased potential for injury (Knapik & Reynolds, 2012; Knapik et al., 2004). Minimum hip moment was another kinetic variable that yielded a

significant finding involving load condition during the 10-min walking trials. The interaction between load condition and grade was not significant for this variable, but there was a significant main effect of load condition. Post hoc tests did not yield significant differences between load conditions. The significant main effect does, however, suggest a difference between the extreme data points. The FL condition had the smallest (least negative) mean value for minimum hip moment and the FL/H_{off} condition had the largest (most negative) mean value.

The findings that the FL/H_{off} condition had larger minimum hip moment values than those for the FL and the other load conditions and that 2nd peak vertical force values for the FL/H_{off} condition had the greatest difference between the 0 and 9% grade, potentially suggests that the FL/H_{off} condition had an effect on the body during the pre-swing phase of the gait cycle, immediately prior to the foot pushing off the ground and into the next step, that was dissimilar to the effects of the FL and the other load conditions. The findings raise the question of whether the higher values for $\dot{V}O_2$ and $\dot{V}CO_2$ with the FL/H_{off} condition compared with the FL are attributable to some interference in executing the ground push off movement when the FL/H_{off} condition was being used. Higher metabolic energy usage would be expected if greater muscle activity was required to propel the body forward in to the next step with the FL/H_{off} than with the FL or the other load conditions. Results of analysis of the muscle activity data from the current study provided some evidence that the FL/H_{off} did differ from the FL and the other load conditions.

Of the three muscle groups from which EMG was recorded during the 10-min treadmill walking trials (i.e., vastus medialis, biceps femoris, and gastrocnemius), only one, the biceps femoris, yielded significant statistical results for the analysis of the load condition variable. The dependent measures that revealed a significant main effect of load condition were peak amplitude and the log of the 5th order spectral index. Although post hoc tests did not reveal significant differences between load conditions for either of these measures, the significant main effects do suggest a difference between the extreme data points. In the case of peak amplitude, the highest mean was associated with the FL/H_{off} condition. The FL/L_{off} condition had an intermediate mean value and the FL, the FL/N_{off}, and the FL/M_{off} conditions had the lowest mean peak amplitudes, which were similar in value. These results indicate that there was a higher level of muscle activity with the FL/H_{off} than with the other load conditions. For the log of the 5th order spectral index, the FL/H_{off} condition had the highest (least negative) value, the FL/L_{off} and FL/M_{off} had intermediate values, and the FL and the FL/N_{off} conditions had the lowest (most negative). This relationship suggests greater local fatigue of the biceps femoris muscle with the FL/H_{off} than with the FL and the other load conditions.

When an individual is walking, the biceps femoris and the other two hamstrings (semitendinosus and semimembranosus) are activated prior to heel strike, during the last part of the swing phase of the gait cycle, and activity continues into the initial stance phase following heel strike. Hamstring activity has also been noted later in the stance phase, during pre-swing (Benedetti, Agostini, Knaflitz, & Bonato, 2012). It is possible that the greater biceps femoris activity and fatigue with the FL/H_{off} condition reflect interference in pushing off from the ground compared with the FL and the other load conditions and resulted in the higher energy usage that was obtained when the FL/H_{off} condition was tested.

Another variable that revealed a significant difference between the FL and the FL/H_{off} conditions was the proportion of false alarms on the auditory go/no-go response inhibition task administered during the 2-h walking trials: there was a significant quadratic interaction between load condition and elapsed time. The means for the load conditions as a function of elapsed time revealed a lower proportion of false alarms at minutes 65 and 85 with the FL/H_{off} than with the FL condition. However, with the exception of these administrations, the proportion of false alarms with the FL and the FL/H_{off} conditions were very similar throughout the trial and both showed a higher proportion of false alarms late in the trial compared with the proportion in the early periods. Among the results of other analyses carried out on the auditory go/no-go task response measures, it was found that the discriminability index was significantly affected by elapsed time: performance decreased over the trial, an effect likely due to the increasing proportion of false alarms.

Aside from the significant quadratic interaction between load condition and elapsed time on the proportion of false alarms for the go/no-go task, none of the analyses carried out on the response measures for the go/no-go task yielded significant interactions between load condition and elapsed time or significant main effects of load condition. On the second cognitive task, the visual target detection task, it was found that accuracy improved significantly over the trial and reaction time on this task was unaffected by elapsed time. However, there were no significant main effects or interactions involving load condition on the visual target detection task.

In administering the auditory go/no-go task in an earlier load-carriage study involving 2-h walking trials on variable treadmill grades, Eddy et al. (2015) found that the proportion of false alarms increased over time when participants carried a 40-kg (88-lb) load, but was relatively unchanged when a 6-kg (13-lb) load was carried. Paralleling the change in cognitive performance, the percentage of peak $\dot{V}O_2$ indicated that physical exertion with time on the march was greater with the heavier load. Eddy et al. (2015) maintained that these results supported Dietrich's (2003) transient hypofrontality hypothesis, which predicts performance decrements in frontally mediated tasks during acute exertion due to a decrease in frontal neural activity with the demands of exercise.

The results obtained on the auditory go/no-go task and on the energy consumption measures in the current study were different than those reported by Eddy et al. (2015) and are not in line with the hypofrontality hypothesis (Dietrich, 2003). In the current study, the absolute values of $\dot{V}O_2$ and of $\dot{V}O_2$ normalized to body mass during the 2-h walking trials were higher, although not significantly so, when the FL/H_{off} condition was used, compared with the FL. However, the proportions of false alarms under the FL and the FL/H_{off} conditions were approximately equal throughout most of the 2-h walking trials. Thus, a difference in physical exertion between the FL and the FL/H_{off} conditions was not reflected by a difference in the proportion of false alarms on the auditory go/no-go task.

In the current study, the FL/H_{off} load condition, at 31.5 kg (69.4 lb), was 1.13 kg (2.50 lb) heavier than the FL condition and was about 4% higher in energy consumption. The 40-kg (88-lb) load tested by Eddy et al. (2015), was 34 kg (75 lb) heavier and roughly 10% higher in energy consumption than the lighter load they tested. It is possible that these differences in the load conditions tested and the magnitudes of the differences in energy consumption between the lighter and the heavier loads account for the fact that the results obtained on the go/no-go task in

the current study did not show a higher proportion of false alarms as the results of Eddy et al. (2015) did.

The visual target detection task also yielded results for the current study that were different than those reported by Eddy et al. (2015). Eddy et al. (2015) found an improvement in accuracy, along with an increase in reaction time, as the trial progressed. In the current study, accuracy on the target detection task also improved significantly over the 2-h trial, but, unlike the findings of Eddy et al. (2015), reaction time was unaffected by elapsed time on the trial. Neither the findings of Eddy et al. (2015) nor the findings from the current study for the target detection task are consistent with the transient hypofrontality hypothesis, which predicts that target detection performance will be relatively unchanged as the trial progresses (Dietrich, 2003).

On the basis of their results, Eddy et al. (2015) maintained that the relationship between exercise and higher and lower level cognition is more complex than the framework proposed by the transient hypofrontality hypothesis suggests (Dietrich, 2003). The findings from the current study support this position. The results of this study and of the work of Eddy et al. (2015) suggest that research into further defining relationships between exertion levels and performance of frontally mediated tasks is necessary in order to assess the usefulness of the transient hypofrontality hypothesis in predicting the cognitive effects of load-carrying activities (Dietrich, 2003).

Measurements made during isokinetic muscle strength testing was another metric that revealed significant differences between the FL and the FL/H_{off} conditions. Testing of trunk, shoulder, and knee flexors and extensors resulted in a significant effect of load condition on total work and on average power measurements related to trunk flexion at 20°·s⁻¹. These effects indicated significantly greater decrements in the post-trial relative to the pre-trial measurements with the FL/H_{off} condition than with the FL condition.

In their study investigating the impact of load mass and walking grade on muscle strength changes over 2-h treadmill marches, Batty et al. (2015) reported that total work and average power related to trunk flexion at 20°·s⁻¹ showed significantly greater decrements after an individual walked with a heavier load and on variable grades compared to walking with a lighter load on a constant downhill grade. Batty et al. (2015) proposed that these findings reflected higher levels of localized fatigue of the lumbar muscles with the heavier load and the variable grades.

The strength data analyzed by Batty et al. (2015), as well as the strength measures analyzed in the current study, were a participant's readings obtained immediately after a 2-h treadmill walking trial subtracted from the readings obtained before the trial began. In both studies, the pre-trial strength measurements were made when the participant arrived for testing, prior to other session activities. It was assumed that the data obtained at this time would be unaffected by the test conditions that the participant would subsequently be exposed to during the 2-h treadmill walking trial. Analyses of the pre-trial data from the current study for trunk flexion at 20°·s⁻¹ did not support the assumption; the measurements of both total work and average power made before the trial began were significantly higher for the FL/H_{off} condition than for the FL.

Prior to beginning activities at a session, participants were told the load condition they would be testing. The difference between the FL and the FL/H_{off} conditions in the pre-trial readings for trunk flexion at 20°·s⁻¹ raises the possibility that the participants' muscle strength performance was influenced by this information. However, further consideration of the pre-trial data suggests that this was not likely. Separate analyses were performed on all trunk, shoulder, and knee flexion and extension measures to contrast the pre-trial data for the FL and the FL/H_{off} conditions. Total work and average power during trunk flexion at 20°·s⁻¹ were the only measurements on which the load conditions differed significantly, a finding that is unlikely if participants' knowledge of the load condition to be tested subsequently during the session influenced their muscle strength performance. In addition, separate analyses were done on the post-trial data for all measures and no significant differences were obtained between the FL and the FL/H_{off} conditions on any of the muscle strength measures. Therefore, although there is no obvious explanation for the higher pre-trial measurements obtained with the FL/H_{off} than with the FL condition for total work and average power during trunk flexion at 20°·s⁻¹, it does appear that the muscle strength measurements taken upon trial completion were not affected by whether the FL or the FL/H_{off} conditions were worn for the 2-h treadmill marches.

Lenton, Doyle, Saxby, et al. (2018) did not obtain significant differences on the RPE between ratings given to armor vest systems with load distribution devices and to the standard Australian Army vest, which did not have a load redistribution capability. In the current study, as well, participants' ratings of perceived exertion for the 10-min and the 2-h walking trials were not significantly affected by whether the load distribution device was present or absent, and the amount of offloading also did not affect RPE ratings. During the 2-h trials, the participants' exertion levels increased as the trial progressed. However, there was no indication that the load condition being used on these trials differentially affected the ratings.

In completing the RPE, participants gave a single rating to reflect their overall feeling of exertion. On the RPSD, participants rated the level of pain, soreness, discomfort, or restriction for each of 12 specific areas of the front of the body and 12 areas on the back of the body. After the 10 min of treadmill walking, there were few RPSD ratings given by the participants that exceeded 0 (i.e., a rating of *no pain, soreness, discomfort, or restriction*) and there were no significant differences between the load conditions in the ratings given. However, the RPSD was more effective than the RPE in differentiating between the FL and the FL/H_{off} conditions after the 2 h of walking: There were significantly more RPSD ratings exceeding 0 (i.e., a rating of at least *slight pain, soreness, discomfort, or restriction*) at the end of the 2-h walking period when the FL was being worn.

The differences in RPSD responses between the FL and the FL/H_{off} conditions associated with the 2 h of treadmill walking were mainly at the shoulders and the hips. The majority of the 13 participants reported at least slight pain, soreness, or discomfort on the front or the back of the shoulders when they were tested in the FL and only three and two participants, respectively, gave a rating of at least slight pain, soreness, or discomfort on the front and on the back of the shoulders when tested in the FL/H_{off} condition. In contrast to the positive ratings for the shoulder area, the participants' responses on the RPSD indicated that the pressure perceived in the pelvic area increased with the offloading of the shoulders. Five of the 13 participants assigned a rating of at least slight pain, soreness, or discomfort to the anterior hip region when using the FL/H_{off}

condition and none of the participants rated the anterior hip region as being a site of pain, soreness, or discomfort when wearing the FL.

4.4 Participants' Questionnaire Responses

Responses on the Load Redistribution Questionnaire aligned with the RPSD ratings to the extent that participants were generally positive about offloading of the shoulders, and all three offloading conditions (i.e., FL/L_{off}, FL/M_{off}, and FL/H_{off}) were viewed positively. The majority of participants were also of the opinion that the load distribution device did not negatively impact their ability to walk and that load redistribution would improve comfort and performance while carrying heavy loads and executing mission-related activities.

The negative responses on the Load Redistribution Questionnaire regarding use of the device were directed at aspects of transfer of the load from the shoulders to the hips, particularly the functioning of the waist belt. To minimize the waist belt slipping, it had to be tightly secured around the waist, eliciting responses of pressure and pain at the hips. Recommendations made by the participants were that the buckle and the padding on the waist belt be improved and that the waist belt be redesigned for easier adjustment and to prevent the belt from slipping down on the torso below the waist.

The problems with the waist belt that participants reported may have been attributable to use of the DWD with the Army 3rd Generation Improved Outer Tactical Vest. The DWD was designed by SOURCE Tactical Gear to be used with a lighter weight, plate carrier vest, which has a smaller profile and is stiffer than the Army vest used in the current study. Further, in outfitting participants in a typical Army fighting load, the TAP, weighing 9.1 kg (20.1 kg), was placed on the front of the Army vest at chest level and the hydration system, weighing only 3.0 kg (6.5 lb), was placed on the back. Thus, there was an asymmetric loading situation on the torso. The asymmetry of the fighting load configuration and the lack of stiffness in the Army armor vest made it difficult to adjust the load and to maintain the offloading conditions. For any system designed in the future, the load configuration and slippage of the waist belt should be assessed, as these are critical to maintaining the offloading and overall comfort.

In other responses on the questionnaire, participants indicated that they would like to be able to adjust the amount of offloading while on the move. It is possible to adjust offloading when wearing the DWD, the load distribution device used in the current study, but participants were not permitted to do so. The participants' support for the capability suggests that offloading adjustment on the move should be a characteristic of any offloading device adopted for military use.

The participants' questionnaire responses indicate that use of a load distribution device to offload the shoulders was viewed favorably. Neither the questionnaire data, nor the RPSD ratings, suggest that the participants had a preference for a particular one of the three levels of shoulder offloading tested in this study. Analyses of the objective data also did not reveal statistically significant differences among the three offloading conditions. However, there were analyses in which the FL/H_{off} condition was found to be significantly different from the FL condition, whereas the other offloading conditions (i.e., FL/L_{off} and the FL/M_{off}) were not. Thus, the participants' questionnaire responses and ratings did not reflect that, compared with the FL

condition, the FL/H_{off} condition was associated with significantly higher rates of oxygen consumption and carbon dioxide production, larger minimum hip moments, relatively high 2nd peak vertical forces at the 9% walking grade, and a higher level of biceps femoris muscle activity. It can be posited that the differences among the offloading conditions on these variables were subtle and that the participants responded primarily to the reduced discomfort in the neck and shoulder areas provided by the load distribution device.

4.5 Limitations

The current study has several limitations. The primary limitation is related to the load condition variable. For the three levels of the load condition variable that entailed offloading the shoulders, the DWD was adjusted before a trial began to achieve settings within a range of predetermined percentages of the baseline FL pressure. Pressure readings taken upon termination of treadmill walking trials revealed that changes had occurred such that the offloading levels were below the pre-established ranges. The relationship among the offloading levels, relative to the baseline FL shoulder pressure, did not change: the lowest to highest pressure reductions at the end of the trials were, in order, FL/L_{off}, FL/M_{off}, and FL/H_{off}.

A second study limitation pertains to the testing activities not evaluated. The Soldier-participants carried out short and prolonged bouts of treadmill walking with a fighting load. Marching is an important element of the physical activities that Soldiers perform in the field, and it was determined that treadmill walking would be an appropriate activity for investigation of load redistribution concepts. However, when redistributing the load from the shoulders to the hips, the vest is physically lifted off of the shoulders, destabilizing the load on the torso. Therefore, there are a myriad of other critical military tasks, such as running, rushing, and firing weapons from standing, prone, and kneeling positions, that should be investigated in determining the efficacy of Soldiers' use of load distribution devices. Understanding the relevant movement tasks with an approach load will also be important as the interactions and influence of a rucksack with respect to load distribution was not investigated in this study. In addition, the ballistic integrity of the body armor and shift in protective coverage with the load distribution system was not assessed. For any potential load distribution device utilized, an assessment on how ballistic protection is affected with the device is needed.

A third study limitation is inherent in the sensors used to measure pressures at the shoulders and the hip areas. The sensors that are part of the Plance dynamic pressure distribution measurement system measure pressure normal to their surfaces — tangential stress and sheer strain are not measured. The characteristics of the pressure sensors may have resulted in an incomplete understanding of shoulder pressures associated with the FL and the other load conditions and lack of information on the pressures in the hip area associated with redistributing the load between the shoulders and the hips.

Another limitation results from the fact that there were few female Soldiers available to recruit as study participants. One enlisted woman and 16 enlisted men volunteered; the woman withdrew from the study early in testing. Therefore, study findings cannot be assumed to apply to female Soldiers.

5 CONCLUSIONS AND RECOMMENDATIONS

The study participants' responses favored a load distribution device to reduce the pressure in the shoulder area experienced when outfitted in a military fighting load. Compared with data acquired when the device was not in place, use of the device during treadmill walking did not change body posture or spatiotemporal gait characteristics and did not negatively affect muscle strength or performance on cognitive tasks. However, the level of discomfort experienced on the body shifted with the pressure as it was redistributed from the shoulders to the hips. An optimal range of pressure offloading at the shoulders was not identified from this study. Although, within the limits of this study, some data outcomes indicate that the highest level of offloading may be least ideal.

Study findings suggest that determining the load reduction characteristics of a device to redistribute loads is a critical design issue. Examination of the effects on treadmill walking of setting the load distribution device to control the proportion of pressure reduction at the shoulders (i.e., reductions of 10 to 20%, 40 to 60 %, and 70 to 90% of pressure recorded when the load distribution device was not worn) indicate that the different percentages of offloading did not differentially affect most of the objective measures analyzed in this study. In addition, statistically significant differences were not obtained between the two lower levels of pressure reduction and the condition in which the fighting load was worn without the load distribution device. Participants' ratings of shoulder comfort also were unaffected by the percentage of offloading for 10-min walking periods. However, for the 2-h walking periods, a significant increase in discomfort was reported in the hip region as the pressure was distributed from the shoulders to the hips.

The treadmill walking data did reveal statistically significant differences in some measures between the highest level of pressure reduction (i.e., 70 to 90% reduction) and the fighting load alone. Relative to wearing the fighting load alone, the highest level of pressure reduction was associated with higher levels of energy expenditure and carbon dioxide production, increased minimum hip moments, and greater activity of the biceps femoris. Based on these results, it can be posited that setting the load distribution device at the highest level of shoulder pressure reduction impeded push off from the ground into the next step as participants walked on the treadmill. Offloading of the shoulders results in transfer of the load to the waist belt, increasing pressure in the hip region of the body. Whether some aspect of the waist belt played a role in the differences obtained between the offloading condition with the highest level of shoulder pressure reduction and the fighting load alone is not known. Findings from the current study do, however, indicate that waist belt design is a critical feature of a load redistribution system. Although few in number, some study participants reported at least slight pain, soreness, or discomfort in the pelvic region when using the high offloading condition. Some participants also commented negatively on the waist belt and reported that the waist belt slipped down on the torso and that the buckle and the padding should be improved.

If Soldiers are to be provided with a device to reduce pressures in the shoulder area, the following are recommendations regarding design of a load redistribution capability:

- As to the proportion of load reduction at the shoulders that the device should be designed to achieve, a greater reduction will not necessarily result in a better product. The design

of the waist belt of the device is critical and may be a major determinant of acceptable levels of pressure reduction at the shoulders.

- With offloading of the shoulders, there is transfer of the load to the hips. During development of load distribution devices, the devices should be placed on people regularly and pressure sensor pads used to check contact pressures at the skin surface, not only in the shoulder region, but in the hip region as well. Mechanical loads can occlude blood flow, damage soft tissue, and induce pain. Regular checks of the design are a means to ensure that recommended safe pressure limits at the skin are not exceeded.
- The load distribution device selected for use in the current study could be adjusted to vary the amount of shoulder offloading, a requirement for the testing protocol executed here. The amount of offloading was set by the investigators. The participants indicated that they liked the adjustment feature and wanted a device that could be adjusted over a range of offloading levels while a Soldier was underway.
- A related design feature viewed positively by the participants was the ability to make initial adjustments of the device and to don the device without assistance.

During development of load distribution systems, there will be a need to evaluate design concepts and prototypes as they become available. Recommendations regarding future testing on Soldiers follow.

- Use of pressure sensor pads at the shoulders and the hips, as was done in the current study, should be continued in future testing. Recording of pressures at the beginning and at the end of a physical activity, with the participant in a stationary standing position, is recommended. If testing involves setting of shoulder pressures as was done in the current study, pilot testing should be conducted to characterize pressure changes during performance of the activity. In the current study, the baseline pressure readings were taken during a period of quiet standing and the pressure reduction settings for the offloading conditions were implemented immediately upon outfitting the participants in the appropriate attire for the test condition. Thus, the participants did not have the opportunity to move around in the attire and to make minor adjustments that may have stabilized the items being worn. In the future, pilot testing should be carried out to assess whether having participants engage in short periods of dynamic activity after they have been outfitted and before pressure settings are made can minimize the changes in pressure readings over the course of testing.
- Physiological, biomechanical, cognitive, muscle strength and subjective data were collected and analyzed in the current study and should be collected in future studies that entail locomotor activity performance with load distribution devices.
- This study was limited to analyses of treadmill walking. In future work on load redistribution, the repertoire of physical activities should be expanded to include running, rushing, diving to prone and rifle firing, at a minimum.

- Use of a load distribution device with a fighting load was investigated in the current study. In future efforts, an approach march load should be included so that testing of the device under a condition in which a rucksack is used can be accomplished.
- The cervical FRR evaluation included in the current study did not yield any significant findings. Cervical FRR testing should be included in future studies in which a rucksack is used along with the load distribution device.
- The impact to ballistic protection from adjusting body armor to redistribute the load should be evaluated with the use of any load redistribution device.

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APPENDIX A

Demographic Survey and Anthropometric Measurements

Vol #: _____

Date: _____

1. Gender (M/F): _____

2. Age: _____

3. If you were to kick a ball, what leg would you kick with (R/L)? _____

4. When you write, what hand do you write with (R/L)? _____

5. When did you enter military service (mm/yyyy)? _____

6. When did you graduate from basic training (mm/yyyy)? _____

7. When did you complete AIT (mm/yyyy)? _____

8. What is your rank? E- _____

9. What is the name of your primary MOS? MOS Name: _____

10. What is the number of your primary MOS? MOS NO: _____

11. When was your most recent PT test (mm/yyyy)? _____

12. What was your score on your most recent PT test? _____

13. What was your 2-mile run time on your most recent PT test? _____ min: _____ sec

14. When was your most recent field training exercise (mm/yyyy)? _____

15. When was the last time you wore an armor vest (mm/yyyy)? _____

16. When you have worn an armor vest, what type have you **usually worn**?

17. Check off the plates that you have **usually worn in your armor vest**.

_____ Front plate _____ Back plate _____ Side plates

18. Have you **usually used** any of the following when you have worn an armor vest? **Check all that apply.**

_____ Neck piece/collar _____ Groin protector _____ Extremity armor

19. During your field training exercises, have you **ever carried a rucksack** (Yes/No)?

a. If you answered YES, have you **ever carried a rucksack with an external frame** during a field training exercise (Yes/No)? _____

20. During your field training exercises, have you **ever carried an assault pack** (Yes/No)?

a. If you answered YES, what **type of assault pack** have you carried?

Measurements:

Body Weight w/boots: _____ Body Weight w/out boots: _____

Total Weight (fighting load configuration): _____

Stature: _____

Waist Front Length: _____ *Chassis Size: M < 410, L > 410*

Waist Back Length: _____

Waist Circumference 2 cm Below Iliac Crest: _____ *Hip Belt Size: S < 970, M 970-1060, L > 1060*

Waist Height, Omphalion: _____ Cervicale Height: _____

WH, O minus CH: _____

Assessment of Body Armor Fit:

Poor	Fair	Good	Very Good
1	2	3	4

Comments:

APPENDIX B

Sample of the Borg Rating of Perceived Exertion Scale

(Reprint of original)

Borg Scale

RPE	Exertion
6	No exertion at all
7	Extremely light
8	
9	Very light
10	
11	Light
12	
13	Somewhat hard
14	
15	Hard (heavy)
16	
17	Very hard
18	
19	Extremely hard
20	Maximal exertion

Instructions for Borg Rating of Perceived Exertion (RPE) Scale

While doing physical activity, we want you to rate your perception of exertion. This feeling should reflect how heavy and strenuous the exercise feels to you, combining all sensations and feelings of physical stress, effort, and fatigue. Do not concern yourself with any one factor such as leg pain or shortness of breath, but try to focus on your total feeling of exertion.

Look at the rating scale below while you are engaging in an activity; it ranges from 6 to 20, where 6 means "no exertion at all" and 20 means "maximal exertion." Choose the number from below that best describes your level of exertion. This will give you a good idea of the intensity level of your activity, and you can use this information to speed up or slow down your movements to reach your desired range.

Try to appraise your feeling of exertion as honestly as possible, without thinking about what the actual physical load is. Your own feeling of effort and exertion is important, not how it compares to other people's. Look at the scales and the expressions and then give a number.

9 corresponds to "very light" exercise. For a healthy person, it is like walking slowly at his or her own pace for some minutes

13 on the scale is "somewhat hard" exercise, but it still feels OK to continue.

17 "very hard" is very strenuous. A healthy person can still go on, but he or she really has to push him- or herself. It feels very heavy, and the person is very tired.

19 on the scale is an extremely strenuous exercise level. For most people this is the most strenuous exercise they have ever experienced.

Borg RPE scale

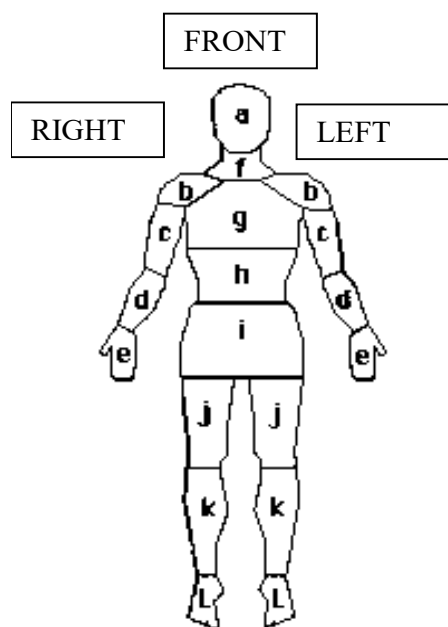
© Gunnar Borg, 1970, 1985, 1994, 1998

APPENDIX C

Ratings of Pain, Soreness, and Discomfort

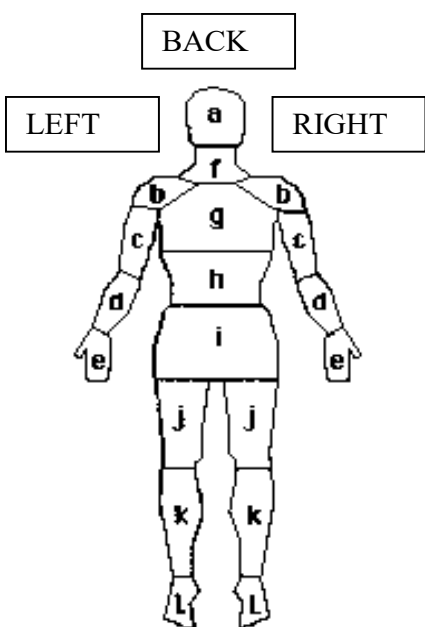
Date: _____ Volunteer #: _____ Morning/Afternoon _____
 Session/Trial Description: _____

Rate the degree of PAIN, SORENESS, or DISCOMFORT that you are currently feeling for Body Parts A through L. Do so for the FRONT and the BACK of the body.



FRONT of Body

	a	b	c	d	e	f	g	h	i	j	k	L
NONE	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
SLIGHT	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
MODERATE	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
SEVERE	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
EXTREME	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐



BACK of Body

	a	b	c	d	e	f	g	h	i	j	k	L
NONE	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
SLIGHT	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
MODERATE	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
SEVERE	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
EXTREME	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐

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APPENDIX D
Load Redistribution Questionnaire

LOAD REDISTRIBUTION QUESTIONNAIRE

The purpose of this survey is to understand the performance of the load redistribution device you wore. Please read the questions carefully and fill-in all of the bubbles completely. All responses will remain confidential. Thank-you for your participation!



ID #: _____

Date: _____

1. Please indicate how much you liked the Load Redistribution device (across all configurations (i.e., ways you wore the device))?

Disliked Very Much	Disliked	Neutral	Liked	Liked Very Much
①	②	③	④	⑤

2. Please indicate how much you liked the Load Redistribution device at **LOW** off loading?

Disliked Very Much	Disliked	Neutral	Liked	Liked Very Much
①	②	③	④	⑤

3. Please indicate how much you liked the Load Redistribution device at **MID** off loading?

Disliked Very Much	Disliked	Neutral	Liked	Liked Very Much
①	②	③	④	⑤

4. Please indicate how much you liked the Load Redistribution device at **HIGH** off loading?

Disliked Very Much	Disliked	Neutral	Liked	Liked Very Much
①	②	③	④	⑤

What did you like *most*?

What did you like *least*?

5. Did you feel the device reduced the load evenly across your shoulders/chest/back?

- ☐ Yes, load relief was even across shoulders/chest/back
- ☐ No, load relief was not even (select all that apply)
- ☐ Reduced load on shoulders
- ☐ Reduced load on upper back
- ☐ Reduced load on chest
- ☐ Reduced load on other area (please specify) _____

LOAD REDISTRIBUTION QUESTIONNAIRE

6. Did you feel the device reduced the load evenly across your hips/pelvis?

- ☐ Yes, load relief was even across hips/pelvis
- ☐ No, load relief was not even (select all that apply)
- ☐ Reduced load on right
- ☐ Reduced load on left
- ☐ Reduced load on front
- ☐ Reduced load on lower back
- ☐ Reduced load on other area (please specify) _____

7. How much would you like the ability to adjust the amount of the offloading, while on the move:

Disliked Very Much	Disliked	Neutral	Liked	Liked Very Much
①	②	③	④	⑤

8. Overall, how would you rate the waist belt of the load redistribution device?

Disliked Very Much	Disliked	Neutral	Liked	Liked Very Much
①	②	③	④	⑤

9. Did you feel this device (as a whole) negatively impacted your ability to walk on the treadmill?

Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree
①	②	③	④	⑤

10. Did you feel the waist belt negatively impacted your ability to walk on the treadmill?

Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree
①	②	③	④	⑤

11. Do you feel having an offloading capability would improve your comfort when carrying heavy loads?

☐ Y ☐ N

If NO, please explain why not.

12. Do you feel having an offloading capability would improve your ability to carry heavy loads during a long march?

☐ Y ☐ N

If NO, please explain why not.

LOAD REDISTRIBUTION QUESTIONNAIRE

13. Did any aspect of the device create or have the potential to create a safety or health hazard to you (e.g. any sore spots on the body due to the device, or any snag hazard that became apparent after wearing the device)?

☐ Y

☐ N

If YES, please explain.

14. Did any aspect of the device create any type of signature (e.g., noise, odor, visual, thermal, etc.) that you noticed during testing?

☐ Y

☐ N

If YES, please explain

15. Do you have any recommendations to improve this device?

16. Do you have any other comments regarding this device, which were not covered in this questionnaire?