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UNITED STATES ARMY AEROMEDICAL RESEARCH LABORATORY

# Evaluation of Litter Carriage Performance and Post-Carry Fatigue Effects in Prolonged Combat Field Care Environments (Part 2): Effects of Assistive Device Use During Simulated Litter Transport

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**14. ABSTRACT**
Litter carriage transport is a standard procedure for initial casualty evacuation from the point of injury to the medical aid or evacuation zone and is generally done on foot. Using an assistive device during litter transport could decrease fatigue and increase the litter bearer's ability to carry the litter, provide critical care, and sustain Warfighter tasks. Improvements in these capabilities are critical with upcoming large scale combat operations (LSCO) and multi-domain operations (MDO), which could extend distance and duration away from medical evacuation zones or definitive medical treatment. We examined the effects of commercial-off-the-shelf (COTS) assistive device use (i.e., shoulder harness and wrist hooks) on litter bearer performance and post-carry fatigue during simulated prolonged care and transport scenarios. Assistive device usage resulted in positive benefits to litter carry distance, grip strength, and spinal posture during the litter carriage task. The use of an assistive device also demonstrated limited benefit to muscular fatigue.

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litter transport, litter carriage, military casualty evacuation and transport, assistive devices, shoulder harness, wrist hooks, dismounted, operational fatigue, operational performance

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14. Abstract (continued)
Overall, the study outcomes demonstrated that an assistive device 2-person litter carry technique could replace the traditional unassisted 4-person litter carry technique in remote and mass casualty scenarios.

**Summary**

Litter carriage transport is a standard procedure for initial casualty evacuation from the point of injury to the medical aid or evacuation zone and is generally done on foot. The process of litter transport consists of either a two- or four-person team carrying a casualty over a long distance or carrying multiple casualties over a short distance. A litter team may transport a single casualty from a remote location, occurring over hours while stopping to provide critical care or protect themselves and the casualty from enemy fire; however, litter teams can carry a single patient only a few hundred meters over rough terrain before needing to rest. Alternatively, a litter team may transport multiple causalities, rapidly and repeatedly, during mass casualty evacuations, such as following a plane crash or improvised explosive device event.

Like transporting standard military loads, such as weapons and equipment, transporting patients using a litter can be physically demanding for Service Members (SMs). During the evacuation, the litter team may be required to provide critical care while actively engaging in combat to protect themselves and the casualty. In anticipation of a future fight with near-peer adversaries, improving the physical abilities of SMs and limiting impediments are of high priority. During large scale combat operations (LSCO) and multi-domain operations (MDO), the anticipated increased number of casualties, along with the anticipated periods and areas of denial by near-peer competitors, highlight the criticality and potential demand for effective and efficient dismounted litter transport.

Additionally, litter bearers can develop musculoskeletal disorders over time due to frequent, repetitive, or extended litter transport scenarios. Furthermore, the onset and severity of such disorders, injuries, or diseases could affect an SM's career and retention. A straightforward approach to the dilemma of litter bearer fatigue may be to develop a technology to lessen the physical demands on the litter bearer.

Using an assistive device (e.g., shoulder harness or wrist hooks) during litter carriage transport could decrease fatigue and increase the litter bearer's ability to carry the litter over longer distances, allowing for increased capabilities in providing casualty care and sustaining SM tasks. Additionally, an assistive device has the potential to not only improve combat performance following litter carriage transport but also improve evacuation times of the injured and increase the opportunities to utilize two-person teams over four-person teams. Currently, no assistive devices are integrated into the standard Military Equipment Set or litter carriage procedures, and there are no standards for evaluating the efficacy of any device to be considered. This is true for commercial-off-the shelf (COTS) as well as novel exoskeletons. Furthermore, although a plethora of exoskeleton research for military applications is being tested against standard lifting and carrying tasks, exoskeleton research for military patient transport scenarios is lacking.

The U.S. Army Aeromedical Research Laboratory (USAARL) conducted a study to evaluate litter carriage performance and post-carry fatigue effects of COTS assistive device use (i.e., shoulder harness and wrist hooks) during simulated litter carriage transport. The study found that using an assistive device provided multiple positive benefits during the litter carry task compared to unassisted carries. Assistive devices reduced the rate of fatigue for important muscles for posture, locomotion, and load carriage. Participants demonstrated more neutral postures during litter carriage with assistive device usage. As a result, use of these devices

increased the distance carried and reduced loss of grip strength during litter carriage. Overall, study outcomes demonstrated that an assistive device two-person litter carry technique could replace the traditional unassisted four-person litter carry technique in remote and mass casualty scenarios resulting in: (a) less personnel needed per casualty transport, (b) decreased evacuation times, (c) an increased number of casualty evacuations, and (d) less risk of musculoskeletal injury to the bearer.

Future work will focus on expanding the types and quantity of assistive devices examined and assessed as well as ensuring real world applicability and feasibility in remote and mass casualty litter carriage transport scenarios in anticipation of future LSCO and MDO environments. These data will aid in establishing a standard to evaluate the efficacy and feasibility of assistive devices as well as the selection and integration of assistive devices into the standard Military Equipment Set.

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# Table of Contents



**List of Figures**

## Table of Contents (Continued)

Page

**List of Figures (Continued)**

**Table of Contents (Continued)**

**Page**

**List of Figures (Continued)**



**List of Tables**

**Table of Contents (Continued)**

Page

**List of Tables (Continued)**

## Introduction

During the Civil War, it was determined that there was not a clear and organized system to quickly remove injured Service Members (SMs) from the battlefield; this awareness led to the development of an organized casualty evacuation process including designating litter bearers within the medical corps for casualty transport. The patient litter has since served as an essential combat casualty care device in the United States military (Reilly, 2016). Litter transport is a standard procedure for initial casualty evacuation from the point of injury to the medical aid or evacuationzone and is generally done on foot. The litter transport process consists of either a two-person or four-person team carrying a casualty during two common scenarios: Carrying a single casualty over a long distance or repeatedly carrying multiple casualties over a short distance (Rice et al., 1996a; Rice et al., 1996b).

While there have been improvements in transporting casualties from the battlefield, it is estimated that 87% of the combat casualties who died during the Afghanistan and Iraq conflicts did so prior to or during transportation to a higher acuity of care (Eastridge et al., 2012; Kotwal et al., 2018). Additionally, 24% of those fatalities may have survived if they were evacuated from the battlefield more quickly (Kotwal et al., 2018). Factors in transport that can negatively affect the quality of combat casualty care and increase the time needed for the transport phase include the security of the casualty and litter bearers, environmental factors (e.g., temperature and terrain), initiation of care, level of care needed en route, and the distance traveled. These factors have a pronounced effect on the comfort and survivability of injured SMs; however, the battle readiness level of the litter bearers during or after litter transport is often overlooked.

Similar to transporting standard military loads, such as weapons and equipment, transporting patients using a litter can be physically demanding for SMs. A military litter occupied by an average sized casualty with medical equipment weighs between 215 and 255 pounds (lb), resulting in the litter bearer carrying between 54 and 64 lb in a four-Soldier litter team (Department of the Army [DA], 2022). This weight can vary based on the anthropometry of the casualty and equipment carried. Additionally, previous research has shown the force on each litter handle oscillates by approximately 11 lb (50 Newtons [N]) during gait (Leyk et al., 2006). Commonly experienced post-carry symptoms include shortness of breath, rapid heartbeat, dry mouth, hand trembling, hand/arm/shoulder aches, backaches, and muscle tightness or stiffness (Rice et al., 1996a). Immediately following litter carry, SMs have been found to experience reductions in shooting accuracy and hand-grip force (Tharion et al., 1993; Rice et al., 1996a; Rice et al., 1996b; Leyk et al., 2006). During an evacuation, the litter bearers may be required to provide critical care to casualties while actively engaging in combat to protect themselves and the casualty, which creates another level of risk if the team member's shooting accuracy and grip strength are reduced. Such detriments can impede an SM's ability to provide the necessary care to a casualty during prolonged field care situations. Additionally, musculoskeletal disorders can develop over time due to frequent, repetitive, or extended litter transport scenarios; the onset and severity of such disorders, injuries, or diseases negatively impact the retention of SMs (Wilson, 2006). In anticipation of a future fight with near-peer adversaries, improving the physical abilities of SMs and limiting impediments are high priorities.

To mitigate the physical impact of litter transport, the current U.S. Army Techniques Publication *Medical Evacuation* (DA, 2019) recommends frequent resting by using secure, covered evacuation routes, a shuttle system to reduce the transport distance for each team, and alternating litter bearing team members to reduce fatigue. Furthermore, the guidance states the need for close coordination between Role 2 medical treatment facilities and battalion aid stations to establish casualty collection and ambulance exchange points in areas where rough terrain prohibits air or ground medical evacuation. This coordination is to reduce the distance traveled and evacuation time as well as conserve personnel. Even when these recommendations, made within *Medical Evacuation*, are applied, they may not be enough to help alleviate the eventual muscular fatigue incurred during litter transport, especially during the long-distance remote and mass casualty transport evacuations, which are anticipated in future multi-domain operations (MDO) and large-scale combat operations (LSCO).

An alternative approach to reduce the risk of litter bearer fatigue is to develop technology to reduce the physical demands on the litter bearer. Using an assistive device (e.g., shoulder harness, wrist hooks, exoskeleton) can shift the litter load from the hands and forearms to larger muscle groups in the body, decreasing the grip force needed by each individual litter bearer during litter transport. One study showed that carrying 30 kilograms (kg) (66 lb or 294 N) in each hand (60 kg total) produced lower spinal compression than carrying 30 kg in one hand only (McGill et al., 2013). Similarly, it would be expected that distributing the weight more centrally with a harness, especially in a four-person team, could benefit the litter bearer. Introducing such devices to the litter transport process could decrease fatigue and increase the litter bearer's ability to provide critical care and complete SM tasks. An assistive device has the potential to not only improve combat performance following a litter carry, but also reduce the evacuation times of injured SMs. However, there are no assistive devices integrated into the standard U.S. Army military equipment set or litter transport procedures, and there are no standards for evaluating the efficacy of any assistive device to be considered.

Shoulder harness assistive devices are designed to provide more ergonomic transport scenarios via upper body and arm weight distribution. The use of a shoulder harness during transport has been previously shown to increase fine-motor performance, lower subjective ratings of adverse physical symptoms, and increase the time to fatigue in same-sex litter carry teams as compared to unassisted litter transport (Rice et al., 1999). Additionally, Rice et al. (1999) showed that SMs could transport patients on litters for a longer duration when a shoulder harness was used. Harness use has also been shown to improve shooting accuracy after litter transport compared to not using a harness (Tharion et al., 1993). Some of these commercial off-the-shelf (COTS) devices, such as the Sherpa Shoulder Harness (Traverse Rescue, Mississauga, Ontario) have been designed for civilian medical rescue scenarios and could potentially be beneficial for use in military litter casualty transport in LSCO and MDO scenarios, but have not been integrated into the standard Military Equipment Set or litter transport procedures.

Another potential type of assistive device is wrist hooks. Wrist hooks are used during heavy weightlifting exercises to train large muscle groups without being limited by an individual's grip strength. In addition to being adjustable to accommodate varying wrist sizes, these devices allow wearers to have a continued grip on the weight even if the hand grip fails. Use of these wrist hooks may be beneficial during litter transport in LSCO and MDO scenarios by redistributing the weight of the litter to the upper arms and shoulders without requiring large amounts of grip strength, potentially reducing hand fatigue while allowing the ability to carry more weight or longer distances. Two examples of wrist hooks devices are Harbinger Lifting Hooks (Rogue, Columbus, OH) and DMoose Weight Lifting Hooks (Dmoose, Buffalo, WY). The Harbinger Lifting Hooks are a dual-hook design with a hook on either side of the hand meant to wrap around a weight-lifting bar while still allowing the user's fingers and palms to obtain a hold on the bar. The Dmoose Weight Lifting Hooks are a single-hook design with a hook the approximate width of the user's palm meant to sit between the user's fingers and a weight-lifting bar. The Dmoose Weight Lifting Hooks were chosen for this study due to there being less opportunity for pinch points as deemed by the research team. However, such devices were not previously tested for litter transport procedures.

Another assistive device to be considered for use in military litter transport is an exoskeleton (i.e., wearable robots, wearable augmentation devices, or human augmentation systems [Crowell et al., 2018]). These wearable devices are typically developed for rehabilitation, assistive, and augmentation purposes (de la Tejera et al., 2020). Rehabilitation and assistive exoskeletons aid people suffering from chronic or acute disabilities, while augmentation exoskeletons enhance the power output of healthy individuals during heavy load-carrying tasks (Kalita et al., 2021) and are primarily designed for use by SMs or laborers. Although a plethora of exoskeleton research for military applications is being conducted for standard lifting and carrying tasks, exoskeleton research for military patient transport scenarios does not currently exist. Furthermore, a survey of existing exoskeletons by the research team found no existing exoskeleton that was feasible for use and wear by litter bearers during dynamic litter carry. The lack of an adaptable exoskeleton for use in our current effort highlighted the research gaps in the design and development of exoskeleton devices for military litter and patient transport scenarios. To begin to address these research gaps, the research team completed a comprehensive review of the state of exoskeleton research to determine essential preliminary design considerations and provide initial recommendations for exoskeleton technology specifically focused on improving or enhancing dismounted military casualty transport scenarios (Madison et al., 2022).

The litter system has seen several iterations and improvements over the years to make it more durable and tactical, but few improvements have been made to aid the litter bearer. While a few previous studies have examined the benefits of assistive devices to litter bearers in mass and remote litter casualty transport scenarios, none have specifically investigated the contributions of different types of assistive devices (e.g., shoulder harness and wrist hooks) and their effect on individual SM litter bearer performance, particularly grip strength and post-carry fatigue (Rice et al., 1996a; Rice et al., 1996b; Rice et al., 1999; Leyk et al., 2006). The purpose of this study was to evaluate litter bearer performance and post-carry fatigue during simulated prolonged care scenarios with and without a COTS assistive device (i.e., shoulder harness and wrist hooks). Specifically, this study was designed to evaluate whether an assisted two-person litter carry technique has the potential to replace the traditional unassisted four-person litter carry technique.

## Methods

During a Combat Casualty Care Research Program In-Progress Review (CCCRP IPR) at the beginning of this effort, our study team was asked to ensure we evaluated the potential of assistive devices to carry litters in a two-person configuration as compared to the typical unassisted four-person configuration. This request transformed our initial plan for a step-wise comparison between assisted and unassisted four-person carries. The resulting study design was a within-subject comparison between simulated unassisted four-person carries and assisted two-person carries.

U.S. Army Service Members (i.e., Active Duty, Reserve, or National Guard) between 18 and 40 years old were recruited from the Fort Novosel, AL (formerly Fort Rucker, AL) area and consented under a protocol approved through the U.S. Army Medical Research and Development Command Institutional Review Board. Additional inclusion criteria required participants to be physically able with no current profile limiting physical training or wear of personal protective equipment, as well as having finished their most recent Army Physical Fitness Test/Army Combat Fitness Test two-mile run in 15 minutes (min) or less. Individuals were excluded from study participation if they were pregnant (urine test), possessed a pacemaker, had silver or adhesive allergies, were unwilling to have video and photos captured during testing (for research needs; presentation and publication opt out were permitted), used any nonsteroidal anti-inflammatory drug/muscle relaxer/other pain medication outside of a physician prescribed regimen, or were unable to follow verbal and written instructions in English.

Following study enrollment, participants were assigned a unique alphanumerical identifier starting with V followed by three numbers and then randomly assigned to one of two assistive device groups (Table 1) and were familiarized with the test conditions (Table 2) and test procedures (e.g., grip strength, fine motor skills, Engagement Skills Trainer 3000 (EST3000) weapons training system, treadmill litter carry, assistive device use). Before testing, participants were familiarized with the testing procedures and assistive devices. The minimum number of familiarization trials varied per test procedure and participants were given the opportunity to practice until they were comfortable with each assessment. All participants completed a baseline simulated 4-person dominant hand unassisted litter carry followed by a simulated 2-person litter carry using a COTS assistive device, either the shoulder harness or wrist hooks, based on test group assignment on individual days separated by at least 48 hours (hr) (Table 3).

*Table 1.* Participant Grouping

| Group Identifier | Target Number of Participants per Group |
|---|---|
| Shoulder Harness (SH) | 15 |
| Wrist Hooks (WH) | 15 |

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*Table 2.* Test Conditions

| Test Condition | Simulated Litter Carry Team Size | Carry Mechanism |
|---|---|---|
| Baseline Unassisted (U) | 4-Person (4) | Unassisted, Dominant Hand (SH-U4)<br>Unassisted, Dominant Hand (WH-U4) |
| Assistive Device (A) | 2-Person (2) | Assisted, Both Hands (SH-A2)<br>Assisted, Both Hands (WH-A2) |

*Table 3.* Sample Test Schedule

| Day 0 | Test Day 1 | Rest Period | Test Day 2 |
|---|---|---|---|
| • Screening<br>• Consent<br>• Enrollment<br>• Anthropometry<br>• Demographics<br>• Familiarization | 4-Person Unassisted Baseline (U4) | At Least 48 Hours | Assisted 2-Person Condition<br><br>• Shoulder Harness (SH-A2)<br>OR<br>• Wrist Hooks (WH-A2) |

**Assistive Device Test Conditions**

After being assigned to a group (Shoulder Harness [SH] or Wrist Hooks [WH]) on Day 0, participants learned more about the assistive device and its adjustable fit capabilities, as well as how the device should be used during the simulated litter carry sequence. No assistive device was worn during the unassisted baseline (U4) testing on Test Day 1. Participants assigned to the SH group completed the simulated 2-person carry (SH-A2) while wearing the Sherpa Shoulder Harness (Traverse Rescue, Mississauga, Ontario; Figure 1A) on Test Day 2. Participants assigned to the WH group completed the simulated 2-person carry (WH-A2) while wearing the DMoose Weight Lifting Hooks (DMoose, Buffalo, WY; Figure 1B) on Test Day 2.

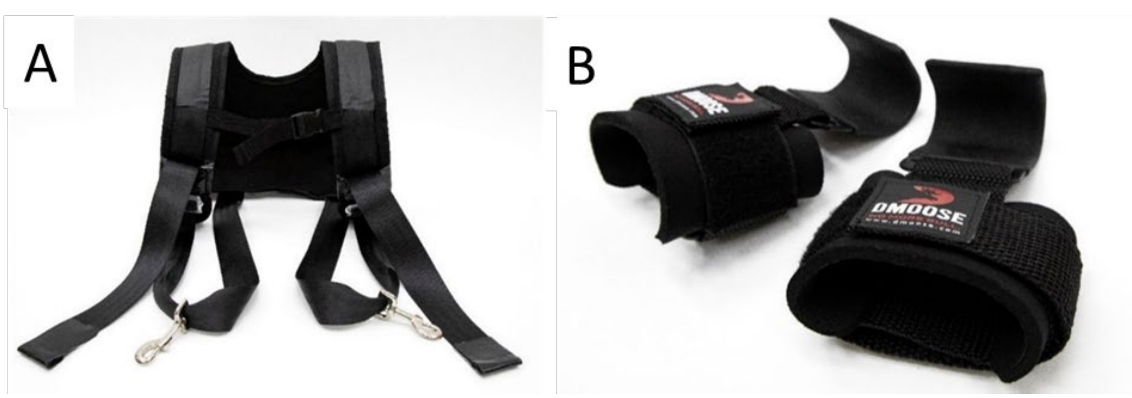


*Figure 1.* Two types of COTS assistive devices were assessed during the 2-person test condition: (A) Sherpa shoulder harness (Traverse Rescue, Mississauga, Ontario) and (B) Weight Lifting Hooks (DMoose, Buffalo, WY).

## Simulated Litter Carry Procedures

All litter carrying procedures were conducted on an Advanced Mechanical Technology Inc (AMTI) Force-Sensing Tandem Treadmill (AMTI, Watertown, MA) configured to simulate 2- and 4-person litter carriage transport techniques in the rear litter bearer position as outlined in Army Techniques Publication 4-02.13 (DA, 2021; Figure 2). The test setups in Figure 2 simulate the typical field litter carriage scenarios shown in Figure 3. A half-sized litter was created from a standard patient litter used by U.S. Army combat medics worldwide (national stock number [NSN] Co6530-01-380-7309 Litter, Folding, Rigid, Pole, Decontaminable). The half-sized litter was weighed with a 140 lb simulated casualty (for a total carry weight of 150 lb). Four safety support straps, one per handle, were used during litter carries. For realistic litter movement and loading, these straps were also used to support a proportion of the load to create the 4- or 2-person simulated carry. Slack in the straps on the handles used by the participants provided no offset of loading. Each rear litter handle required between 30 and 40 lb to lift and carry. Based on the feedback and input of military medical casualty transport subject matter experts, participants attempted five 1 kilometer (km) (0.6 miles) litter carries at 5.6 km per hour (3.5 miles per hour [mph]) (approximately 10 min per carry attempt) for each test condition. Previous research has shown a treadmill incline of 1% simulates the energy expenditure of level-ground walking/running (Jones & Doust, 1996). A treadmill incline of 2% was used in this study to simulate litter carry over moderate terrain. Each carry attempt was concluded when the participant released the litter or reached 1 km. For each attempt, carry time was recorded and distance was calculated.

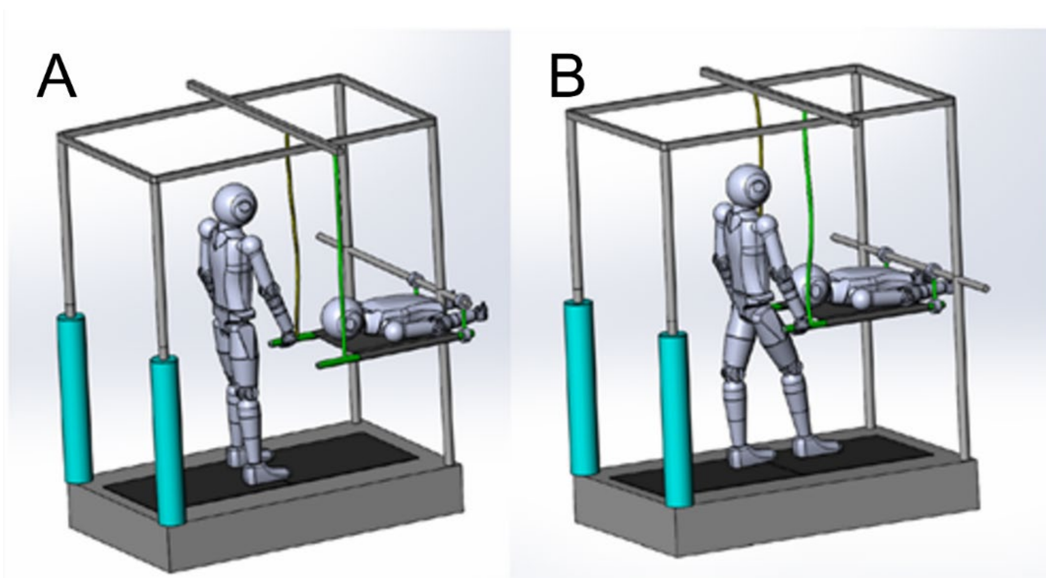


*Figure 2.* An AMTI Force-Sensing Tandem Treadmill (Advanced Mechanical Technology Inc., Watertown, MA) with speed set to 3.5 mph and incline set to 2% was used with a weighted half-sized litter to simulate (A) 4-person unassisted dominant hand (baseline) and (B) 2-person assisted litter transport scenarios. Green straps are support bungees to allow realistic litter movement. Teal covers around bars are pads for participant safety considerations.


*Figure 3.* Litter evacuations involving (A) four-person (Limon, 2018) or (B) two-person teams (Volkman, 2022) are used to transport patients as outlined in Army Techniques Publication 4-02.13 (DA, 2021).

**Participant Instrumentation**

All participants wore sleeveless compression shirts to minimize the occurrence of sensor movement and interference along with their personal Army Regulation (AR) 670-1 pants and boots. Motion capture markers were placed at specific anatomical landmarks, the first and twelfth thoracic vertebrae (T1 and T12), sacrum, manubrium, nose, and bilaterally on the tragion notches and acromion processes, to collect kinematic data during the simulated transport conditions (Figure 4). Markers were adhered to the skin using double-sided tape or cloth tape and reinforced with clear-adhesive dressing in non-facial regions. Motion capture data were collected via Vicon (Vicon, Oxford, United Kingdom), a motion capture camera system that creates data derived from the movement of precisely placed retro-reflective markers. An initial capture was conducted 20 seconds (s) after the beginning of each litter carry attempt. Subsequent captures were conducted every 60 seconds during litter carry attempts, for the duration of each dynamometer grip assessment, and for the duration of each tapping fine motor skills assessment. All captures during litter carry attempts had a duration of 5 seconds.

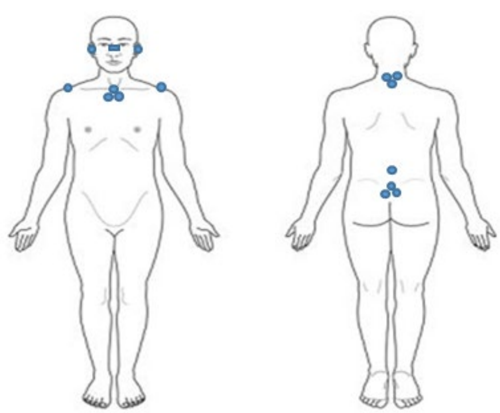

*Figure 4.* Motion capture markers (singular or cluster) were placed at T1, T12, sacrum, manubrium, nose, tragion notches, and acromion processes to collect kinematic data throughout the litter carry attempts.

**Assessments**

Anthropometric and demographic data were collected following participant enrollment. On each test day before baseline assessments, participants completed 10 repetitions each of dynamic stretching exercises (e.g., wrist circles, arm swings, torso rotations) and light resistance warm-up exercises (e.g., goblet squat). Participant baseline grip strength, fine motor skills, marksmanship, and subjective questions were collected prior to attempting five one-kilometer litter carries. Grip strength, fine motor skills, and subjective questions were assessed between each litter carry attempt, while marksmanship assessments were conducted during baseline testing and post-litter carry testing. At the end of the test day, participants repeated the dynamic stretching exercises and completed a set of subjective measures including User Acceptance.

**Anthropometric and demographic.**

Participant anthropometry (height, weight, arm length, leg length, shoulder breadth, hip breadth) were measured and recorded in accordance with Gordon et al. (2014). Participants self-reported their military occupational specialty (MOS), years in service, number of deployments, and age.

**Grip Strength.**

Participants' grip strength was assessed using the BTE PrimusRS dynamometer (BTE Technologies, Hanover, MD) with grip strength attachment (Figure 5). The tool was positioned horizontally, and the width was set closest to the participants carrying conditions. Participants practiced grip strength assessments on Day 0 for technique familiarization. During the Baseline assessment on Test Days 1 and 2, participants completed three 4-second voluntary contractions progressing through approximate 50%, 75%, and 100% Maximum Voluntary Contraction (MVC) efforts. After each carrying attempt, participants completed one 4-second 100% MVC effort.

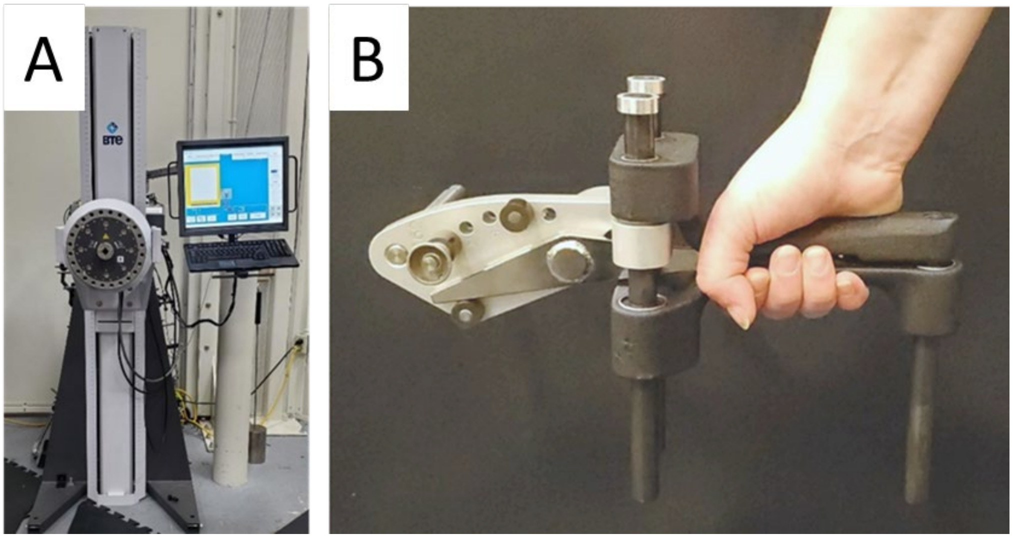


*Figure 5.* The (A) BTE PrimusRS dynamometer (BTE Technologies, Hanover, MD) with (B) grip strength attachment (Tool #162) was used to conduct isometric grip strength assessments.

**Fine motor skills.**

Participants completed four fine motor skill tasks (steadiness, line tracing, aiming, and tapping) using the Vienna Test System MLS Work Panel (Lafayette Instrument Company, Lafayette, IN; Figure 6) during Baseline and each Post-Carry attempt assessment. Participants were familiarized with the fine motor skills assessment procedures on Day 0 by completing each of the tasks at least three times.

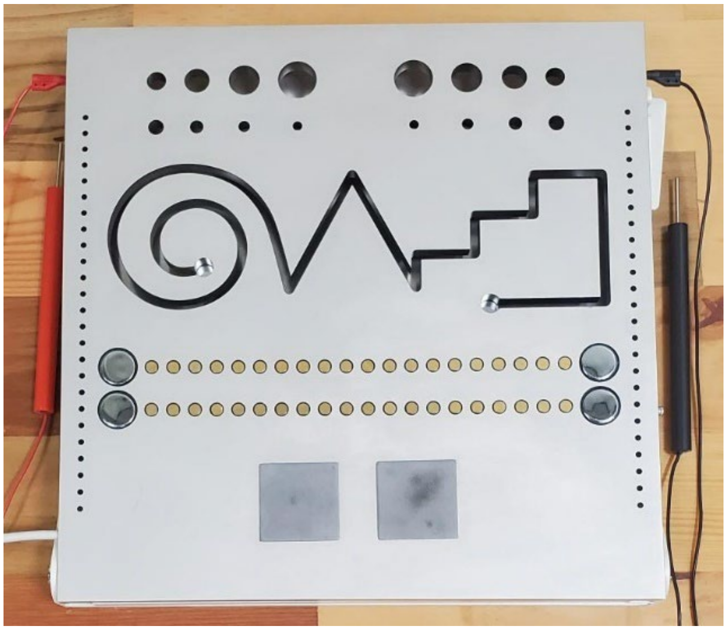

*Figure 6.* The MLS Work Panel (Lafayette Instrument Company, Lafayette, IN) was used to conduct the fine motor skills assessment.

The four fine motor skill tasks are as follows:

1. Steadiness - Participants attempted to hold a pen inside the second smallest (5.8 millimeter [mm] diameter) hole without touching the sides for 32 seconds (Figure 7A). The number of errors and total time of errors were collected and recorded.
2. Line Tracing - Participants attempted to hold a pen inside the line while tracing from one side to the other (direction dependent on dominant hand) without touching the sides (Figure 7B). The time to complete the task, total number of errors, and time of errors were collected and recorded.
3. Aiming - Participants attempted to tap 20 pins from one side to the other (direction dependent on dominant hand) (Figure 7C). The time to complete the task, total number of hits, total number of errors, and time of errors were collected and recorded.
4. Tapping - Participants attempted to tap the work panel with the pen as many times as possible in 32 seconds (Figure 7D). The total number of taps was collected and recorded.

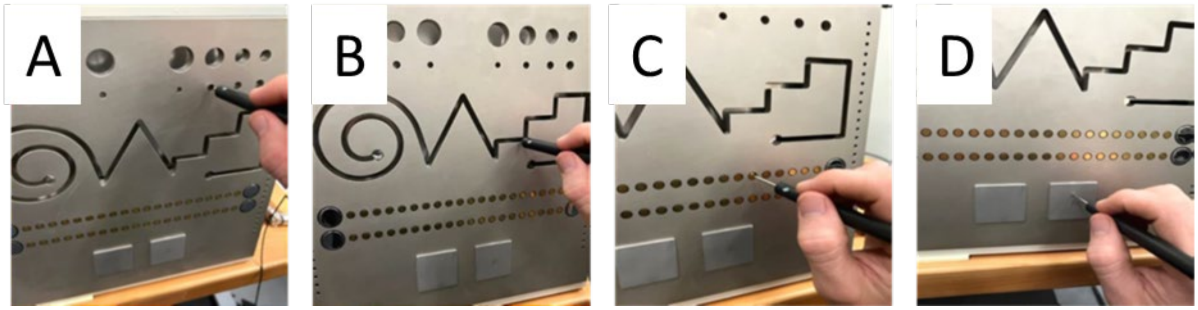


*Figure 7.* Demonstrations of right hand fine motor skill assessments using the MLS Work Panel: (A) steadiness, (B) line tracing, (C) aiming, and (D) tapping.

**Marksmanship.**

Participants completed marksmanship assessments using an Engagement Skills Trainer (EST) 3000 (Cubic Global Defense, Orlando, FL; Figure 8). Marksmanship assessments were conducted prior to initiating testing with each litter carriage condition (Baseline) and after the fifth litter carry attempt (Post-Carry). Participants fired 40 rounds using a simulated pneumatic M4 rifle with iron-sights at 40 targets with distances ranging from 50 to 300 meters. Participants fired at 20 targets in a prone supported position, 10 targets in a prone unsupported position, and 10 targets in a kneeling position. Participants completed each of the shooting positions on Day 0 for technique familiarization and to ensure required preliminary measurements were collected for test day assessments on Test Days 1 and 2. Marksmanship testing in each position was repeated after completing the fifth round of litter carry testing on Test Days 1 and 2. The total number of targets hit, missed, or not fired upon was recorded for each assessment.

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*Figure 8.* The EST 3000 (Cubic Global Defense, Orlando, FL) marksmanship assessment was completed in prone supported, prone unsupported, as well as kneeling (shown) positions before starting each simulated litter carry test condition (Baseline) and after completing the fifth round of testing (Post-Carry) with each simulated litter carry test conditions.

**Subjective questions.**

Participants reported their rating of perceived exertion (RPE) on a scale of 6 to 20, level of fatigue on a scale of 0 to 10, and level of discomfort on a scale of 0 to 10 at baseline and after each litter carry attempt (Borg, 1998). User acceptance on a scale of 0 to 10 was only reported at the end of each test day (Figure 9). All questions were reviewed with participants on Day 0 to provide assessment understanding and familiarization prior to the litter carry assessments. On Test Days 1 and 2, subjective questions were asked before carry attempts (Baseline), immediately after each carry attempt, and after conducting post-carry assessments.

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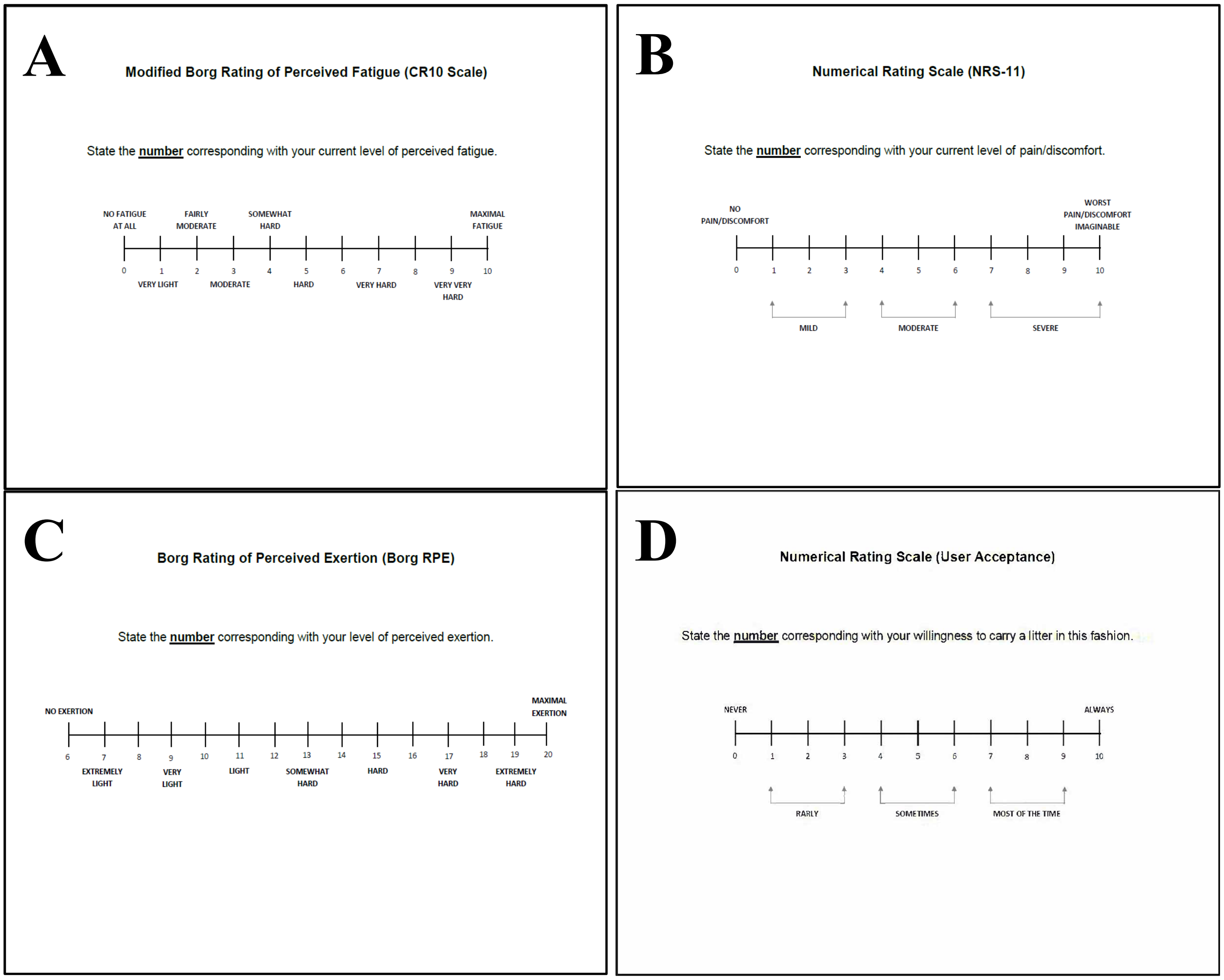


*Figure 9*. The subjective assessments were conducted to get participant feedback regarding levels of: (A) Fatigue, (B) Discomfort, and (C) Rate of Perceived Exertion after each litter carry attempt, and (D) User Acceptance at the end of each test day.

## Analysis

For each response variable, the time series and discrete response data for all participants within a group (SH or WH) were reviewed for quality and outliers. Sub-sets of interest from each activity with time series response data were identified for further analysis. For each variable, metric, and period of interest, the data within a group (SH or WH) for each condition (U4 or A2) were compiled and basic descriptive statistics, including ranges, means, medians, standard deviations, and minimum and maximum values, were calculated. Data collected from the grip strength assessments and motion capture camera system required additional preparation to develop the resulting variables and metrics of interest. These data and basic statistics were then used for more advanced analysis depending on variable or metric of interest. No statistical analyses were conducted to compare responses between assistive devices (SH-A2 versus WH-A2) as this was not within the scope of the study design.

**Grip strength.**

An example of a typical grip strength data trace is shown in Figure 10. The data trace is comprised of several segments; the grip strength data relevant to this study are shown in Segment C.

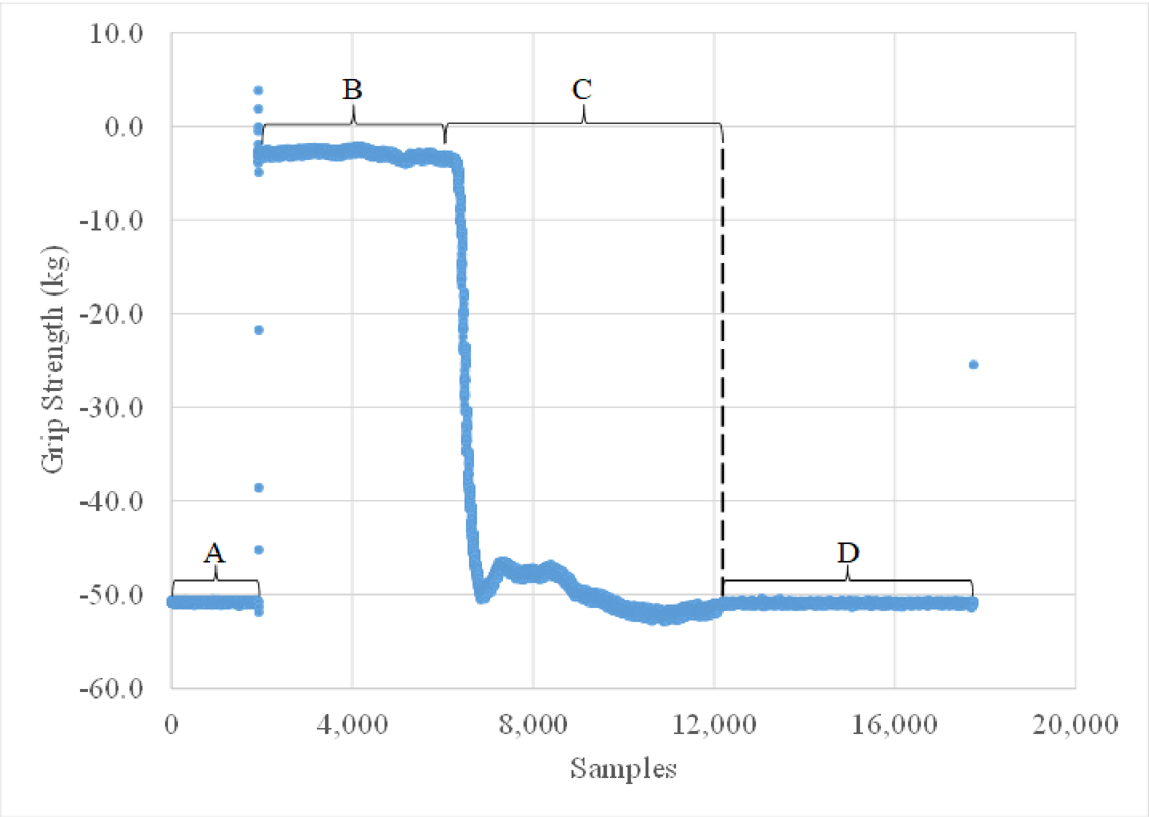


*Figure 10.* Grip strength datasets were comprised of multiple segments. Segment A represents the dynamometer signal in an unarmed mode (i.e., dynamometer not prepped for strength assessment). Segment B represents the armed baseline mode, ready to begin the strength assessment. Segment C represents the actual grip strength data collection event; Segment C was initiated when the dynamometer detected a change from the armed baseline and lasted for 4 seconds. In this example, Segment C starts at approximately sample 6000 and lasts to approximately sample 12,000, indicating a sample rate of 1500 samples per second. After the 4-second grip strength data collection event, the dynamometer returned to its unarmed mode (Segment D).

To calculate overall grip strength, a two-step process was used. First, an average armed baseline was calculated for each trial using the first 150 points in Segment B. This was done because, as shown in Figure 10, the armed baseline (Segment B) was typically offset from 0.0 kg. Next, the average sustained grip strength was calculated based on the last 2050 points in Segment C (Figure 10); the end of Segment C was typically indicated by a “knee” in the grip strength data that occurred immediately before the dynamometer returned to its unarmed value (i.e., the start of Segment D). Finally, overall grip strength was calculated by subtracting the average armed baseline from the average sustained grip strength.

A custom Matlab (The Mathworks, Natick, MA) code was written to facilitate calculating a subject's grip strength for each trial. The Matlab code plotted the grip strength data in a figure similar to Figure 10. The code allowed the study team members to visually identify and select the point at the beginning of Segment B; the index of this data point was determined, as was the index of a 100-data point section beginning 50 points after the selected beginning of Segment B. The average armed baseline was then calculated using these 100 data points within Segment B. The Matlab code was then used to visually identify and select the final point within Segment C. The index of this data point was identified, as was the index of a 2000-data point section ending 50 points prior to the selected end of Segment C. The average sustained grip strength was calculated based on these 2000 data points within Segment C. The data sections used for calculations were separated from the selected start and end of Segments B and C, respectively, to avoid potential effects from data signal "knees" on calculated values. After calculating the overall grip strength based on these two values, the code plotted the data for the next trial, and the process was repeated for all available grip strength data traces.

Technical difficulties in data collection resulted in some additional processing for three of the 120 collected grip strength assessments. For two of the strength assessment trials, the participant began the strength assessment portion immediately after the dynamometer was armed causing there to be an insufficient number of samples for the armed baseline calculation. The selected initial value for Segment B was used for these trials as opposed to a calculated average armed baseline for other trials. Additionally, one participant started exerting force for the strength assessment immediately before the dynamometer was armed, causing a complete lack of Segment B in the signal for baseline calculation. For this trial, the average of the calculated offset values from the participant's other assessments on the same testing day was used in their grip strength calculation.

**Motion capture.**

Positional data from marker clusters placed at participants' T1 vertebra and sacrum were used to determine torso angles in the anterior-posterior (A-P) plane and lateral plane. Each cluster consisted of three markers. Marker positions were averaged for each cluster to acquire a singular positional signal. The torso A-P and lateral angles were then calculated for every capture during the litter carry attempts (Figures 11 and 12, respectively). The *x*-, *y*-, and *z*-directions were respectively aligned with the carry direction, participant's lateral direction, and the vertical direction. The mean A-P and lateral angles were computed from the first and final motion capture collections for each carry attempt. As participants carried either for 1 km or until fatigued for each carry attempt, these angles were considered to represent the postural degradation as a result of fatigue. A lesser A-P angle and a lesser lateral angle indicated a high level of posture retention. Lateral angles are presented in Figures 12 as absolute values to indicate the magnitude of deviation from a neutral posture.

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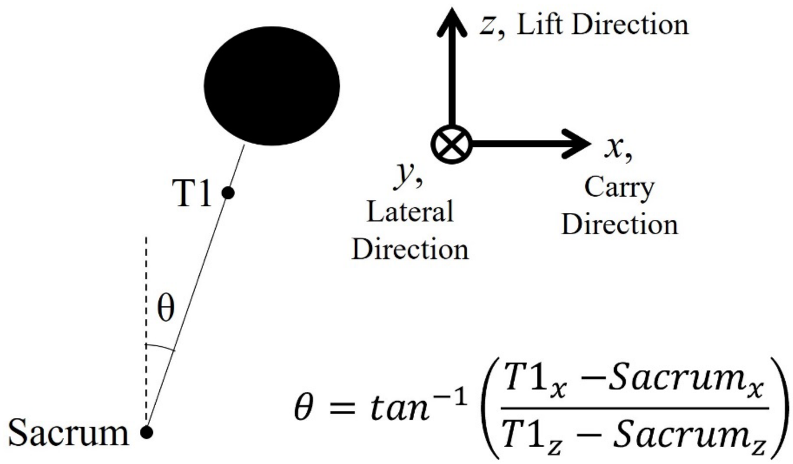


*Figure 11.* Kinematic data from motion capture markers placed at the T1 vertebra and sacrum were used to calculate the angle between the torso and vertical in the anterior-posterior (A-P) plane. The kinematic data were collected incrementally throughout each litter carry attempt.

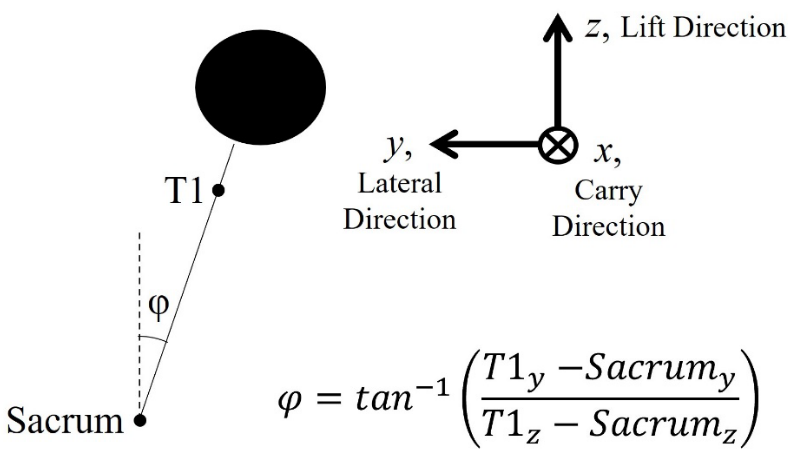


*Figure 12.* Kinematic data from motion capture markers placed at the T1 vertebra and sacrum were used to calculate the angle between the torso and vertical in the lateral plane. The kinematic data were collected incrementally throughout each litter carry attempt.

**Statistical Analysis**

After data or summary metrics were compiled by Group and Carry Condition (SH-U4, SH-A2, WH-U4, WH-A2) as applicable, descriptive statistics, including ranges, means, medians, standard deviations, and minimum and maximum values, were calculated for all variables. Statistical analysis methods were used on all participant responses of interest (dependent variables) and only differed depending on the test procedure assessment or calculated metric being assessed. Post-hoc analyses were then conducted, as appropriate.

By study design, SH and WH Groups were assessed separately in all statistical tests comparing U4 and A2 Carry Conditions, but the statistical analysis methods were the same for each Group. The only between-Group comparisons were completed to assess the between-subjects difference (by comparing subject performance) in unassisted conditions (SH-U4, WH-U4) where a two-way analysis of variance (ANOVA) (or three-way, as appropriate) was used with a Tukey post-hoc for any significant independent variables or interaction of the independent variables.

For all comparisons between Carry Conditions U4 and A2, paired *t*-tests (two- and one-tailed) and repeated measures ANOVAs (two- and three-way, as appropriate) were conducted to determine statistical significance of all data. For any missing data (due to a technical difficulty or test setup error), all data for that subject were removed from analysis for that particular assessment. Paired *t*-tests assessed, at a minimum, the conditions after the first one-kilometer carry attempt (Carry Attempt 1) and after all five carry attempts (Carry Attempts 1 through 5), in addition to a pre-testing condition, as data allowed. Paired *t*-tests were conducted in sequence for a data set (two-tailed for difference and follow-up one-tailed to determine if the difference was an increase or a decrease) for dependent variables. The repeated measures ANOVAs were assessed for all test conditions available for the data. Post-hoc analyses, such as simple main effect and pairwise *t*-tests at every level with the Bonferroni correction, were evaluated for significant independent variables or interactions of independent variables.

An alpha of $p \leq 0.05$ was considered statistically significant for all statistical analyses. Statistical analyses were implemented using R (v 4.2.1) with RStudio (v 1.4.1743, [R Foundation, Ames, IA]). Specific statistical assessments (test, independent and dependent variables, and comparisons) and variations are described in the text and Tables 4 through 6.

**Anthropometry and demographics.**

Anthropometrics and Demographics consisted of seven continuous variables and two self-reported categorical variables. Correlation analysis was conducted for the continuous variables to assess if they were correlated to each other. Subjects in the SH Group were compared for differences to the WH Group for the continuous variables with a Student's *t*-test. The categorical variables were assessed using a Chi-Square Test of Independence.

**Carry distance and time.**

Using the above described general statistical analysis methodology, Carry Distance and Time were assessed after each carry attempt. In addition, Carry Distance and Time Totals were assessed with a paired *t*-test. These variables were the accumulation of time or distance, respectively, from each individual carry attempt. Two-way repeated measures ANOVA were conducted for conditions (independent variables) of Carry Condition and Carry Attempt, with Carry Time (or Distance) as the dependent variable for which the difference was assessed: Is there a significant difference in Carry Time (or Distance) when Conditions of the independent variables are changed? Table 6 summaries this methodology, which results in a total of 10 unique cells within the ANOVA matrix covering all combinations of test conditions (Carry Condition has two levels, unassisted and assisted; and Carry Attempt has five levels, one for each attempt).

#### Grip strength.

Grip Strength was assessed using the same general statistical analysis methodology. In addition to the dependent response variables after each Carry Attempt, a Baseline Grip Strength was measured each test day prior to any carry attempt. These Baseline data were included in all statistical assessments (Tables 4 through 6).

#### Marksmanship.

Because marksmanship was only assessed twice each test day, the dependent response variable was Targets Hit with two levels: Baseline (before any carry attempts were conducted on a test day) and Post-Carry (after all carry attempts were completed on a test day). The general statistical analysis methologdies for two-way ANOVAs and repeated measures ANOVA (with respective post-hoc analyses) were used to analyze all marksmanship response data (Tables 5 and 6).

#### Subjective questions.

Three Subjective Questions (RPE, Discomfort, Fatigue) were assessed throughout each test day: Baseline (before any carry attempts were conducted on a test day) as well as after each carry attempt. Data were analyzed using the general statistical analysis methodology (Tables 4 through 6). User Acceptance was only assessed at the end of each test day (Post-Carry); therefore, only paired *t*-tests were used to analyze the User Acceptance data (Table 4). Within the Subjective Question assessments, only paired *t*-tests (two-tailed for difference and follow-up one-tailed to determine if the difference was an increase or decrease) were used for User Acceptance with Carry Condition as the independent variable. Carry Condition had two levels, U4 and A2, and was used to group the dependent variables into two groups for pairwise comparison.

#### Fine motor skills.

Using general statistical analysis metholodgy, seven dependent response variables taken from the Fine Motor Skills' four tasks (Steadiness, Line Tracing, Aiming, Tapping) were statistically analyzed (Tables 4 through 6). These variables included values at Baseline (before any carry attempts were conducted on a test day) as well as after each carry attempt. One of the dependent response variables, Steadiness Non-Error Percent Duration, was calculated using the recorded duration of error in the Steadiness task. The other six variables were directly recorded during the testing. The Tapping task was conducted during a set time (32 seconds) with only the number of taps recorded. The analyzed set of Fine Motor Skills dependent response variables provided an action response (hit or error) for each task and an associated duration.

#### Motion capture.

Motion capture occurred throughout both test days; however, only two selected motion capture periods (the first and last during any Carry Attempt) were used to calculate Torso Angles. Three-way ANOVAs (standard and repeated) were conducted for three independent variables: Carry Condition, Carry Attempt, and First/Last motion capture, and two dependent variables (one ANOVA per dependent variable, A-P and Lateral angle means). For the standard

ANOVA (Table 5), Carry Condition had two levels, SH-U4 and WH-U4, while the repeated-measures ANOVA (Table 6) Carry Condition had two levels, unassisted and assisted device (for each SH or WH Group). For the standard and repeated-measures ANOVA, Carry Attempt had five levels (one for each attempt). First/Last motion capture had two levels, first reading and last reading captured during each litter carry attempt. This is a total of 20 unique groups (or cells of the ANOVA matrix) covering all combinations of test conditions. For the standard ANOVA, Tukey post-hocs for any significant independent variables or interactions of the independent variables was used. For the repeated-measures ANOVA, two types of post-hoc analyses were investigated: Simple main effect and simple pairwise comparisons. Simple main effect were one-way ANOVAs for a single independent variable at every level of the other independent variable with a Bonferroni correction. The simple pairwise comparisons were *t*-tests for one independent variable at every level of the other independent variable with the Bonferroni correction.

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*Table 4.* Paired *t*-tests Completed on Assessments

| Assessment | Measurement | Independent (Categorical) | Dependent (Continuous) |
|---|---|---|---|
| Carry Distance/ Time | Carry Distance | Carry Condition (Two Levels: Unassisted and assisted [U4 vs. A2]) | Carry Distance Attempt 1<br>Carry Distance Attempt 5<br>Carry Distance Total |
| | Carry Time | Carry Condition (Two Levels: Unassisted and assisted [U4 vs. A2]) | Carry Time Attempt 1<br>Carry Time Attempt 5<br>Carry Time Total |
| Grip Strength | Grip Strength | Carry Condition (Two Levels: Unassisted and assisted [U4 vs. A2]) | Grip Strength Baseline<br>Grip Strength Attempt 1<br>Grip Strength Attempt 5 |
| Marksmanship | Targets Hit | N/A | N/A |
| Subjective | RPE | Carry Condition (Two Levels: Unassisted and assisted [U4 vs. A2]) | RPE Baseline<br>RPE Attempt 1<br>RPE Attempt 5 |
| | Discomfort | Carry Condition (Two Levels: Unassisted and assisted [U4 vs. A2]) | Discomfort Baseline<br>Discomfort Attempt 1<br>Discomfort Attempt 5 |
| | Fatigue | Carry Condition (Two Levels: Unassisted and assisted [U4 vs. A2]) | Fatigue Baseline<br>Fatigue Attempt 1<br>Fatigue Attempt 5 |
| | User Acceptance | Carry Condition (Two Levels: Unassisted and assisted [U4 vs. A2]) | User Acceptance |

*Note.* Carry Distance/Time Total was the accumulation of time/distance from each individual carry attempt.

*Table 4.* Paired *t*-tests Completed on Assessments (Continued)

| Assessment | Measurement | Independent (Categorical) | Dependent (Continuous) |
|---|---|---|---|
| Fine Motor Skills | Steadiness Errors | Carry Condition<br>(Two Levels: Unassisted and assisted [U4 vs. A2]) | Steadiness Errors Baseline<br>Steadiness Errors Attempt 1<br>Steadiness Errors Attempt 5 |
| | Steadiness Non-Error Percent Duration | Carry Condition<br>(Two Levels: Unassisted and assisted [U4 vs. A2]) | Steadiness Non-Error Percent Duration Baseline<br>Steadiness Non-Error Percent Duration Attempt 1<br>Steadiness Non-Error Percent Duration Attempt 5 |
| | Line Tracing Duration | Carry Condition<br>(Two Levels: Unassisted and assisted [U4 vs. A2]) | Line Tracing Duration Baseline<br>Line Tracing Duration Attempt 1<br>Line Tracing Duration Attempt 5 |
| | Line Tracing Errors | Carry Condition<br>(Two Levels: Unassisted and assisted [U4 vs. A2]) | Line Tracing Errors Baseline<br>Line Tracing Errors Attempt 1<br>Line Tracing Errors Attempt 5 |
| | Aiming Hits | Carry Condition<br>(Two Levels: Unassisted and assisted [U4 vs. A2]) | Aiming Hits Baseline<br>Aiming Hits Attempt 1<br>Aiming Hits Attempt 5 |
| | Aiming Total Duration | Carry Condition<br>(Two Levels: Unassisted and assisted [U4 vs. A2]) | Aiming Total Duration Baseline<br>Aiming Total Duration Attempt 1<br>Aiming Total Duration Attempt 5 |
| | Tapping Hits | Carry Condition<br>(Two Levels: Unassisted and assisted [U4 vs. A2]) | Tapping Hits Baseline<br>Tapping Hits Attempt 1<br>Tapping Hits Attempt 5 |
| Motion Capture | N/A | N/A | N/A |

*Table 5.* ANOVA Tests Completed on Assessments

| Assessment | Measurement | Independent (Categorical) | Dependent (Continuous) |
|---|---|---|---|
| Carry Distance/Time | Carry Distance | Group (Two levels: SH-U4 or WH-U4)<br>Carry Attempt (Five levels: One for each 1 km attempt) | Carry Distance |
| | Carry Time | Group (Two levels: SH-U4 or WH-U4)<br>Carry Attempt (Five levels: One for each 1 km attempt) | Carry Time |
| Grip Strength | Grip Strength | Group (Two levels: SH-U4 or WH-U4)<br>Carry Attempt (Six levels: A Baseline and one after each 1 km attempt) | Grip Strength |
| Marksmanship | Prone Supported Targets Hit | Group (Two levels: SH-U4 or WH-U4)<br>Baseline/Post-Carry (Two levels: A Baseline and one after all five attempts) | Prone Supported Targets Hit |
| | Prone Unsupported Targets Hit | Group (Two levels: SH-U4 or WH-U4)<br>Baseline/Post-Carry (Two levels: A Baseline and one after all five attempts) | Prone Unsupported Targets Hit |
| | Kneeling Targets Hit | Group (Two levels: SH-U4 or WH-U4)<br>Baseline/Post-Carry (Two levels: A Baseline and one after all five attempts) | Kneeling Targets Hit |
| | Total Targets Hit | Group (Two levels: SH-U4 or WH-U4)<br>Baseline/Post-Carry (Two levels: A Baseline and one after all five attempts) | Total Targets Hit |
| Subjective | RPE | Group (Two levels: SH-U4 or WH-U4)<br>Carry Attempt (Six levels: A Baseline and one after each 1 km attempt) | RPE |
| | Discomfort | Group (Two levels: SH-U4 or WH-U4)<br>Carry Attempt (Six levels: A Baseline and one after each 1 km attempt) | Discomfort |
| | Fatigue | Group (Two levels: SH-U4 or WH-U4)<br>Carry Attempt (Six levels: A Baseline and one after each 1 km attempt) | Fatigue |

*Note.* All ANOVAs were two-way with the exception of Motion Capture (three-way).

*Table 5.* ANOVA Tests Completed on Assessments (Continued)

| Assessment | Measurement | Independent (Categorical) | Dependent (Continuous) |
|---|---|---|---|
| Fine Motor Skills | Steadiness Errors | Group (Two levels: SH-U4 or WH-U4)<br>Carry Attempt (Six levels: A Baseline and one after each 1 km attempt) | Steadiness Errors |
| | Steadiness Non-Error Percent Duration | Group (Two levels: SH-U4 or WH-U4)<br>Carry Attempt (Six levels: A Baseline and one after each 1 km attempt) | Steadiness Non-Error Percent Duration |
| | Line Tracing Duration | Group (Two levels: SH-U4 or WH-U4)<br>Carry Attempt (Six levels: A Baseline and one after each 1 km attempt) | Line Tracing Duration |
| | Line Tracing Errors | Group (Two levels: SH-U4 or WH-U4)<br>Carry Attempt (Six levels: A Baseline and one after each 1 km attempt) | Line Tracing Errors |
| | Aiming Hits | Group (Two levels: SH-U4 or WH-U4)<br>Carry Attempt (Six levels: A Baseline and one after each 1 km attempt) | Aiming Hits |
| | Aiming Total Duration | Group (Two levels: SH-U4 or WH-U4)<br>Carry Attempt (Six levels: A Baseline and one after each 1 km attempt) | Aiming Total Duration |
| | Tapping Hits | Group (Two levels: SH-U4 or WH-U4)<br>Carry Attempt (Six levels: A Baseline and one after each 1 km attempt) | Tapping Hits |
| Motion Capture | Torso A-P Angle | Group (Two levels: SH-U4 or WH-U4)<br>Carry Attempt (Five levels: One for each 1 km attempt)<br>First/Last (Two levels: First and Last captures during an attempt) | Torso A-P Angle |
| | Torso Lateral Angle | Group (Two levels: SH-U4 or WH-U4)<br>Carry Attempt (Five levels: One for each 1 km attempt)<br>First/Last (Two levels: First and Last captures during an attempt) | Torso Lateral Angle |

*Note.* All ANOVAs were two-way with the exception of Motion Capture (three-way).

*Table 6*. Repeated Measures Tests Completed on Assessments

| Assessment | Measurement | Independent (Categorical) | Dependent (Continuous) |
|---|---|---|---|
| Carry Distance/ Time | Carry Distance | Carry Condition (Two levels: Unassisted and assisted [U4 vs. A2])<br>Carry Attempt (Five levels: One for each 1 km attempt) | Carry Distance |
| | Carry Time | Carry Condition (Two levels: Unassisted and assisted [U4 vs. A2])<br>Carry Attempt (Five levels: One for each 1 km attempt) | Carry Time |
| Grip Strength | Grip Strength | Carry Condition (Two levels: Unassisted and assisted [U4 vs. A2])<br>Carry Attempt (Six levels: A Baseline and one after each 1 km attempt) | Grip Strength |
| Marksmanship | Prone Supported Targets Hit | Carry Condition (Two levels: Unassisted and assisted [U4 vs. A2])<br>Baseline/Post-Carry (Two levels: A Baseline and one after all five attempts) | Target Hits |
| | Prone Unsupported Targets Hit | Carry Condition (Two levels: Unassisted and assisted [U4 vs. A2])<br>Baseline/Post-Carry (Two levels: A Baseline and one after all five attempts) | Target Hits |
| | Kneeling Targets Hit | Carry Condition (Two levels: Unassisted and assisted [U4 vs. A2])<br>Baseline/Post-Carry (Two levels: A Baseline and one after all five attempts) | Target Hits |
| | Total Targets Hit | Carry Condition (Two levels: Unassisted and assisted [U4 vs. A2])<br>Baseline/Post-Carry (Two levels: A Baseline and one after all five attempts) | Target Hits |
| Subjective | RPE | Carry Condition (Two levels: Unassisted and assisted [U4 vs. A2])<br>Carry Attempt (Six levels: A Baseline and one after each 1 km attempt) | RPE |
| | Discomfort | Carry Condition (Two levels: Unassisted and assisted [U4 vs. A2])<br>Carry Attempt (Six levels: A Baseline and one after each 1 km attempt) | Discomfort |
| | Fatigue | Carry Condition (Two levels: Unassisted and assisted [U4 vs. A2])<br>Carry Attempt (Six levels: A Baseline and one after each 1 km attempt) | Fatigue |

*Note.* Each Group (SH or WH) was tested independently with a repeated measures ANOVA.

*Table 6.* Repeated Measures Tests Completed on Assessments (Continued)

| Assessment | Measurement | Independent (Categorical) | Dependent (Continuous) |
|---|---|---|---|
| Fine Motor Skills | Steadiness Errors | Carry Condition (Two levels: Unassisted and assisted [U4 vs. A2])<br>Carry Attempt (Six levels: A Baseline and one after each 1 km attempt) | Steadiness Errors |
| | Steadiness Non-Error Percent Duration | Carry Condition (Two levels: Unassisted and assisted [U4 vs. A2])<br>Carry Attempt (Six levels: A Baseline and one after each 1 km attempt) | Steadiness Non-Error Percent Duration |
| | Line Tracing Duration | Carry Condition (Two levels: Unassisted and assisted [U4 vs. A2])<br>Carry Attempt (Six levels: A Baseline and one after each 1 km attempt) | Line Tracing Duration |
| | Line Tracing Errors | Carry Condition (Two levels: Unassisted and assisted [U4 vs. A2])<br>Carry Attempt (Six levels: A Baseline and one after each 1 km attempt) | Line Tracing Errors |
| | Aiming Hits | Carry Condition (Two levels: Unassisted and assisted [U4 vs. A2])<br>Carry Attempt (Six levels: A Baseline and one after each 1 km attempt) | Aiming Hits |
| | Aiming Total Duration | Carry Condition (Two levels: Unassisted and assisted [U4 vs. A2])<br>Carry Attempt (Six levels: A Baseline and one after each 1 km attempt) | Aiming Total Duration |
| | Tapping Hits | Carry Condition (Two levels: Unassisted and assisted [U4 vs. A2])<br>Carry Attempt (Six levels: A Baseline and one after each 1 km attempt) | Tapping Hits |
| Motion Capture | Torso A-P Angle | Carry Condition (Two levels: Unassisted and assisted [U4 vs. A2])<br>Carry Attempt (Six levels: A Baseline and one after each 1 km attempt)<br>First/Last (Two levels: First and Last captures during an attempt) | Torso A-P Angle |
| | Torso Lateral Angle | Carry Condition (Two levels: Unassisted and assisted [U4 vs. A2])<br>Carry Attempt (Six levels: A Baseline and one after each 1 km attempt)<br>First/Last (Two levels: First and Last captures during an attempt) | Torso Lateral Angle |

*Note.* Each Group (SH or WH) was tested independently with a repeated measures ANOVA. All ANOVAs were two-way with the exception of Motion Capture (three-way).

## Results

A total of 15 participants (14 male, 1 female) were screened, consented, and enrolled for participation. Data from two participants were incomplete due to study dropout and were excluded from this analysis. Data from the one female participant were excluded from analysis to avoid potential gender effects. Therefore, data from 12 male participants were analyzed and consisted of data from six participants (*n* = 6) in each group. The Shoulder Harness group (SH) data are presented as SH-U4 for an unassisted 4-person simulated carry and SH-A2 for an assisted 2-person simulated carry. Data from the Wrist Hooks group (WH) are presented as WH-U4 and WH-A2, for an unassisted 4-person simulated carry and an assisted 2-person simulated carry, respectively.

### Anthropometry and Demographics

Participant demographics are presented in Table 7. For both SH and WH groups, three paricipants had no deployments; these individuals had 5 years or less experience for SH group and 1 year or less experience for WH group. The MOS of participants are presented in Table 8. Years of service were self reported by volunteers as whole years. For any Soldier with less than one year of service, 0 years was recorded on the data sheet. The large concentration of aviation-based MOSs is reflective of the local Fort Novosel Soldier population.

Although the SH group averages were greater than the WH group in 5 out of the 6 anthropometric measures (Weight, Arm and Leg Length, Hip and Shoulder Breadth) and the SH group on average had more Years of Service in the military, there was no statistically significant difference found between the SH or WH groups for any anthropometric or demographic variable.

*Table 7.* Mean and Standard Deviation of Participant Anthropometry and Demographics

| Group (*n* = 6) | Average Anthropometry | | | | | | Average Demographics | | |
|---|---|---|---|---|---|---|---|---|---|
| | Height (centimeters [cm]) | Weight (kg) | Arm Length (cm) | Leg Length (cm) | Hip Breadth (cm) | Shoulder Breadth (cm) | Age (Years) | Years of Service* | Number of Deployments |
| **Shoulder Harness** | 177.2 (±5.9) | 83.9 (±10.8) | 81.4 (±3.9) | 104.1 (±11.3) | 32.7 (±2.5) | 47.6 (±4.6) | 27.7 (±5.1) | 7.5 (±6.0) | 2.5 (±3.5) |
| **Wrist Hooks** | 177.9 (±7.5) | 77.2 (±16.3) | 79.4 (±4.5) | 103.4 (±3.4) | 31.6 (±2.1) | 45.9 (±3.4) | 28.7 (±6.9) | 5.8 (±6.4) | 1.3 (±1.8) |

*Note.* The * denotes years of service self reported by volunteers as whole years. For any Soldier with less than one year of service, 0 years was recorded on the data sheet.

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*Table 8.* Participant Military Occupational Specialty (MOS)

| Group | Army Aviator<br><br>15A, 153A, 153M/L | Air Traffic Controller Operator<br>15Q | CH-47 Helicopter Repairer<br>15U |
|---|---|---|---|
| **Shoulder Harness (SH)**<br>**(*n* = 6)** | 5 | 1 | 0 |
| **Wrist Hooks (WH)**<br>**(*n* = 6)** | 5 | 0 | 1 |

## Carry Distance and Time

The results for the average litter carry distance for each carry attempt are presented in Figure 13 and Appendix Table A1; corresponding average carry times are presented in Appendix Table A5. Because the treadmill was set to a constant speed, carry distance is basically a multiple of carry time. A full 1000 meters (1 km) at 3.5 mph was completed in 10.8 minutes (or 645 seconds including treadmill startup and stop). In this section, carry distance is discussed as the primary response (dependent variable); however, all trends and statistical findings apply equally to carry time. Descriptive statistics are presented in tabular form in Appendix A for carry distance (Tables A1 through A4) and carry time (Tables A5 through A8) for 4-person simulated carries (SH-U4 and WH-U4) and 2-person simulated carries (WH-A2 and SH-A2).

### Unassisted carry attempts.

On average, carry distance and time for Carry Attempt 1 for SH-U4 was almost 600 meters (591m and 6.4 min) or 200 meters (218 m, 2.3 min) less than the approximate 800 meter carry distance (809 m, 8.7 min) for Carry Attempt 1 for WH-U4. The average carry distances and times for the unassisted SH group showed a reduction between Carry Attempts 1 and 5 of just over 100 meters (113 m, 1.3 min) or 19.2%. The average carry distances and times for the unassisted WH group showed a reduction from Carry Attempt 1 to Carry Attempt 5 of approximately 300 meters (302 m, 3.2 min) or 37.3%. However, no statistical difference was found between the SH and WH Groups (unassisted only) for carry time and distance.

### Assisted carry attempts.

For the SH group, the assisted condition simulating a 2-person carry (SH-A2) resulted in a longer average carry distance and time for each Carry Attempt as compared to the unassisted condition simulating a 4-person carry (SH-U4). The two-way repeated measures ANOVA revealed a statistically significant difference between the unassisted SH-U4 and assisted SH-A2 carry conditions. Post-hoc analysis further revealed the pairwise comparison of carry condition is statistically significant in the Shoulder Harness group for Carry Attempts 2 through 5 (Figure 13 and Table A1).

On average, the carry distance and time of the assisted condition for the SH group (SH-A2) increased by 1.2% from Carry Attempt 1 to Carry Attempt 5 (Figure 13). Paired $t$-tests revealed this increase was statistically significant for Attempt 5 and Total (only Attempts 1 and 5, and Total were examined through paired $t$-tests).

For the WH group, the assisted condition simulating a 2-person carry (WH-A2) resulted in a slightly longer average carry distance and time for each Carry Attempt when compared to the unassisted condition simulating a 4-person carry (WH-U4). On average, WH-A2 showed a similar decrease (31.5%) in average carry distance and time from Carry Attempt 1 to Carry Attempt 5 as the unassisted condition simulated 4-person carry (WH-U4).

For the WH group, the two-way repeated measures ANOVA revealed there was a statistically significant difference in carry distance and carry time for Carry Attempt. If carry condition was ignored for the WH group, carry distance and time for Carry Attempts 3, 4, and 5 were found to be significantly different from Carry Attempt 1. Furthermore, WH-U4 was more affected (as found through post-hoc analysis) by subsequent Carry Attempts than WH-A2.

**Individual performance.**

On average, carry distance and time increased per Carry Attempt for both assisted conditions (SH-A2 and WH-A2) when compared to unassisted conditions (SH-U4 and WH-U4) respectively (Figure 13 and Appendix A). For all individuals in the SH group, Carry Attempt distance and time were maintained or increased when compared to unassisted conditions. For individuals in the WH group, Carry Attempt distance and time were maintained or increased by four of the six participants when compared to unassisted conditions.

During several unassisted Carry Attempts, participants reached the full 1 kilometer carry distance and time: 6 of 30 Carry Attempts during SH-U4 and 8 and of 30 Carry Attempts during WH-U4 (Appendix Tables A3 and A4 for carry distance and Tables A7 and A8 for carry time). For both unassisted conditions, one participant reached the total carry distance of 5 kilometers, resulting in a total carry time of approximately 54 minutes.

In both assistive device test conditions, the number of full 1 kilometer carry attempts completed increased: 24 of 30 Carry Attempts during SH-A2 and 13 of 30 Carry Attempts during WH-A2 (Appendix Tables A3 and A4 for carry distance and Appendix Tables A7 and A8 for carry time). Additionally, the assisted SH condition allowed four of six participants to complete the full 5 kilometers and the assisted WH condition allowed two participants to complete the full 5 kilometers.

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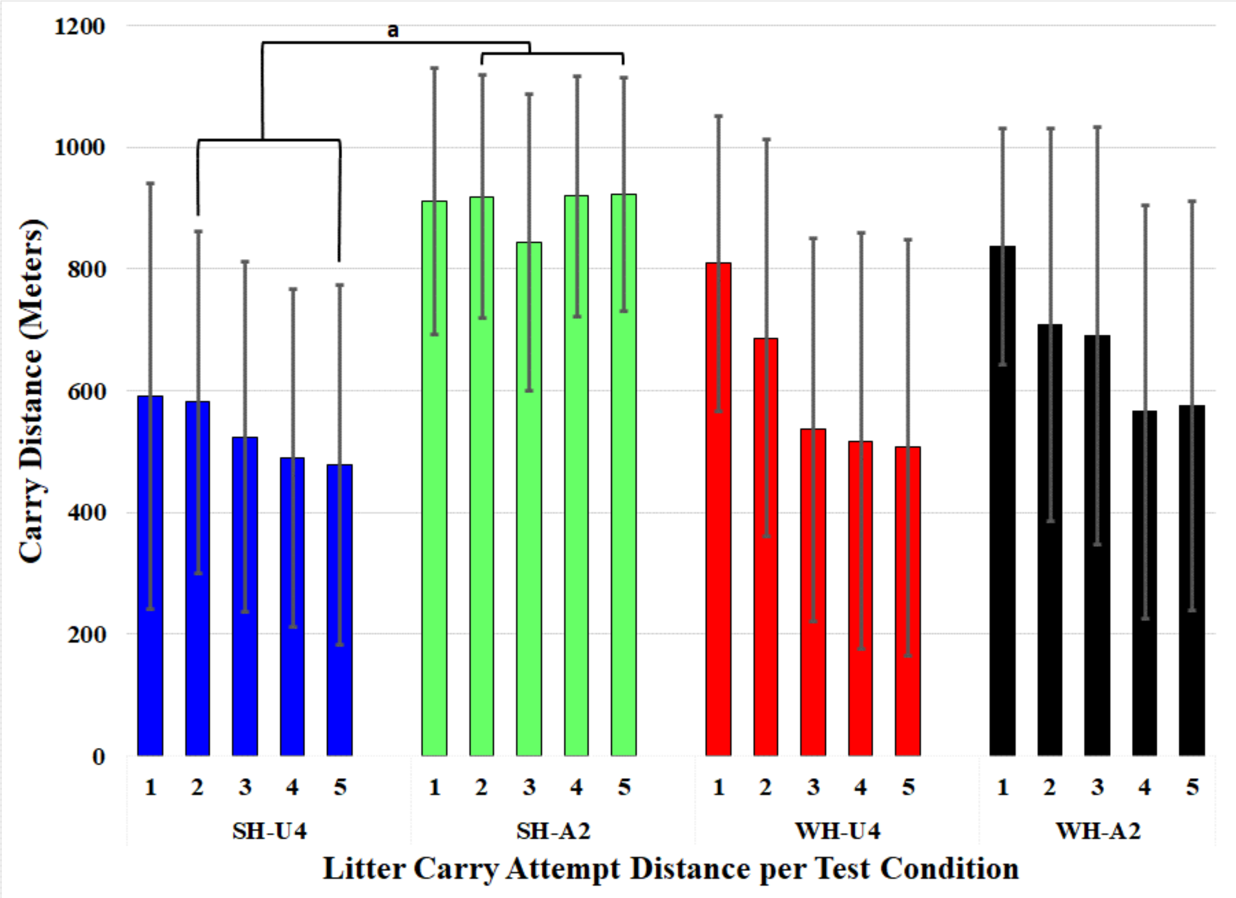


*Figure 13.* Litter carry distance for five one-kilometer attempts for the unassisted shoulder harness (SH-U4) (4-person simulated carry), shoulder harness (SH-A2) (2-person simulated carry), unassisted wrist hooks (WH-U4), and wrist hooks (WH-A2) test conditions. [a] indicates a statistically significant difference between test conditions (SH-U4 and SH-A2) in Carry Attempts 2 through 5 for the Shoulder Harness group.

**Total carry distance/time.**

Both assisted conditions (SH-A2 and WH-A2), on average, increased distance and time for the Total Carry Distance (Figure 14 and Appendix Tables A2, A3, and A4 for distance and Appendix Tables A6, A7, and A8 for time). The mean Total Carry Distance of the Shoulder Harness group was 2662 meters (28.6 min) and 4514 meters (48.5 min) for SH-U4 and SH-A2 conditions, respectively. In the Wrist Hooks group, the Total Carry Distances for WH-U4 and WH-A2 conditions were 3055 meters (32.8 min) and 3375 meters (36.3 min), respectively (Figure 14, Appendix Table A2 and A6). A statistically significant difference (Figure 14) was found between SH-U4 (unassisted 4-person simulated carry) and SH-A2 (assisted 2-person simulated carry) conditions in the Shoulder Harness group for Total Carry Distance and Time.

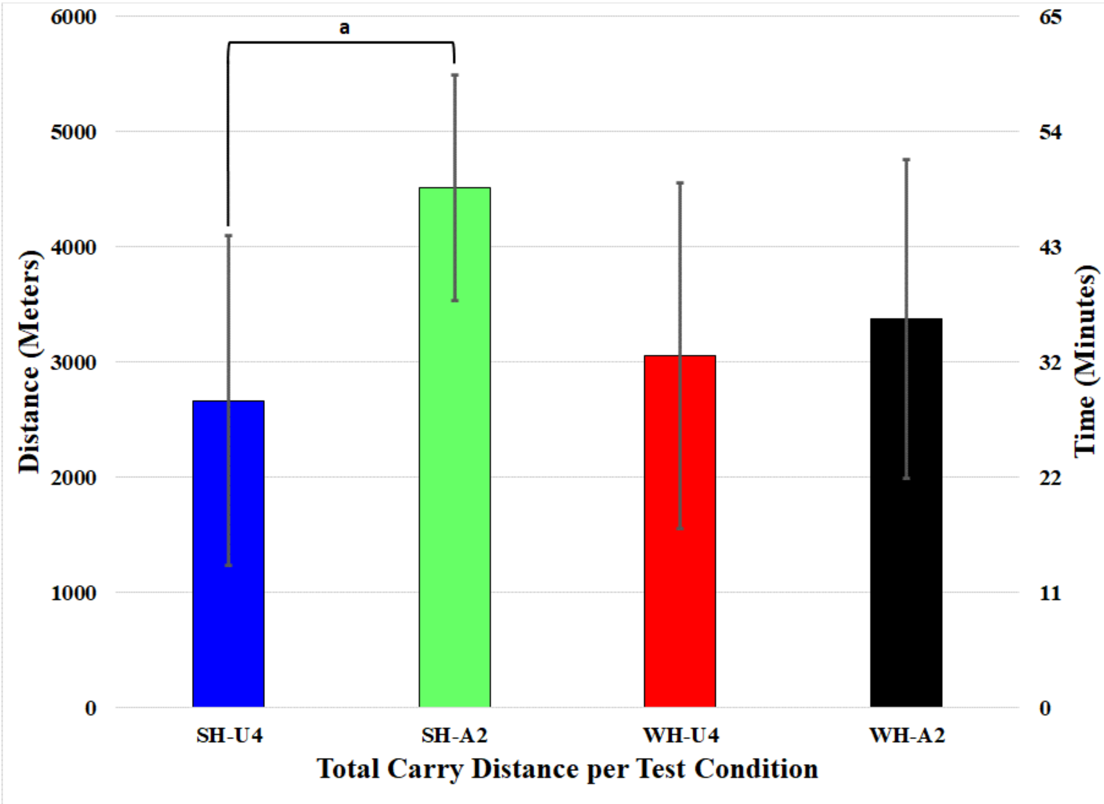


*Figure 14.* Total litter carry distance for the unassisted shoulder harness (SH-U4), shoulder harness (SH-A2), unassisted wrist hooks (WH-U4), and wrist hooks (WH-A2) test conditions. [a] indicates a statistically significant difference between Total Carry Distances for the Shoulder Harness group.

## Grip Strength

Each group included the data from five participants because the data from one participant in each of the groups had to be excluded due to technical issues. The data outcomes for the grip strength assessments are presented in Figure 15 and Appendix B. The average maximum 100% MVC at Baseline for all groups and test conditions was around 45 kg; however, individual Baselines ranged from 34.8 to 56.2 kg for the SH group and 38.9 to 56.7 kg for the WH group. Descriptive statistics are presented in tabular form in Appendix B for group grip strength (Table B1) and individual grip strength (Tables B2 and B3) for 4-person simulated carries (SH-U4 and WH-U4) and 2-person simulated carries (WH-A2 and SH-A2).

### Unassisted carry attempts.

The loss of grip strength due to repeated Carry Attempts (or increasing distance and time) was seen in individuals, averages, and statistical findings for the unassisted condition. For both groups (SH and WH) during unassisted 4-person simulated carry (U4), one participant had measured grip strength of 21 kg after Carry Attempt 5, which was the minimum grip strength measured from any individual. This minimum grip strength was less than half of the average Baseline grip strength of all participants (approximately 45 kg). The impact of repeated Carry

Attempts (or increasing distance and time) on Grip Strength is seen in the decreasing average Grip Strength plotted in Figure 15 for the unassisted conditions (SH-U4 and WH-U4). On average, Grip Strength between Baseline (pre-carry) and Carry Attempt 5 was reduced by 32.5% for the SH-U4 and 37.8% for the WH-U4 litter carries. A two-way ANOVA found Carry Attempt to be statistically significant in Grip Strength for the unassisted conditions (SH-U4 and WH-U4). A Tukey post-hoc test revealed significant pairwise differences between Baseline and all Carry Attempts as well as Carry Attempts 1 and 5. Similarly, the two-way repeated measures ANOVA and subsequent post-hoc analysis found Carry Attempt to be statistically significant for SH-U4 and WH-U4 with pairwise analysis finding statisticially significant differences for SH-U4 between Baseline and Carry Attempt 5 and for WH-U4 between Baseline and Carry Attempts 2, 3, and 5. No other significance was found between or within the grip strength data from the unassisted carry attempts.

**Assisted carry attempts.**

The assisted conditions maintained more grip strength than the unassisted conditions on average and by individual participant. When Grip Strength was compared between unassisted (U4) and assisted (A2) conditions, a statistically significant difference was found: For both groups, the assisted condition resulted in less of a reduction in Grip Strength when compared to the unassisted conditions, or greater grip strength retention. Both the paired two-tail *t*-tests as well as the two-way repeated measures ANOVA with post-hoc analysis revealed a statistically significant difference in grip strength with the paired one-tail *t*-test confirming a statistically significant increase in grip strength after Carry Attempt 5 for both SH group and WH group when assisted and unassisted conditions were compared.

Specifically after Carry Attempt 5, both the average Grip Strength and every participant's individual Grip Strength was greater in the assisted condition when compared to the respective unassisted condition. Figure 15 and Appendix Table B1 show the average Grip Strength after Carry Attempt 5 is 14.5 kg greater for SH-A2 versus SH-U4 and 11.5 kg greater for WH-A2 versus WH-U4.

Every individual participant maintained more Grip Strength after Carry Attempt 5 in the assisted condition; this is seen in the measured grip strength (regardless of Baseline) and the grip strength relative to Baseline (Appendix Tables B2 and B3). When comparing grip strength after Carry Attempt 5 (regardless of Baseline), individuals in SH-A2 had at least 10 kg higher grip strength and individuals in WH-A2 had at least 6 kg higher grip strength than after the unassisted Carry Attempt 5. When comparing relative Grip Strength after Carry Attempt 5 to Baseline for the SH group, individuals in the assisted condition (SH-A2) had no more than an 11% loss and gains of up to 10% compared to a range of 16% to 42% loss for the unassisted condition (SH-U4). When comparing relative grip strength after Carry Attempt 5 to Baseline for the WH group, individuals in the assisted condition (WH-A2) had no more than a 29% loss (for a full 5 km carry series) and gains of up to 3% compared to a range of 24% to 55% loss for the unassisted condition (WH-U4).

Statistical analysis revealed further differences between the assisted and unassisted conditions. For SH group, the paired two-tail *t*-tests revealed a statistically significant difference in grip strength between SH-UA and SH-A2 after Carry Attempt 5. The paired one-tail *t*-test further revealed the difference was a statistically significant increase in Grip Strength. Further for the SH group, the two-way repeated measures ANOVA revealed a statistically significance difference in grip strength for Carry Condition, Carry Attempt, and the interaction. Post-hoc analysis revealed the simple main effect of carry condition is statistically significant after Carry Attempts 4 and 5 (SH-U4 and SH-A2 (Figure 15 and Appendix B). For the WH group, the paired two-tail *t*-tests revealed a statistically significant difference in Grip Strength after Carry Attempts 1 and 5. The paired one-tail *t*-tests further revealed the difference was a statistically significant increase after both carry attempts. Further, for WH group, the two-way repeated measures ANOVA revealed a statistically significance difference in grip strength for Carry Condition, Carry Attempt, and the interaction. Post-hoc analysis revealed the simple main effect of carry condition was statistically significant in Carry Attempts 1, 2, 3, and 5 (Figure 15 and Appendix B).

For all assisted Carry Attempts, Grip Strength was maintained more consistently across carries as well as when compared to the unassisted Carry Attempts. This was seen within and across individuals, averages, and statistical findings. Assisted Carry Attempts resulted in a less than 5 kg standard deviation for any individual across Baseline and all Carry Attempts for SH-A2 and WH-A2, while unassisted conditions resulted in a greater than 5 kg standard deviation (Appendix Tables B2 and B3). Average Grip Strength was maintained from Baseline within 9% (4 kg) for the SH group and 13% (6 kg) for the WH group for the simulated 2-person carries when compared to the grip strength loss of over 30% for the unassisted simulated 4-person carries. Post analysis after the two-way repeated measures ANOVA did not find the affect of Carry Attempt on grip strength to be statistically significant for either assisted 2-person carry condition (SH-A2 and WH-A2).

**Individual performance.**

For assisted carry attempts, four of the five SH group participants had less than a 5% loss in Grip Strengh after Carry Attempt 5 or an increase over the day's measured Baseline grip strength. The largest Grip Strength loss occurred in one of the three SH participants who completed the entire 5 km carry (Appendix Table B2). For the assisted WH group after Carry Attempt 5, two WH participants had an increase in grip strength over the day's measured Baseline Grip Strength and these two WH participants completed the entire 5 km carry (Appendix Table B3). Although loss of "grip" was often thought to be the cause of litter drops, there was no consistent level of absolute or relative loss of grip strength.

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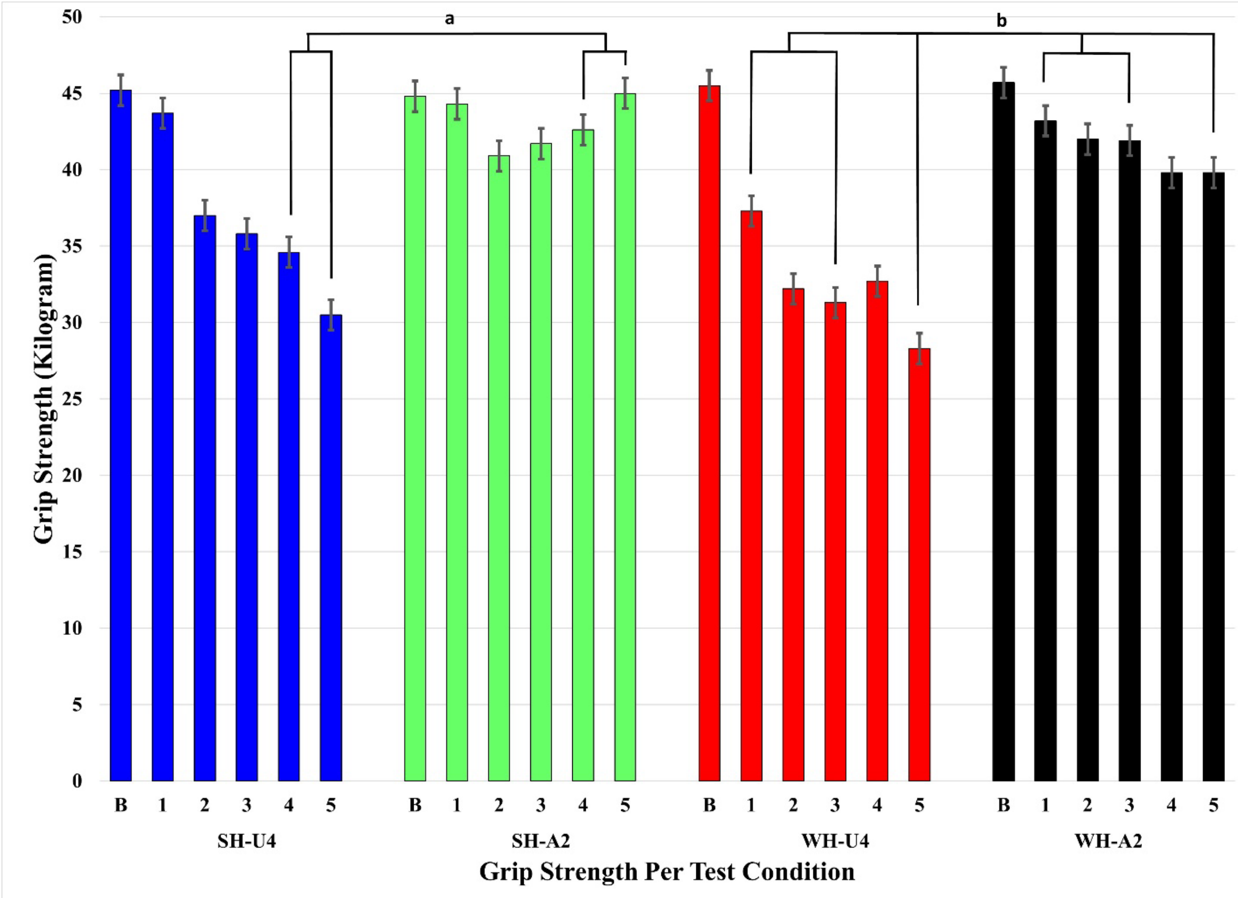


*Figure 15.* Grip strength Baseline (B) before any carry attempt for a particular test day and after-carry attempt measurements for the unassisted shoulder harness (SH-U4), shoulder harness (SH-A2), unassisted wrist hooks (WH-U4), and wrist hooks (WH-A2) test conditions. [a] indicates a statistically significant difference in the Shoulder Harness group between conditions SH-U4 and SH-A2 for Carry Attempts 4 and 5. [b] indicates a statistically significant difference in the Wrist Hooks group between conditions WH-U4 and WH-A2 for Carry Attempts 1, 2, 3, and 5.

## Marksmanship

The average number of targets hit by participants within each study condition (± one standard deviation) are presented in Figure 16 and Appendix Table C1. Data were grouped by firing position (prone supported, prone unsupported, kneeling, and total results for all firing positions) and simulated litter carriage condition (SH-U4, SH-A2, WH-U4, and WH-A2). Results of Baseline assessments and assessments taken after Carry Attempt 5 for each trial are presented for each group.

Generally, marksmanship scores declined after subjects completed five rounds of testing in each simulated litter carriage condition when compared to Baseline assessments. The average number of targets hit was lower after Carry Attempt 5 for all analyzed data except three conditions/marksmanship assessment combinations: WH-A2 in the prone supported firing position, SH-A2 in the prone unsupported firing position, and WH-U4 in the kneeling firing position (Figure 16, A through C). When all firing positions are considered together (total marksmanship shown at the bottom right of Figure 16, D), the average number of targets hit after completing five litter carry attempts were lower than the number of targets hit during the Baseline assessment; this finding is independent of simulated litter carriage condition.

While the number of targets hit differed between the Baseline assessments and assessments taken after five litter carry attempts, no statistically significant differences were found between these conditions for any litter carriage condition or firing position.

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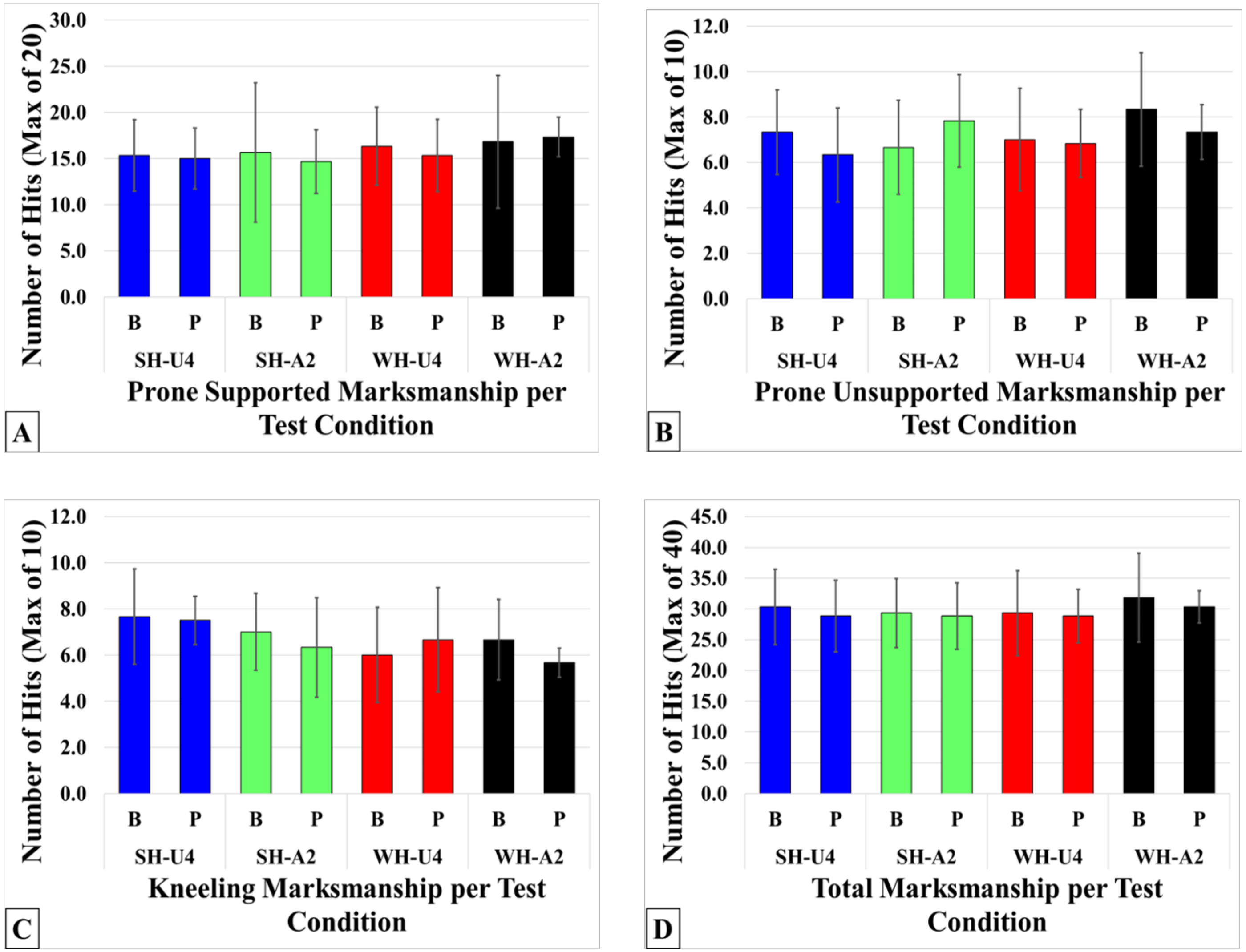


*Figure 16*. Marksmanship (A) prone supported, (B) prone unsupported, (C) kneeling, and (D) total Baseline and Post-Carry measurements for the unassisted shoulder harness (SH-U4), shoulder harness (SH-A2), unassisted wrist hooks (WH-U4), and wrist hooks (WH-A2) test conditions. For all test conditions, marksmanship assessments were conducted prior to initiating testing (e.g., Baseline) and Post-Carry, which are denoted by the “B” and “P” in the column labels, respectively.

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## Subjective Questions

The participants responses to subjective RPE, Discomfort, Fatigue, and User Acceptance questions are presented in Figure 17 and Appendix D: Subjective Assessment Supplemental Data.

For all three subjective variables assessed throughout the test day (RPE, Discomfort, and Fatigue), the action of carrying a litter, as expected, changed the participants' response from Baseline (reported before any litter carry). Furthermore, with increasing Carry Attempts, each of these three subjective variables also showed an overall trend for increasing average RPE, Discomfort, and Fatigue. At the end of the day (after the completion of all Carry Attempts, other post-testing evaluations, and cool down), the average reported values for RPE, Discomfort, and Fatigue were all less than their respective average reponses after Carry Attempt 1, but the Post-Carry average responses did not return to their respective average Baselines. With the average response, the influence of the assistive device was not consistent across the these three subjective variables but it was consistent within a variable. Specifically, average RPE and average Fatigue generally decreased for both SH group and WH group when comparing unassisted 4-person carries to assisted 2-person carries; however, average Discomfort generally increased when an assistive device was used.

Statistical analysis consistently supported the above observations in regard to the influence of Carry Attempts that can also be seen in Figure 17. Specifically, both the two-way ANOVAs and the two-way repeated measures ANOVAs (and respective post-hoc analyses) found the influence of Carry Attempt to be significant. Specifics findings are detailed within each variable section below.

An unexpected finding was that the two-way ANOVA analysis revealed statistically significant difference between SH-U4 and WH-U4 in all three subjective variables assessed throughout the test day (RPE, Discomfort, and Fatigue) for Carry Attempt and Carry Condition but not for the interaction. Despite this, the subjective variable responses after carry attempts were found to be significantly different from the Baseline.

The two-way repeated measures ANOVAs similarly revealed statistically significant differences in assisted versus unassisted carries within the SH group and within the WH group. Carry Attempt was identified for all three variables, except for RPE where both Carry Attempt and Carry Condition were both identified.

### Rating of Perceived Exertion (RPE).

The influence of Carry Attempt on RPE can be seen in each test condition (SH-U4, SH-A2, WH-A2, WH-U4): Participants reported exertion above Baseline and generally greater exertion (higher RPE values) with the number of litter carry attempts (Figure 17A). Additionally, participant's reported exertion decreased (lower RPE values) from RPE reported immediately after Carry Attempt 5 to the RPE reported at the end of test day ("P") following the testing completion and cool-down exercise. Overall, the RPE values for the assistive device test conditions (SH-A2 and WH-A2) were lower in comparison to the unassisted test conditions (SH-U4 and WH-U4), with statistically significant differences being found within the Shoulder

Harness group (SH-U4 versus SH-A2) and within the Wrist Hooks group (WH-U4 versus WH-A2).

Statistically significant differences were found between the unassisted conditions, Carry Attempts, and unassisted versus assisted conditions. The two-way ANOVA revealed a statistically significant difference in RPE between SH-U4 and WH-U4 for Carry Attempt and Carry Condition but not for the interaction. For RPE, a Tukey post-hoc test revealed significant pairwise differences between Baseline and Carry Attempt 1, 2, 3, 4, and 5 and confirmed the significant difference between WH-U4 and SH-U4. For the assisted versus unassisted condition for SH group, the two-way repeated measures ANOVAs revealed statistical significant differences for Perceived Exertion for Carry Condition and Carry Attempt but not the interaction. Specifically, post-hoc analysis revealed the simple main effect of Carry Condition is significant in Baseline and Carry Attempt 1. For the SH group responses for RPE, post-hoc analysis further revealed the simple main effect of Carry Attempt is significant for carry conditions SH-U4 and SH-A2. Likewise, for WH group responses for RPE, post-hoc analysis revealed the simple main effect of Carry Attempt is significant for carry conditions WH-U4 and WH-A2.

**Discomfort.**

The influence of Carry Attempt on reported Discomfort can be seen in each test condition (SH-U4, SH-A2, WH-A2, WH-U4): Participants reported Discomfort above Baseline and generally greater Discomfort (higher values) with the number of litter carry attempts (Figure 17B). The reported average Discomfort levels for the assistive device test conditions (SH-A2 and WH-A2) were greater in comparison to the unassisted test conditions (SH-U4 and WH-U4, respectively) through the five Carry Attempts. However, for the end of day Post-Carry assessment, the average Discomfort of the assistive device test conditions (SH-A2 and WH-A2) were lower in comparison to the unassisted test conditions (SH-U4and WH-U4) although none of the Post-Carry average Discomfort levels returned to Baseline.

Statistically significant differences were found between the unassisted conditions, Carry Attempts, and unassisted versus assisted conditions. The two-way ANOVA revealed statistically significant difference between SH-U4 and WH-U4 in Discomfort for Carry Attempt and Carry Condition but not for the interaction. For Discomfort, a Tukey post-hoc test revealed significant pairwise differences between Baseline and Carry Attempt 1, 2, 3, 4, 5, and confirmed the sign difference between WH-U4 and SH-U4. For SH group, the two-way repeated measures ANOVAs revealed statistical significant differences for Discomfort for Carry attempt but not Carry Condition or the interaction. For the SH group responses for Discomfort, post-hoc analysis further revealed the simple main effect of Carry Attempt is significant for carry conditions SH-U4 and SH-A2. Likewise, for WH group responses for Discomfort, post-hoc analysis revealed the simple main effect of Carry Attempt is significant for carry conditions WH-U4 and WH-A2.

**Fatigue.**

The influence of Carry Attempt on reported Fatigue can be seen in each test condition (SH-U4, SH-A2, WH-A2, WH-U4): Participants reported Fatigue above Baseline and generally greater Fatigue (higher values) with the number of litter carry attempts (Figure 17C). Additionally, participant's reported fatigue decreased (lower values) from Fatigue levels reported immediately after Carry Attempt 5 to the Fatigue reported at the end of test day ("P") following the testing completion and cool-down exercise. Overall, the Fatigue values for the assistive device test conditions (SH-A2 and WH-A2) were lower in comparison to the unassisted test conditions (SH-U4 and WH-U4).

Statistically significant differences were found between the unassisted conditions, Carry Attempts, and unassisted versus assisted conditions. The two-way ANOVA revealed statistically significant difference between SH-U4 and WH-U4 in Fatigue for Carry Attempt and Carry Condition but not for the interaction. For Fatigue, a Tukey post-hoc test revealed significant pairwise differences between Baseline and Carry Attempt 1, 2, 3, 4, 5, between Carry Attempt 1 and 5, and confirmed the sign difference between WH-U4 and SH-U4. For SH group, the two-way repeated measures ANOVAs revealed statistical significant differences for Fatigue for Carry attempt but not Carry Condition or the interaction. For the SH group responses for Fatigue, post-hoc analysis further revealed the simple main effect of Carry Attempt is significant for carry conditions SH-U4 and SH-A2. Likewise, for WH group responses for Fatigue, post-hoc analysis revealed the simple main effect of Carry Attempt is significant for carry conditions WH-U4 and WH-A2.

#### User acceptance.

Participants in both the Shoulder Harness and Wrist Hooks groups reported greater user acceptance (larger values) after using the assistive device (SH-A2 and WH-A2) during litter carriage in comparison to the unassisted test conditions (SH-U4 and WH-U4). For SH, the paired two-tail *t*-test (and follow-on paired one-tail *t*-test) revealed there was a statistically significant increase in User Acceptance between SH-U4 and SH-A2; however, there was no significant difference found between WH-U4 and WH-A2.

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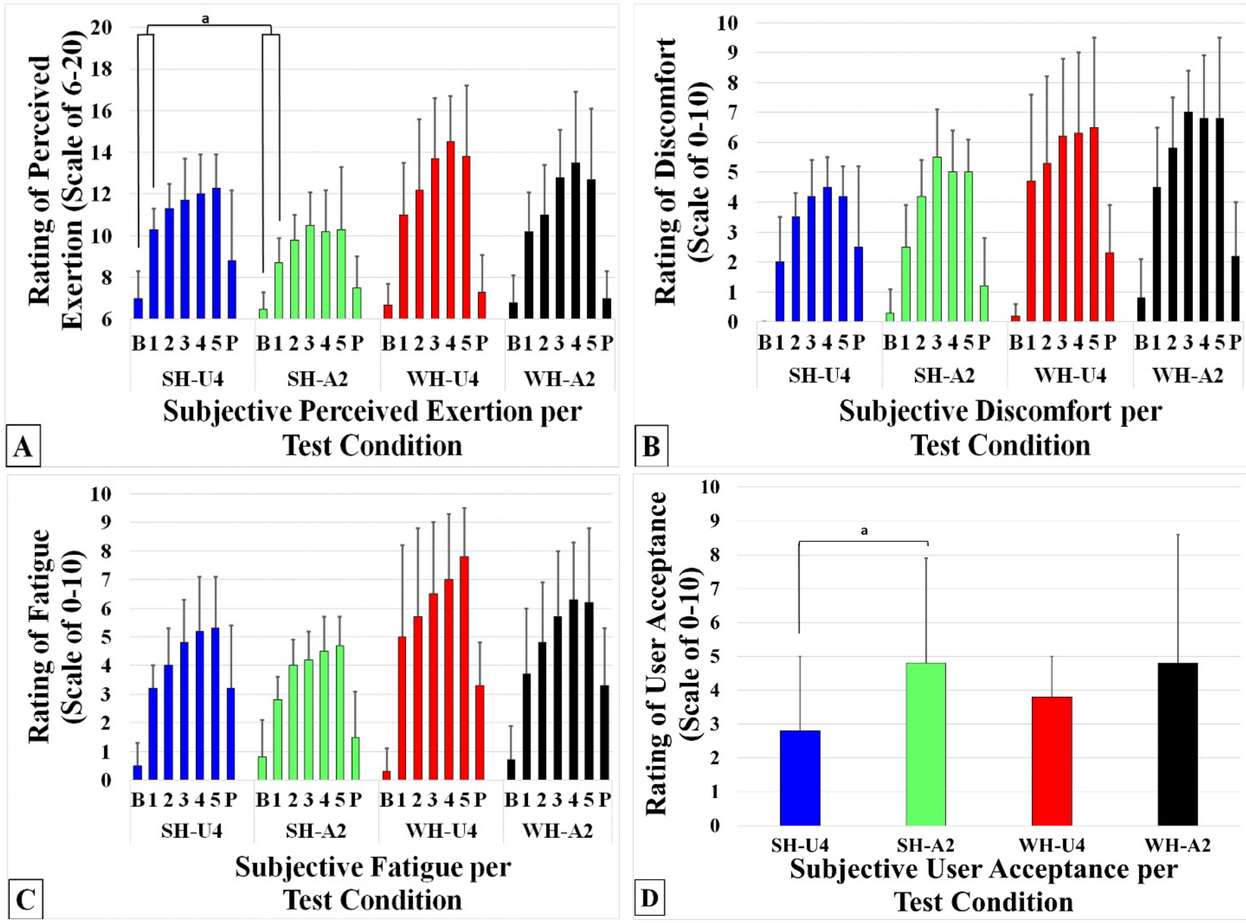


*Figure 17.* (A) Perceived exertion, (B) discomfort, and (C) fatigue Baseline, per carry attempt, and Post-Carry (end of test day) subjective ratings for the unassisted shoulder harness (SH-U4), shoulder harness (SH-A2), unassisted wrist hooks (WH-U4), and wrist hooks (WH-A2) test conditions. For all test conditions, Perceived Exertion, Discomfort, and fatigue assessments were conducted prior to initiating testing (e.g., Baseline), after each litter carry attempt, and at the end of test day, which are denoted by the "B," "1," "2," "3," "4," "5," and "P" in the column labels, respectively. Higher numbers are indicative of greater subjective feelings of exertion, discomfort, or fatigue, respectively. (D) User Acceptance subjective ratings were acquired at the end of test day only. Higher numbers indicate greater User Acceptance. [a] indicates statistically significant difference in RPE between carry conditions (SH-U4 and SH-A2) and in User Acceptance between carry conditions (SH-U4 and SH-A2) for the Shoulder Harness group.

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**Fine Motor Skills**

The outcomes for the fine motor skills assessments (Steadiness, Line Tracing, Aiming, and Tapping) are presented in Figure 18 through Figure 23 and Appendix E: Fine Motor Skills Assessments Supplemental Data. Aiming data were removed for one subject due to confusion between dominant hand and the hand to use on the board. SH-U4 and WH-U4 were test conditions with unassisted 4-person simulated carries while WH-A2 and SH-A2 were test conditions with assisted 2-person simulated carries.

Due to large individual differences in measured performance between trials for an individual (both within the unassisted and assisted conditions) as well as across individuals within unassisted and assisted conditions, large standard deviations often resulted. In some group-condition-carry attempt combinations, a single individual heavily influenced the average response while in other cases, half of the participants demonstrated a trend while the other half demonstrated the opposide trend. Other tasks resulted in almost little to no variation in measured responses. With the variation in individual response and resulting averages, few generalizations and statistically significant findings were revealed.

Large variation can be seen in the calculated standard deviations for both Steadiness and Line Tracing tasks (Appendix E: Fine Motor Skills Assessments Supplemental Data). For the Steadiness Errors, one or more participants performed worse than the rest of the participants within their group; however, on average participants completing the Steadiness task remained in non-error status for at least 96% of the duration of the Steadiness task. For Line Tracing for the SH group, half of the participants completed in less than 15 seconds while the other half of the participants required longer than 15 seconds with maximum durations lasting over 30 seconds for participants in SH-A2 and 45 seconds for participants in SH-U4. On average, the Shoulder Harness group appeared to have a slight improvement completing the line tracing with less errors for SH-A2 than SH-U4. Among the WH-U4 and WH-A2 groups, there were inconsistent performances within individuals and between individuals for the Line Tracing task. On average, subjects showed a decrease in Line Tracing Errors overall following trials using wrist hooks. For Line Tracing Total Duration, there was more variability in total time to complete the task in the Shoulder Harness group than in the Wrist Hooks group.

The Aiming Task was a task where there was little variation in number of hits and duration to complete the task with over 76% of the trials for every condition (SH-U4, SH-A2, WH-U4, and WH-A2) resulting in perfect aiming scores. Likewise, for the timed period allowed for the Tapping task, the average taps completed were greater 200.

Some highlights of the statistical analysis included the following. The two-way ANOVA and subsequent post-hoc analysis revealed statistically significant differences between SH-U4 and WH-U4 conditions for Steadiness Errors, Line Tracing Total Duration, Aiming Total Duration, and Tapping Hits. For the SH group, the two-way repeated measures ANOVAs revealed statistically significant differences between SH-U4 and SH-A2 for Line Tracing Total Duration; however, post-hoc analysis revealed the simple main effect of Carry Condition was statistically significant in the Baseline only. For the WH group, the two-way repeated measures ANOVAs (and post-hoc analyses) revealed statistically significant differences between WH-U4 and WH-A2 for Aiming Total Duration after Carry Attempts 3 and 4, Line Tracing Errors (no specific Attempt), Line Tracing Total Duration (Baseline, Attempt 3, Attempt 4), and Tapping Hits (Attempt 4).

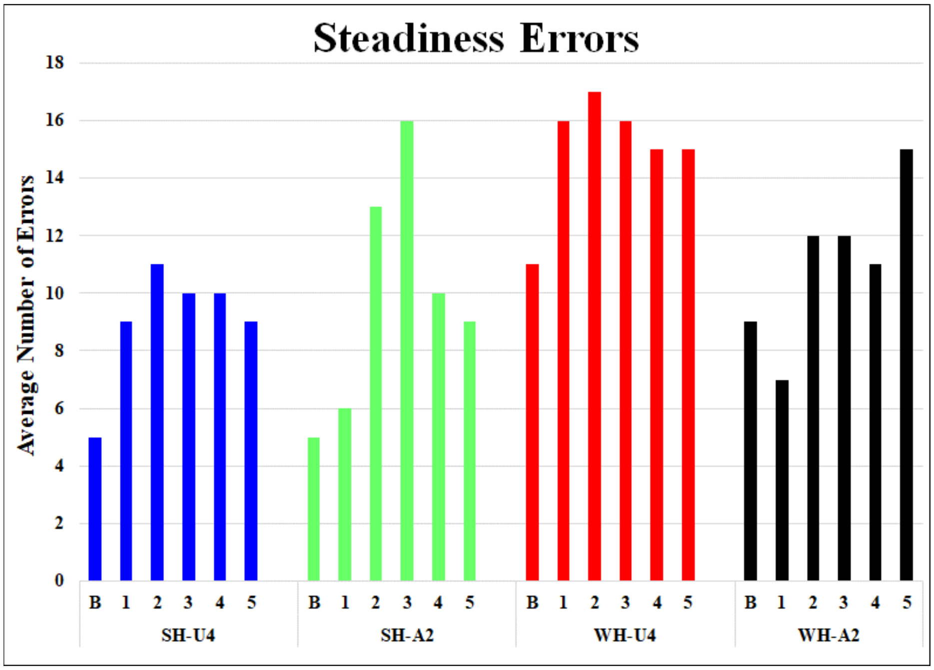


*Figure 18.* Steadiness errors for the SH-U4, SH-A2, WH-U4, and WH-A2 test condition. Refer to Table E1 in Appendix E for standard deviations.

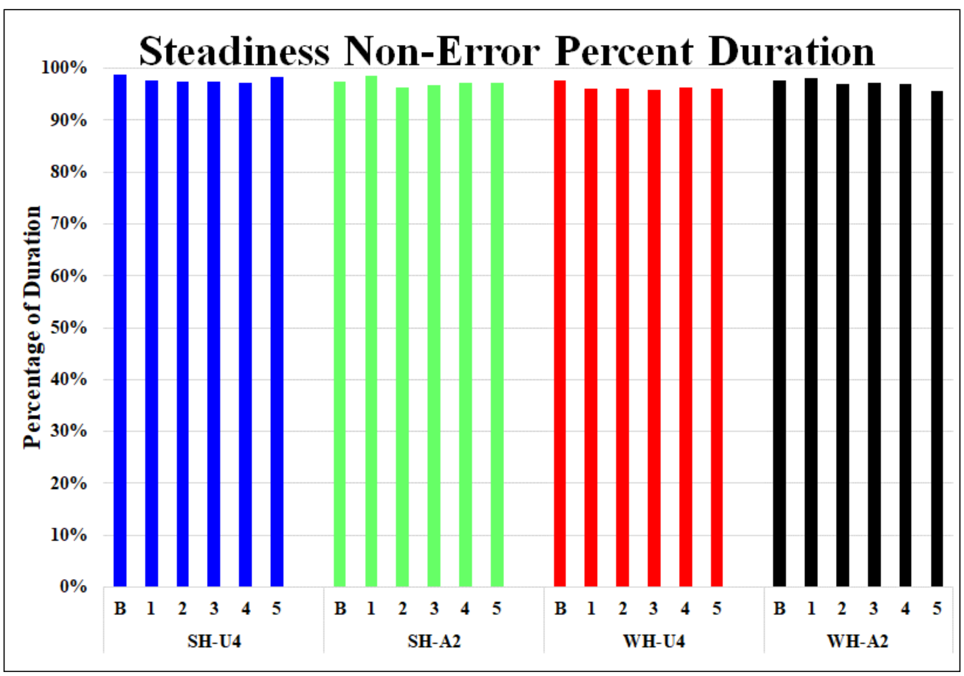


*Figure 19.* Steadiness Non-Error Percent Duration for the SH-U4, SH-A2, WH-U4, and WH-A2 test condition. Refer to Table E1 in Appendix E for standard deviations.

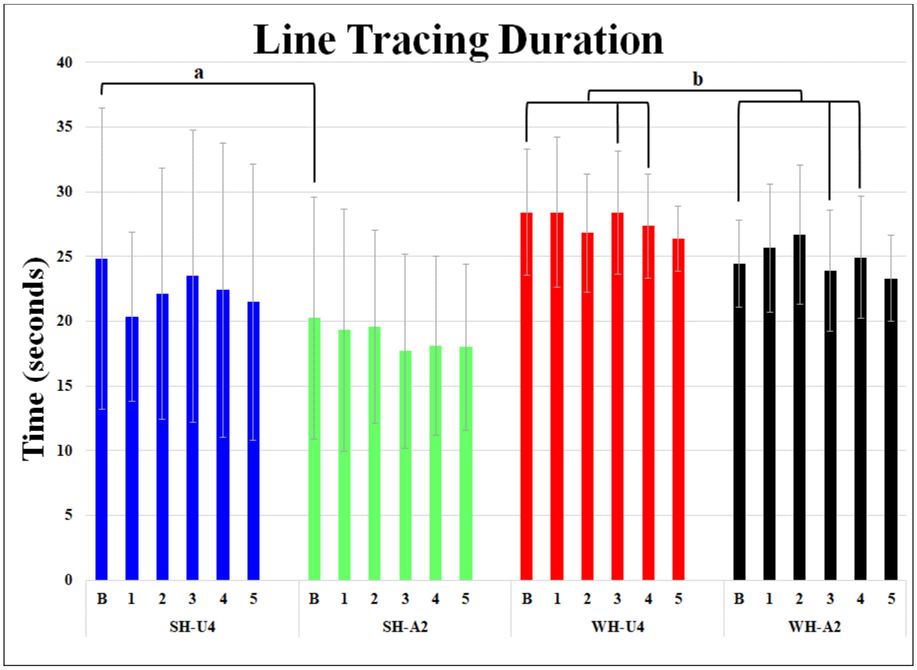


*Figure 20.* Line Tracing Duration for the SH-U4, SH-A2, WH-U4, and WH-A2 test condition. [a] indicates a statistically significant difference in line tracing duration Baseline assessments between unassisted and assisted carry for the Shoulder Harness group. [b] indicates a statistically significant difference in line tracing duration Baseline, after Carry Attempt 3, and after Carry Attempt 4 between unassisted and assisted carry for the Wrist Hooks group.

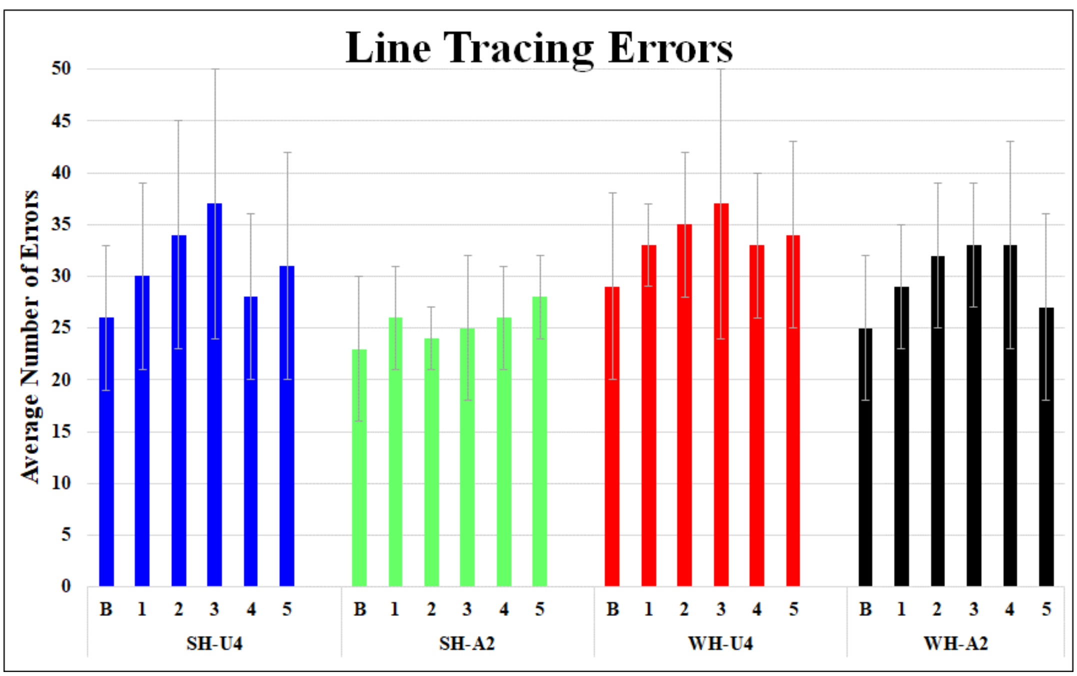


*Figure 21.* Line Tracing Errors for the SH-U4, SH-A2, WH-U4, and WH-A2 test condition.

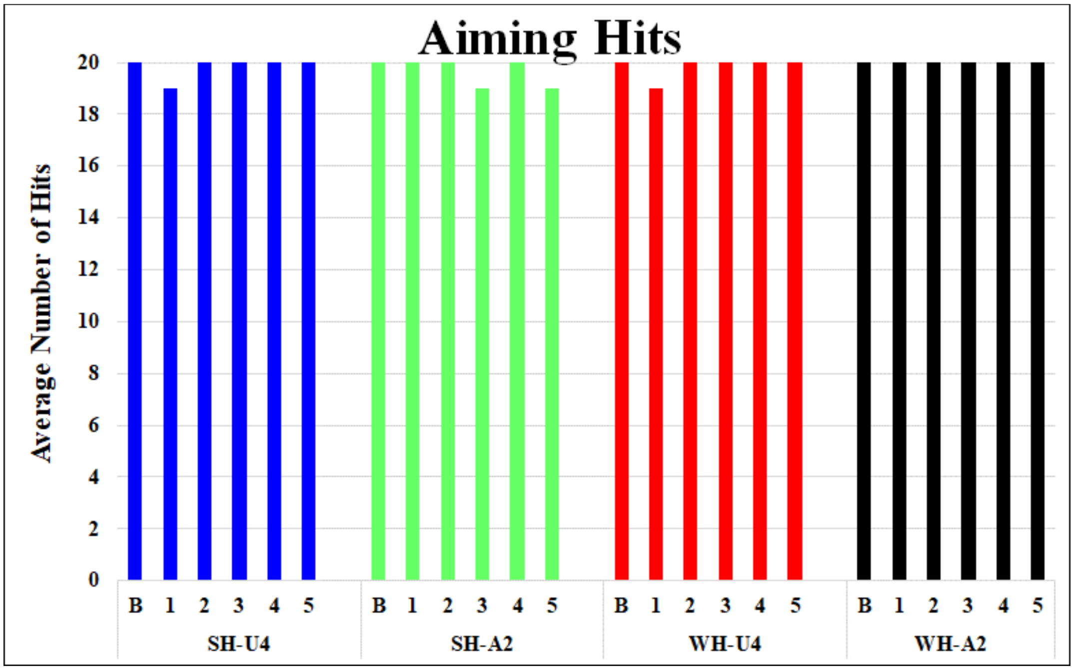


*Figure 22.* Aiming Hits for the SH-U4, SH-A2, WH-U4, and WH-A2 test condition. Refer to Table E3 in Appendix E for standard deviations.

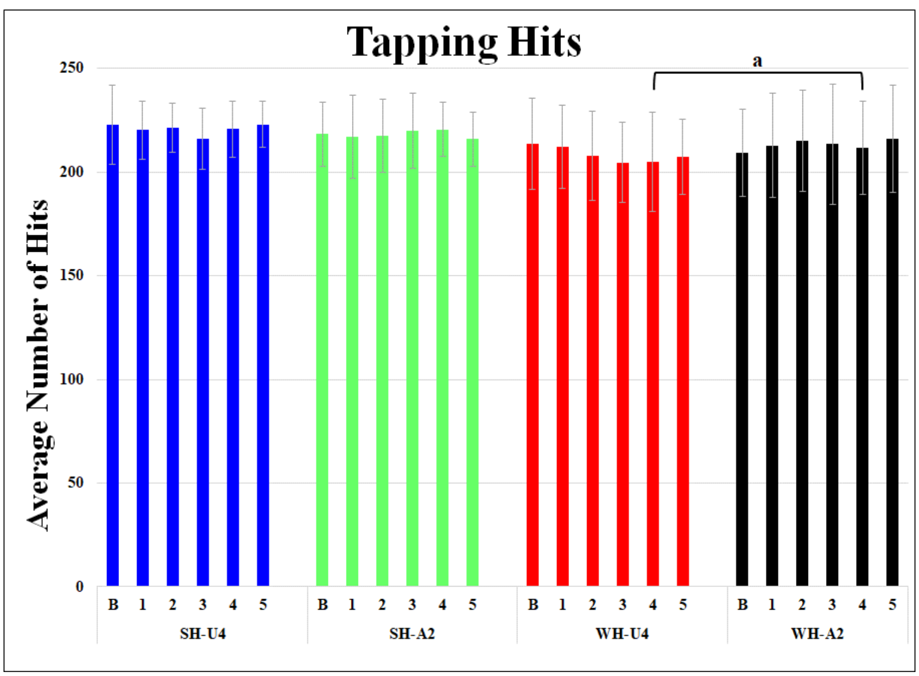


*Figure 23.* Tapping Hits for the SH-U4, SH-A2, WH-U4, and WH-A2 test condition. [a] indicates a statistically significant difference in Tapping Hits between unassisted and assisted Carry Attempt 4 for the Wrist Hooks group.

## Motion Capture

For motion capture analysis, one participant from the Shoulder Harness group was excluded due to technical issues during data collection. Torso angles were computed from the first and final motion capture for each carry attempt. Anterior-Posterior (A-P) angles are between the torso and vertical, aligned with the carry direction (Figure 24); lateral angles are between the torso and vertical, aligned with the participant's lateral direction (Figure 25). Motion capture data are presented in Figure 24, Figure 25, Appendix Table F1, and Appendix Table F2. All angles are presented as absolute values. SH-U4 and WH-U4 were test conditions with unassisted 4-person simulated carries while WH-A2 and SH-A2 were test conditions with assisted 2-person simulated carries.

For statistical analyses, a three-way ANOVA was used to assess the between subjects difference for the unassisted (SH-U4 and WH-U4) Carry Attempts. A three-way repeated measures ANOVA was used to assess differences within the Shoulder Harness and Wrist Hooks groups for Carry Condition, Carry Attempt, and differences between first and last torso angles. While the differences in torso angles were not statistically significant for all comparisons, the assisted carry conditions (SH-A2 and WH-A2) displayed lower mean torso angles than the unassisted carry conditions (SH-U4 and WH-U4) for every carry attempt, indicating the ability for assistive devices to maintain or improve posture during litter carriage.

### Torso A-P angles.

First and last torso A-P angles (Figure 24 and Appendix Table F1) were lesser on average for assisted carry conditions (SH-A2 and WH-A2) compared to their respective unassisted carry conditions (SH-U4 and WH-U4), indicating more upright, neutral postures when assistive devices were used in carry attempts. Statistical analyses found the differences between first and last torso A-P angles were statistically significant for unassisted Carry Attempts in both groups (SH-U4 and WH-U4) and for wrist hooks assisted (WH-A2) Carry Attempts 1 through 4, demonstrating a decline in posture throughout these carry attempts. No statistically significant differences were found between first and last torso A-P angles for the shoulder harness assisted (SH-A2) Carry Attempts. While declines in torso A-P angles were observed from the first to last capture across carry attempts, the last angles for assisted carries (SH-A2 and WH-A2) were smaller than the first angles in unassisted carries (SH-U4 and WH-U4) for respective carry attempts, reflecting overall more neutral postures in the assisted Carry Attempts than the unassisted.

First torso A-P angles were lower for assisted carries than unassisted carries across both Shoulder Harness and Wrist Hooks groups (Appendix Table F1). As these measurements were taken 20 seconds from the start of the carry attempt, a lesser first torso A-P angle indicates the participant was able to begin the carry attempt from a more upright, neutral posture. The Wrist Hooks group had statistically lower first torso A-P angles for assisted Carry Attempts 1-5.

Last torso A-P angles were lower for all assisted carries compared to their respective unassisted carry attempts (Figure 24); however, these differences were statistically significant only for the Wrist Hooks group for Carry Attempts 2 and 4.

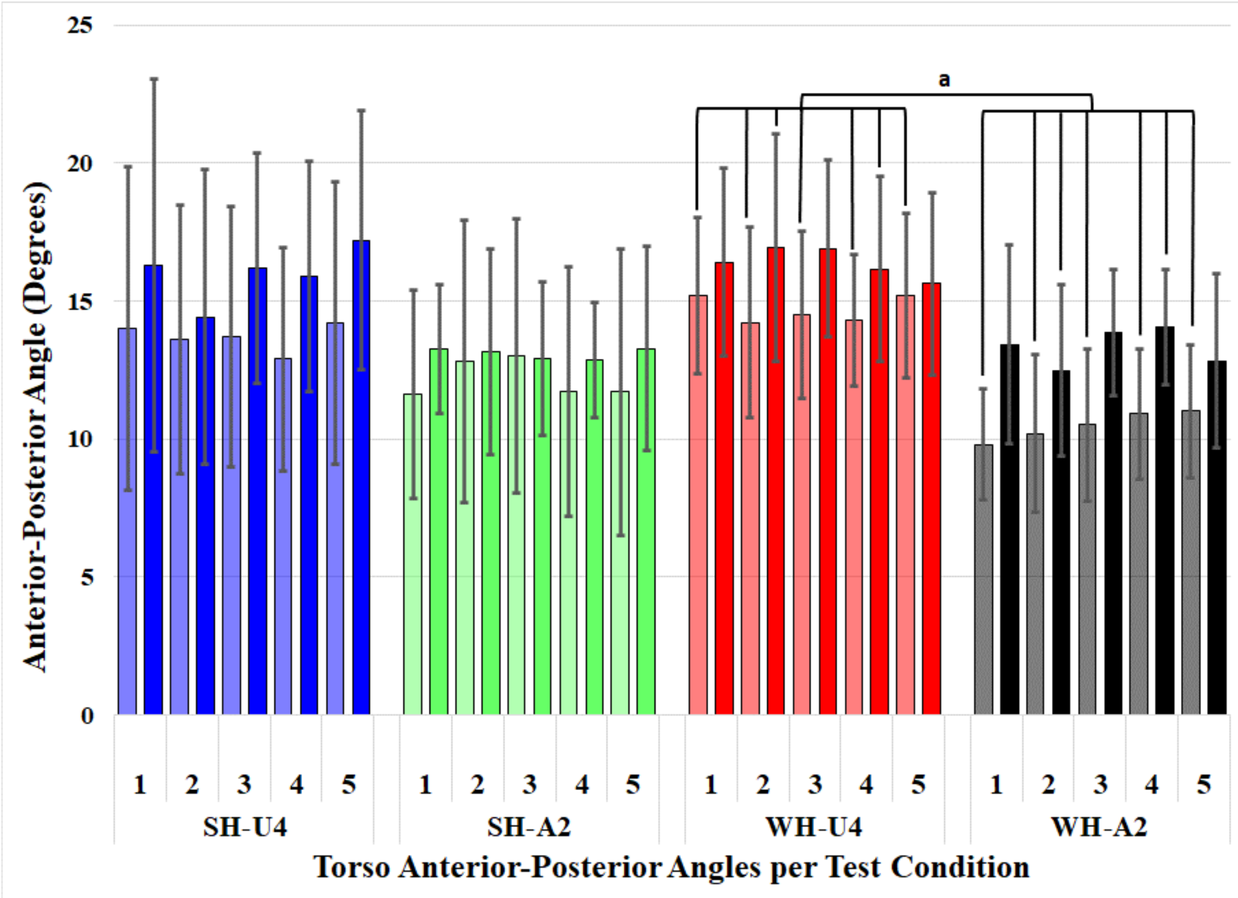


*Figure 24.* First and last torso anterior-posterior (A-P) angles (lighter and darker shades, respectively) for the unassisted shoulder harness (SH-U4), shoulder harness (SH-A2), unassisted wrist hooks (WH-U4), and wrist hooks (WH-A2) test conditions. A-P angles are between the torso and horizontal in the A-P plane. [a] indicates a statistically significant difference in torso A-P angles between carry conditions (WH-U4 and WH-A2) for the Wrist Hooks group.

**Torso lateral angles.**

Average torso lateral angles were smaller in assisted carries (SH-A2 and WH-A2) than unassisted carries (SH-U4 and WH-U4) for all respective carry attempts (Figure 25 and Appendix Table F2). A lateral angle closer to zero indicates a more upright posture through the carry attempt. The subject groups exhibited statistically significant differences in torso lateral angles between SH-U4 and WH-U4. Further statistical analysis determined there was a difference between SH-U4 and SH-A2. Specifically, the post-hoc analysis found that the first torso lateral angles in the Shoulder Harness group assisted carries (SH-A2) to be significantly less than unassisted carries (SH-U4) for Carry Attempts 1, 2, 4, and 5. Examination of the mean torso lateral angles shows use of assistive devices (SH-A2 and WH-A2) resulted in smaller torso lateral angles than all unassisted carry attempts but one (Appendix Table F2).

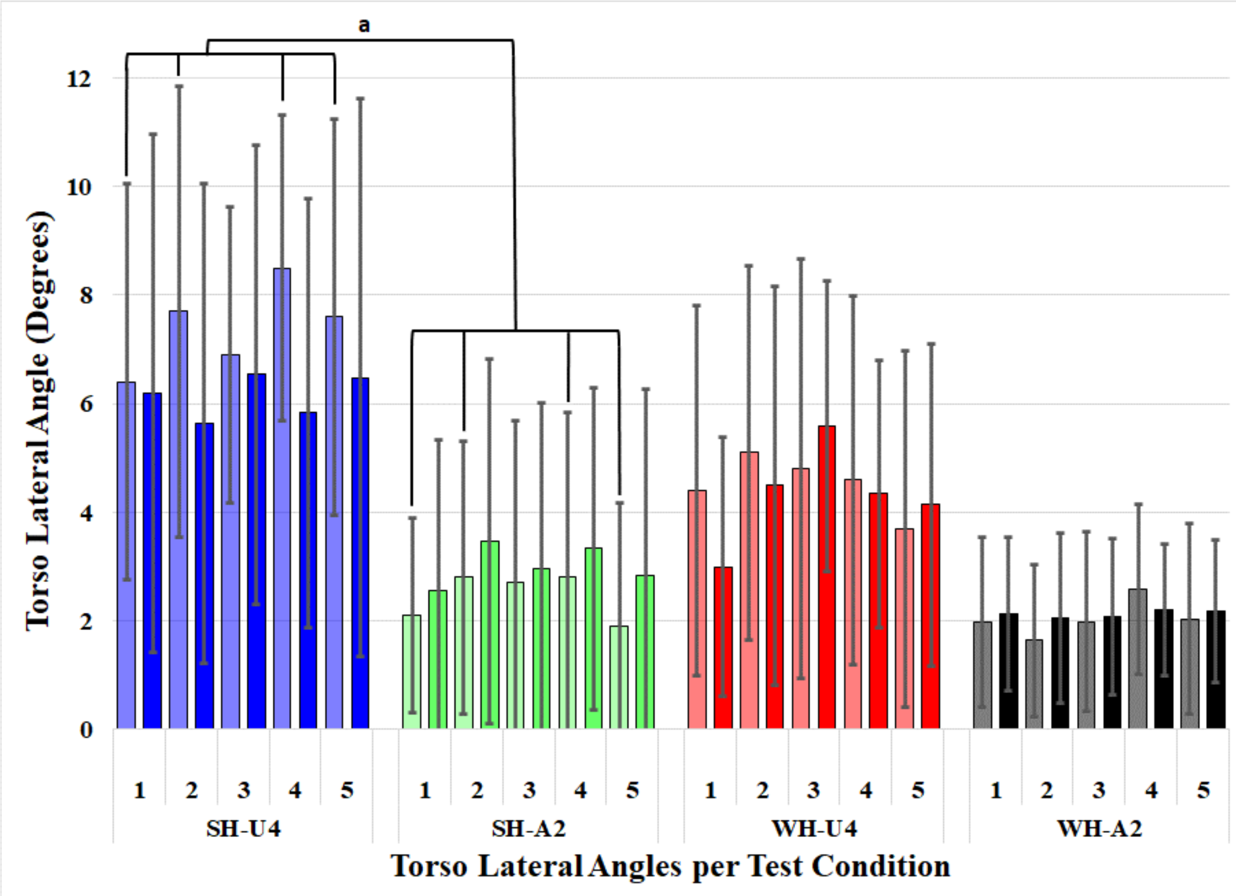


*Figure 25.* First and Last torso lateral angles (lighter and darker shades, respectively) for the unassisted shoulder harness (SH-U4), shoulder harness (SH-A2), unassisted wrist hooks (WH-U4), and wrist hooks (WH-A2) test conditions. Lateral angles are between the torso and vertical in the medio-lateral plane. [a] indicates a statistically significant difference in first torso lateral angles between carry conditions for the Shoulder Harness group, Carry Attempts 1, 2, 4, and 5 only.

## Discussion

This study is the first of its kind to perform a comprehensive investigation of the effects of multiple types of COTS assistive devices (i.e., shoulder harness and wrist hooks) on grip strength retention, individual SM performance, and post-care fatigue in 2-person and 4-person simulated litter carries. Other previous studies have only examined a portion of these conditions and a few performance metrics. Leyk et al. (2006) examined the effects of grip strength and hand steadiness after 2-person litter carriage; however, assistive devices were not assessed. Rice et al. (1996a; 1996b; and 1999) evaluated the effects of assistive device use in men and women in 2- and 4-person simulated litter carry scenarios. Rice et al. did not evaluate the effects of assistive device use on grip strength retention through repeated litter carry attempts; grip strength was collected for the determination of pre-testing participant demographics. Additionally, only harness assistive device types were assessed. Furthermore, these assessments were conducted in group settings, which may have influenced outcomes.

Overall, the findings of this study show that using a COTS assistive device provides multiple positive benefits on the litter carry task compared to unassisted carries. In general we found that when compared to a simulated unassisted 4-person carry, our simulated assisted 2-person litter carries resulted in more consistent outcomes over repeated carry attempts and maintained or improved the litter bearer's performance and response to carrying a litter despite the litter bearer supporting more weight. These findings suggest that the use of an assistive device may decrease casualty evacuation time, increase the number of casualties evacuated, and reduce the rate of acute or chronic injury experienced by litter bearers from overexertion during extended litter transport. Additionally, these findings also demonstrate that assistive device 2-person litter carry techniques could be used instead of the traditional unassisted 4-person litter carry approach, resulting in a lower number of personnel needed for casualty transport without increased musculoskeletal detriment or risk to the litter bearer.

**Anthropometry and Demographics**

The lack of significant differences between test groups demonstrate that no anthropometric or demographic biases or effects contributed to the differences in observed and reported assistive device outcomes. Additionally, participant anthropometric and demographic data show that our sample population is age-representative of the current active duty military population (DoD, 2020) while the large concentration of aviation-based MOSs is reflective of the local Fort Novosel Soldier population (Table 8). Furthermore, the aviation-based MOSs reflected in our participant population suggest that they likely did not have much experience or exposure to litter casualty carriage transport prior to study participation. The participant population, in conjunction with the data outcomes, demonstrate that the use of assistive devices can be beneficial to any SM at the squad, platoon, battalion, brigade, or division level tasked with remote or mass casualty transport and evacuation. Future work will examine and compare 2-person and 4-person teams using male and female SMs, with participants completing all assistive device conditions, to confirm the effects are due to assistive device use and not differences in single-handed and double-handed litter carriage or gender effects.

**Assistive Device Test Conditions**

The initial objective of this study was to assess COTS (i.e., shoulder harness or wrist hooks) and novel technology (i.e., exoskeleton) assistive devices in simulated litter transport conditions. However, an exoskeleton could not be identified for use in this study. Exoskeleton prototype designs for military casualty carriage transport scenarios are scarce; the necessity for grip strength augmentation and continual dynamic movements was a major limitation within current designs. The lack of an adaptable exoskeleton for use in this effort further highlights the research gaps in the design and development of exoskeleton devices for military litter and patient transport scenarios. Exoskeleton designs should continue to be explored based on the design considerations and specifications outlined in Part 1 of this report (Madison et al., 2022). Due to the inability to identify an exoskeleton for use in the study, the focus shifted to the evaluation of two types of COTS devices: Shoulder harnesses and wrist hooks.

The specific shoulder harness assistive device type, Sherpa Shoulder Harness, was selected for assessment because of its current design use in civilian rescue and transport scenarios. In general, shoulder harnesses are lightweight and usually include adjustments to allow for individual anthropometry, body type, and potentially Soldier gear. This was true for the type chosen for our study. Because of the design of the shoulder harness, we anticipated that litter carry weight would be redistributed from the hands and arms to the torso thereby reducing the load on the hands and preserving grip strength. Additionally, the shoulder harness could help maintain a more neutral posture during litter carry; however, the shoulder harness was only evaluated in an assisted 2-person simulated carry that would by practical considerations maintain a more neutral posture than a 4-person carry. The shoulder harness device type has several features (e.g., adjustability, lessening demand on the hands and forearms) that would potentially reduce the onset of fatigue and performance decrement. Lastly, harness design used in our study included clips/latches that could be easily leveraged as a connection point to the standard military litter.

While traditionally used for weightlifting scenarios, a pair of wrist hooks was selected as an assistive device for this study because of the device's original design intent: For the user to be able to lift more weight longer during a session while not being limited by their grip strength or the loss of grip strength. Additionally, wrist hooks design and use could minimize interference with SM personal protective equipment. Two types of wrist hooks devices, the Harbinger Lifting Hooks (Rogue, Columbus, OH) and the DMoose Weight Lifting Hooks (DMoose, Buffalo, WY) were initially considered. Ultimately, the DMoose Weight Lifting Hooks were selected for use in this study to minimize pinch point and snag safety hazards between the participant and litter in our configured simulated litter transport design scenario. Participants anecdotally stated that the wrist hooks design evaluated in this study did not appear to accommodate smaller hands and wrists. Other wrist hooks designs may be more accommodating for different hand anthropometries and should be investigated in future work.

In addition to the study design, the statistical differences in the subjective outcomes reported by unassisted groups (SH-U4 versus WH-U4) as well as identical average User Acceptance for wrist hooks and shoulder harness reinforce that the data outcomes presented in this work should neither be used to infer the endorsement of a specific type of assistive device (e.g., shoulder harness, wrist strap, or exoskeleton) nor a specific brand of assistive device.

The study's main objective was to demonstrate the benefits of assistive devices in 2-person transport techniques to provide information and insight as to whether it can be substituted for the traditional 4-person carry technique in remote and mass casualty transport scenarios. Future work will further examine and quantify the use of various types of assistive devices during litter carry in various transport scenarios.

**Carry Distance and Time**

The use of the assistive devices allowed for farther carry distances and longer carry times in comparison to unassisted carry attempts. During the unassisted test conditions (SH-U4 and WH-U4), participants anecdotally referred to their hand and an inability to maintain a grip of the handle as reasoning for stopping during a litter carry, while comments during the 2-person assisted test conditions (SH-A2 and WH-A2) generally referred to the device slippage or the lack of adjustability to best adapt to the individual.

The use of either assistive device increased the incremental carry attempt distances and times in comparison to the unassisted carries as well as across all carry attempts (Figure 13 and Appendix A: Litter Carry Distance and Time Supplemental Data). On average, the shoulder harness (SH-A2) test condition resulted in longer and more consistent carry distances and times as compared to the 4-person unassisted carry (SH-U4).

Assistive devices also increased the number of full 1 kilometer (10.8 min) attempts completed. In the Shoulder Harness group, assistive device use (SH-A2) resulted in 80% (24 of 30) of full carry attempts completed in comparison to the unassistive test condition (SH-U4), where only 20% (6 of 30) were completed (Appendix A). In the Wrist Hooks group, assistive device use (WH-A2) resulted in 43% (13 of 30) of full carry distance and time attempts in comparison to the unassisted test condition (WH-U4), where only 27% of full carry attempts were completed (Appendix A: Litter Carry Distance and Time Supplemental Data).

Additionally, assistive device use increased the total carry distance and time in comparison to the unassisted carries (Figure 14 and Appendix Table A2). The use of a shoulder harness (SH-A2) increased the total carry distance and time by nearly 70% compared to the unassisted carry (SH-U4), and wrist hooks use (WH-A2) increased total carry distance and time by 11% for 2-person simulated carries in comparison to the unassisted 4-person simulated carry (WH-A4).

The findings for carry distance and time reflect previous work that reported increases in 2-person harness-carry distance compared to 4-person unassisted carries (Rice, 1999). The increased distance carried while using a shoulder harness is most likely due to shifting the load of the litter to the larger muscle groups of the body (i.e., torso, back, core), which decreases reliance on the smaller muscle groups of the arm (i.e., hands, forearms, shoulders). The increases, though smaller, in both incremental attempt and total carry distances and times in the Wrist Hooks group also support this rationale. Despite the variance in incremental and total carry distance and time increases, the data outcomes demonstrate that two-person litter carry with the use of assistive devices could be more effective in reducing litter bearer fatigue, decreasing evacuation times, and increasing the number of casualties evacuated, which are all beneficial and necessary for the anticipated LSCO and MDO casualty carriage transport scenarios.

### Grip Strength and Fine Motor Skills

Maintaining grip strength and fine hand motor skills throughout and after bouts of litter carriage is important to conducting other duties, such as providing care (e.g., administering intravenous fluids). Assistive device use showed higher grip strength retention after litter carries in comparison to the unassisted carries between the Baseline and last carry attempt as well as across carry attempts (Figure 15 and Appendix B). Although loss of grip strength was referred to as contributing to litter drop (or the end of litter carry), there was no identified consistent level of absolute or relative loss of grip strength recognized in this study. Overall, grip strength was significantly higher and maintained across carry attempts with the use of both assistive devices during 2-person simulated carries in comparison to unassisted 4-person simulated carries (Figure 15 and Appendix B).

Fine motor skill variables did not provide consistent results nor widespread significant differences between the assisted and unassisted test conditions nor across carry attemps. There was an observed increase in steadiness errors in all test conditions over the five litter carry attempts. This hand steadiness finding aligns with previous work that reported up to three times the number of hand steadiness errors following a 2-person unassisted litter carry (Leyk, 2006). The variability within individual performance and across individuals suggests additional familiarization trials as well as additional participants may reduce the variability and lead to more insight into the effects of litter carriage on fine motor skills. Further work with the fine motor skill test battery may be needed to improve the identification of the influence of fatigue (without neurological deficit) on hand steadiness and other fine motor skill tasks. However, the lack of significant differences between assistive and unassisted test conditions supports the rationale that a 2-person litter transport technique with the use of assistive devices can be implemented instead of the traditional 4-person transport technique without increased musculoskeletal detriment or risk of damage to the litter bearer.

**Marksmanship**

The use of an assistive device during five one-kilometer litter carry attempts did not result in statistically significant differences for marksmanship compared to unassisted carries (Figure 16 and Table C1 ). Scores (average number of targets hit) for most conditions decreased from Baseline after the five attempts were completed; these outcomes are similar to those reported by Rice et al. (1999). Rice et al. (1999) showed that 2-person unassisted carries resulted in significant accuracy degradation when compared to carries involving assistive devices.

The potential causes of accuracy degradation vary based on litter carry conditions. For example, participants anecdotally stated that pulling the trigger and supporting the weapon during the prone unsupported assessment after the 4-person unassisted carry was noticeably more difficult than after the 2-person assisted carry. During the shoulder harness (SH-A2) test condition, participants carried the litter significantly longer; thus, the decreased shot accuracy may have been a result of more overall fatigue and less attributed to difficulties squeezing the trigger and supporting the weapon. The study design comparison of 2-person assisted device carries to 4-person unassisted carries is also likely to contribute to the marksmanship assessment findings, as previous works showed that shoulder harness assisted 4-person carries had 17% tighter shot groupings (Tharion et al., 1993) and that 2-person unassisted carries were the only condition to result in significant accuracy degradation (Rice et al., 1999) when comparing team-size and device use.

Evans et al. (2003) found that marksmanship scores reportedly returned to baseline within 10 minutes after completing upper body exercises to fatigue. The EST 3000 marksmanship assessment was included as the final post-carry assessment after the grip strength and fine motor skills assessments. The time needed to complete these assessments as well as the EST3000 marksmanship assessment, which takes approximately 20 minutes to complete, exceeded the 10-minute recovery time reported by Evans et al. (2003) and may have factored into the absence of statistically significant results. Using marksmanship as the sole operationally relevant post-carry performance metric during testing or conducting a faster-paced assessment prior to other metrics assessed (i.e., grip strength and hand steadiness) may have resulted in more significant findings overall. While this study was unable to conclusively determine whether the use of assistive devices resulted in improved combat performance, the findings further support the rationale that 2-person litter transport with the use of assistive devices can be implemented instead of the traditional 4-person transport technique without increased detriment or risk to the litter bearer or casualty.

Our study used the EST 3000, which is the U.S. Army's Active duty, National Guard, and Reserve units small arms training device, and includes part of the Army Infantry Schools Basics Rifle Marksmanship (BRM) strategy. The inclusion of this marksmanship assessment in the study contributed to an operationally relevant simulated military casualty litter transport scenario by incorporating tasks that the litter bearer may have to perform during casualty transport, such as actively engaging in combat to protect themselves and the casualty during evacuation.

**Subjective Questions**

Ratings of perceived exertion (RPE), discomfort, and fatigue showed an overall increasing trend among all conditions as the number of litter carriage attempts increased from the Baseline levels (Figure 17, Appendix D: Subjective Assessment Supplemental Data). However, the values for RPE and fatigue were lower overall in the assistive device test conditions (SH-A2 and WH-A2) in comparison to the unassisted test conditions (SH-U4 and WH-U4) despite longer carry distances and times. The unilaterality of the 4-person unassisted test conditions (SH-U4 and WH-U4) is likely a contributing factor of the higher RPE and fatigue reported by participants.

The greater levels of discomfort reported for the assistive device test conditions (SH-A2 and WH-A2) could be attributed to the longer carry distances and times in comparison to the unassisted conditions (SH-U4 and WH-U4). The slight differences in discomfort levels between SH-A2 and WH-A2 align with the anecdotal feedback that the litter weight in combination with the design made litter carriage during extended periods with the wrist hooks less comfortable in comparison to the shoulder harness. However, the User Acceptance data outcomes from both groups demonstrate that despite the increased discomfort, the use of an assistive device in a 2-person carry condition (SH-A2 and WH-A2) is preferred over an unassisted carry condition (SH-U4 and WH-U4).

Lastly, the subjective assessments in this study were conducted to assess general RPE, Discomfort, Fatigue, and User Acceptance comparisons between unassisted and assistive device litter casualty transports. Previous work by Rice et al. (1999) included questions for ratings of soreness, pain, and discomfort (SPD) relative to anatomical locations. For example, Rice et al. reported greater SPD in the anterior head/neck, shoulder, and chest during a shoulder harness carry, and greater SPD in the forearm and hand for unassisted carries. While future work will incorporate more specific questions to identify detailed causes and contributors of reported RPE, fatigue, pain, discomfort, and user acceptance related to different assistive device types and designs with the aims of identifying specific assistive devices for integration in military casualty transport scenarios, the overall subjective data findings from this study support the use of 2-person assistive device litter carry techniques in remote and mass casualty transport scenarios.

**Motion Capture**

The use of motion capture technology is a reliable way to quantify spinal kinematics (Schmid et al., 2016; Rast et al., 2016; Ignasiak et al., 2017; Mousavi et al., 2018). To our knowledge, the current study's approach of using motion capture to identify postural changes over a prolonged load carriage task is the first of its kind. Examination of the torso angles provides an observation of the postural fatigue during litter carry. A lower A-P angle and lateral angle from vertical indicate a greater ability of the individual to retain an upright, neutral posture. Shoulder harness and wrist hooks use resulted in mean torso A-P and lateral angles that were lower than their respective unassisted carries (Figures 24 and 25), suggesting that using either assistive device allowed participants to have a more upright, neutral posture; however, the assisted carries were 2-person simulated carries which also engaged both hands resulting in a more balanced carry.

Trends in the torso A-P and lateral angles indicate that assistive device use during litter carriage allows a litter bearer for a 2-person carry to maintain an improved trunk posture compared to a 4-person carry scenario. These postural outcomes are especially beneficial, as the weight carried approximately doubled for assisted carries compared to unassisted carries. Additionally, bilateral carry may reduce occurrences of lower back injury as 4-person teams have produced greater reports of soreness, pain, and discomfort in the lower back compared to 2-person teams (Rice et al., 1999). This is supported by findings of smaller spinal compression when a load is carried bilaterally than when half of the load is carried unilaterally (McGill et al., 2013).

While both assistive devices showed improvements in posture retention over their respective unassisted carries, the effects were demonstracted in varying ways. Shoulder harness use resulted in statistically sifnificant differences in torso lateral angles between most first carry attempts. Wrist hooks use resulted in statistically significant differences in torso A-P angles between most first and last carry attempts. A potential explanation for the postural differences is the mechanism by which each device distributes the litter load. The wrist hooks require large efforts from the upper arms and shoulders wheresas the shoulder harness transfers the majority of the load to the torso. However, limitations of the current study design do not allow for direct comparisons between assistive device carries, and future research is aimed at addressing this gap. Additionally, these efforts resulted in the development and application of a novel motion capture analysis approach. Future research will leverage our motion capture analysis approach to assess the posture retention effects between assistive devices and/or alternative litter carry techniques. Motion capture torso angle analysis findings, like the other study metrics, also support the rationale that 2-person litter transport with the use of assistive devices can be implemented instead of the traditional 4-person transport technique without increased musculoskeletal detriment or risk to the bearer.

## Conclusion

In this study, USAARL investigated the use of COTS assistive devices during litter carriage transport to increase litter bearer performance and reduce post-carry fatigue. In general, researchers found that when compared to an unassisted 4-person carry, our simulated assisted 2-person litter carries provided more consistent outcomes over repeated carry attempts and, in general, maintained or improved the litter bearer's performance and response to carrying a litter despite the litter bearer supporting more weight. The general findings of this pilot study include:

- The COTS assistive devices, with little exposure or training, can be used by any SM at the squad, platoon, battalion, brigade, or division level tasked with remote or mass casualty dismounted carriage litter transport and evacuation scenarios.
- The use of the assistive devices in 2-person simulated carries allowed for farther and more consistent incremental and total carry distances in comparison to unassisted 4-person simulated carries. This can result in decreased evacuation times and an increased number of casualty evacuations in LSCO and MDO scenarios.
- Grip strength was used as a test metric to gauge the litter bearer's ability to continue litter carriage and is expected to play a role in other operational tasks such as providing care and security for the casualty. Both devices improved retention of grip strength over unassisted carries.
- Motion capture determined participants had more neutral spinal postures when using assistive devices during simulated 2-person litter carries than during simulated unassisted 4-person litter carries. Proper spinal posture can reduce fatigue and lower the risk of spinal pain or injury.
- Subjective user feedback data showed the impact of repeated carries or increased distance and time of litter carry, but provided mixed outcomes on the use of assistive devices with three of the four self-reported metrics indicating the perceived benefit of the assistive device. When comparing the assisted 2-person simulated carries to the unassisted 4-person carries, reported perceived exertion and fatigue were generally reported to decrease; however, discomfort was generally reported to increase. Lastly, user acceptance of litter carries was increased when an assistive device was used.
- The fine motor skills assessments will likely require future work to develop proper methodology for more robust results. There were some trends of assistive device use that resulted in improved fine motor skills, but the variances in the data suggest there could also be a familiarization effect among participants.

Based on these outcomes, an assistive device 2-person litter carry technique could replace the traditional unassisted 4-person litter carry technique in remote and mass casualty scenarios resulting in: (a) less personnel needed per casualty transport, (b) decreased evacuation times, and (c) an increased number of casualty evacuations without increased musculoskeletal detriment or risk to the litter bearer.

This pilot study has demonstrated that assistive device use can provide a myriad of benefits to litter bearers; however, it is recommended that more work is needed to further examine and quantify the use of assistive devices during litter carry in a variety of transport scenarios. Future work should compare 2-person and 4-person teams, with male and female participants completing the tasks under all assisted and unassisted conditions to confirm the effects found here are due to assistive device usage and not differences in single-handed and double-handed load carriage. Future studies should also aim to include the use of other assistive devices, such as exoskeletons, to be examined for their effects on litter bearer performance and post-carry fatigue while taking into consideration: (1) internal and external design, (2) personal protective equipment and evacuation duties, (3) load effects, (4) dynamic movement and environment durability, (5) storage, transport, and deployment, and (6) safety and reliability

(Madison et al., 2022). Future work also needs to be conducted in a field environment and with individuals specifically serving in a litter bearer role to ensure real-world applicability and to include other tasks associated with litter transport such loading and unloading of casualities into vehicles. These data outcomes will aid in establishing a standard to evaluate the efficacy and feasibility of assistive devices as well as the selection and integration of assistive devices into the standard Military Equipment Set for litter carriage transport procedures.

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## Appendix A. Litter Carry Distance and Time Supplemental Data

*Table A1*. Mean, Standard Deviation (SD), and Range of Litter Carry Distance per Five One-Kilometer Attempts

| One-Kilometer Carry Attempt | Shoulder Harness ($n$ = 6) | | | | | | Wrist Hooks ($n$ = 6) | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | SH-U4 | | | SH-A2 | | | WH-U4 | | | WH-A2 | | |
| | Mean (m) | SD (m) | Range (m) | Mean (m) | SD (m) | Range (m) | Mean (m) | SD (m) | Range (m) | Mean (m) | SD (m) | Range (m) |
| **1** | 591 | 349 | 183-1000 | 911 | 219 | 464-1000 | 809 | 243 | 491-1000 | 838 | 194 | 552-1000 |
| **2** | 581[a] | 280 | 310-1000 | 919[a] | 199 | 513-1000 | 686 | 326 | 357-1000 | 708 | 322 | 349-1000 |
| **3** | 524[a] | 288 | 290-1000 | 843[a] | 243 | 526-1000 | 536 | 315 | 243-1000 | 690 | 343 | 296-1000 |
| **4** | 489[a] | 277 | 256-1000 | 919[a] | 197 | 516-1000 | 517 | 342 | 175-1000 | 565 | 339 | 299-1000 |
| **5** | 478[a] | 295 | 236-1000 | 922[a] | 191 | 533-1000 | 507 | 342 | 161-1000 | 574 | 336 | 268-1000 |

*Note.* Unassisted shoulder harness (SH-U4), shoulder harness (SH-A2), unassisted wrist hooks (WH-U4), and wrist hooks (WH). Range (meters) equals minimum to maximum carry distance values recorded. [a] denotes statistically significant difference between test conditions (SH-U4 and SH-A2) in Carry Attempts 2 through 5 for the Shoulder Harness group.

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*Table A2.* Mean, Standard Deviation, and Range of Total Litter Carry Distance

| Group ($n$ = 6) | Test Condition | Mean (m) | SD (m) | Range (m) |
|---|---|---|---|---|
| **Shoulder Harness** | SH-U4 | 2662[a] | 1432 | 1476-5000 |
| | SH-A2 | 4514[a] | 976 | 2560-5000 |
| **Wrist Hooks** | WH-U4 | 3055 | 1501 | 1476-5000 |
| | WH-A2 | 3375 | 1380 | 1834-5000 |

*Note.* Unassisted shoulder harness (SH-U4), shoulder harness (SH-A2), unassisted wrist hooks (WH-U4), and wrist hooks (WH-A2). Range (meters) equals minimum to maximum carry distance values recorded. [a] denotes statistically significant difference between test conditions for the Shoulder Harness group.

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*Table A3*. Mean, Standard Deviation, and Total Distance of Each Litter Carry Attempt for all Shoulder Harness Group Participants

| One-Kilometer Carry Attempt | V001 | | V003 | | V005 | | V007 | | V009 | | V014 | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | SH-U4 (m) | SH-A2 (m) | SH-U4 (m) | SH-A2 (m) | SH-U4 (m) | SH-A2 (m) | SH-U4 (m) | SH-A2 (m) | SH-U4 (m) | SH-A2 (m) | SH-U4 (m) | SH-A2 (m) |
| **1** | 332 | 1000 | 183 | 1000 | 397 | 464 | 634 | 1000 | 1000 | 1000 | 1000 | 1000 |
| **2** | 363 | 1000 | 490 | 1000 | 468 | 513 | 310 | 1000 | 853 | 1000 | 1000 | 1000 |
| **3** | 290 | 1000 | 307 | 526 | 392 | 533 | 398 | 1000 | 757 | 1000 | 1000 | 1000 |
| **4** | 256 | 1000 | 273 | 1000 | 402 | 516 | 422 | 1000 | 580 | 1000 | 1000 | 1000 |
| **5** | 236 | 1000 | 239 | 1000 | 349 | 533 | 408 | 1000 | 634 | 1000 | 1000 | 1000 |
| **Mean** | 295 | 1000 | 298 | 905 | 402 | 512 | 434 | 1000 | 765 | 1000 | 1000 | 1000 |
| **SD** | 53 | 0 | 117 | 212 | 43 | 29 | 120 | 0 | 169 | 0 | 0 | 0 |
| **Total** | 1476 | 5000 | 1491 | 4526 | 2008 | 2560 | 2172 | 5000 | 3823 | 5000 | 5000 | 5000 |

*Note*. Unassisted shoulder harness (SH-U4) and shoulder harness (SH-A2). Participants received a unique alphanumerical label starting with "V" and followed by three numbers. Values are represented in meters. Shaded cells represent the participant reaching the maximum distance to carry (1000 meters) for that carry attempt.

*Table A4.* Mean, Standard Deviation, and Total Distance of Each Litter Carry Attempt for all Wrist Hooks Group Participants

| One-Kilometer Carry Attempt | V004 | | V006 | | V008 | | V011 | | V013 | | V015 | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | WH-U4 (m) | WH-A2 (m) | WH-U4 (m) | WH-A2 (m) | WH-U4 (m) | WH-A2 (m) | WH-U4 (m) | WH-A2 (m) | WH-U4 (m) | WH-A2 (m) | WH-U4 (m) | WH-A2 (m) |
| **1** | 491 | 797 | 840 | 552 | 1000 | 1000 | 521 | 1000 | 1000 | 1000 | 1000 | 678 |
| **2** | 403 | 440 | 409 | 349 | 1000 | 1000 | 357 | 1000 | 947 | 1000 | 1000 | 459 |
| **3** | 310 | 425 | 243 | 296 | 1000 | 1000 | 247 | 1000 | 676 | 1000 | 738 | 419 |
| **4** | 329 | 398 | 175 | 307 | 1000 | 1000 | 183 | 1000 | 625 | 299 | 792 | 388 |
| **5** | 372 | 456 | 161 | 330 | 1000 | 1000 | 169 | 1000 | 533 | 268 | 806 | 391 |
| **Mean** | 381 | 503 | 366 | 367 | 1000 | 1000 | 295 | 1000 | 756 | 713 | 867 | 467 |
| **SD** | 72 | 166 | 283 | 105 | 0 | 0 | 146 | 0 | 206 | 392 | 124 | 121 |
| **Total** | 1905 | 2516 | 1829 | 1834 | 5000 | 5000 | 1476 | 5000 | 3781 | 3567 | 4336 | 2333 |

*Note*. Unassisted wrist hooks (WH-U4) and wrist hooks (WH). Participants received a unique alphanumerical label starting with "V" and followed by three numbers. Values are represented in meters. Shaded cells represent the participant reaching the maximum distance to carry (1000 meters) for that carry attempt.

*Table A5*. Mean, Standard Deviation, and Range of Litter Carry Time per Five One-Kilometer Attempts

| One-Kilometer Carry Attempt | Shoulder Harness (*n* = 6) | | | | | | Wrist Hooks (*n* = 6) | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | SH-U4 | | | SH-A2 | | | WH-U4 | | | WH-A2 | | |
| | Mean (min) | SD (min) | Range (min) | Mean (min) | SD (min) | Range (min) | Mean (min) | SD (min) | Range (min) | Mean (min) | SD (min) | Range (min) |
| **1** | 6.4 | 3.7 | 2.0-10.8 | 9.8 | 2.4 | 5.0-10.8 | 8.7 | 2.6 | 5.3-10.8 | 9.0 | 2.1 | 5.9-10.8 |
| **2** | 6.2 | 3.0 | 3.3-10.8 | 9.9 | 2.1 | 5.5-10.8 | 7.4 | 3.5 | 3.8-10.8 | 7.6 | 3.5 | 3.8-10.8 |
| **3** | 5.6 | 3.1 | 3.1-10.8 | 9.1 | 2.6 | 5.7-10.8 | 5.8 | 3.4 | 2.6-10.8 | 7.4 | 3.7 | 3.2-10.8 |
| **4** | 5.3 | 3.0 | 2.8-10.8 | 9.9 | 2.1 | 5.6-10.8 | 5.6 | 3.7 | 1.9-10.8 | 6.1 | 3.6 | 3.2-10.8 |
| **5** | 5.1 | 3.2 | 2.5-10.8 | 9.9 | 2.0 | 5.7-10.8 | 5.5 | 3.7 | 1.7-10.8 | 6.2 | 3.6 | 2.9-10.8 |

*Note.* Unassisted shoulder harness (SH-U4), shoulder harness (SH-A2), unassisted wrist hooks (WH-U4), and wrist hooks (WH). Range (minutes) equals minimum to maximum carry time values recorded. Participants completed each litter carry attempt at a pace of 3.5 mph.

*Table A6.* Mean, Standard Deviation, and Range of Total Litter Carry Time

| Group ($n$ = 6) | Test Condition | Mean (min) | SD (min) | Range (min) |
|---|---|---|---|---|
| **Shoulder Harness** | SH-U4 | 28.6[a] | 15.4 | 15.9-53.8 |
| | SH-A2 | 48.5[a] | 10.5 | 27.5-53.8 |
| **Wrist Hooks** | WH-U4 | 32.8 | 16.1 | 15.9-53.8 |
| | WH-A2 | 36.3 | 14.8 | 19.7-53.8 |

*Note.* Unassisted shoulder harness (SH-U4), shoulder harness (SH-A2), unassisted wrist hooks (WH-U4), and wrist hooks (WH-A2). Range (minutes) equals minimum to maximum carry time values recorded. [a]Statistically significant difference between test conditions for the Shoulder Harness group.

*Table A7*. Mean, Standard Deviation, and Total Time of Litter Carry Attempts for Each Participant in Shoulder Harness Group

| One-Kilometer Carry Attempt | V001 | | V003 | | V005 | | V007 | | V009 | | V014 | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | SH-U4 (min) | SH-A2 (min) | SH-U4 (min) | SH-A2 (min) | SH-U4 (min) | SH-A2 (min) | SH-U4 (min) | SH-A2 (min) | SH-U4 (min) | SH-A2 (min) | SH-U4 (min) | SH-A2 (min) |
| **1** | 3.6 | 10.8 | 2.0 | 10.8 | 4.3 | 5.0 | 6.8 | 10.8 | 10.8 | 10.8 | 10.8 | 10.8 |
| **2** | 3.9 | 10.8 | 5.3 | 10.8 | 5.0 | 5.5 | 3.3 | 10.8 | 9.2 | 10.8 | 10.8 | 10.8 |
| **3** | 3.1 | 10.8 | 3.3 | 5.7 | 4.2 | 5.7 | 4.3 | 10.8 | 8.1 | 10.8 | 10.8 | 10.8 |
| **4** | 2.8 | 10.8 | 2.9 | 10.8 | 4.3 | 5.6 | 4.5 | 10.8 | 6.2 | 10.8 | 10.8 | 10.8 |
| **5** | 2.5 | 10.8 | 2.6 | 10.8 | 3.8 | 5.7 | 4.4 | 10.8 | 6.8 | 10.8 | 10.8 | 10.8 |
| **Mean** | 3.2 | 10.8 | 3.2 | 9.7 | 4.3 | 5.5 | 4.7 | 10.8 | 8.2 | 10.8 | 10.8 | 10.8 |
| **SD** | 0.6 | 0.0 | 1.3 | 2.3 | 0.5 | 0.3 | 1.3 | 0.0 | 1.8 | 0.0 | 0.0 | 0.0 |
| **Total** | 15.9 | 53.8 | 16.0 | 48.7 | 21.6 | 27.5 | 23.4 | 53.8 | 41.1 | 53.8 | 53.8 | 53.8 |

*Note.* Unassisted shoulder harness (SH-U4) and shoulder harness (SH-A2). Participants received a unique alphanumerical label starting with "V" and followed by three numbers. Values are represented in minutes. Participants completed each litter carry attempt at a pace of 3.5 mph.

*Table A8.* Mean, Standard Deviation, and Total Time of Litter Carry Attempts for Each Participant in Wrist Hooks Group

| **One-Kilometer Carry Attempt** | **V004** | | **V006** | | **V008** | | **V011** | | **V013** | | **V015** | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | **WH-U4 (min)** | **WH-A2 (min)** | **WH-U4 (min)** | **WH-A2 (min)** | **WH-U4 (min)** | **WH-A2 (min)** | **WH-U4 (min)** | **WH-A2 (min)** | **WH-U4 (min)** | **WH-A2 (min)** | **WH-U4 (min)** | **WH-A2 (min)** |
| **1** | 5.3 | 8.6 | 9.0 | 5.9 | 10.8 | 10.8 | 5.6 | 10.8 | 10.8 | 10.8 | 10.8 | 7.3 |
| **2** | 4.3 | 4.7 | 4.4 | 3.8 | 10.8 | 10.8 | 3.8 | 10.8 | 10.2 | 10.8 | 10.8 | 4.9 |
| **3** | 3.3 | 4.6 | 2.6 | 3.2 | 10.8 | 10.8 | 2.7 | 10.8 | 7.3 | 10.8 | 7.9 | 4.5 |
| **4** | 3.5 | 4.3 | 1.9 | 3.3 | 10.8 | 10.8 | 2.0 | 10.8 | 6.7 | 3.2 | 8.5 | 4.2 |
| **5** | 4.0 | 4.9 | 1.7 | 3.6 | 10.8 | 10.8 | 1.8 | 10.8 | 5.7 | 2.9 | 8.7 | 4.2 |
| **Mean** | 4.1 | 5.4 | 3.9 | 3.9 | 10.8 | 10.8 | 3.2 | 10.8 | 8.1 | 7.7 | 9.3 | 5.0 |
| **SD** | 0.8 | 1.8 | 3.0 | 1.1 | 0.0 | 0.0 | 1.6 | 0.0 | 2.2 | 4.2 | 1.3 | 1.3 |
| **Total** | 20.5 | 27.1 | 19.7 | 19.7 | 53.8 | 53.8 | 15.9 | 53.8 | 40.7 | 38.4 | 46.6 | 25.1 |

*Note.* Unassisted wrist hooks (WH-U4) and wrist hooks (WH-A2). Participants received a unique alphanumerical label starting with "V" and followed by three numbers. Values are represented in minutes. Participants completed each litter carry attempt at a pace of 3.5 mph.

## Appendix B. Grip Strength Supplemental Data

*Table B1.* Mean, Standard Deviation, and Range of Grip Strength at Baseline and per Carry Attempt

| Attempt | SH (*n* = 5) | | | | | | WH (*n* = 5) | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | SH-U4 | | | SH-A2 | | | WH-U4 | | | WH-A2 | | |
| | Mean (kg) | SD (kg) | Range (kg) | Mean (kg) | SD (kg) | Range (kg) | Mean (kg) | SD (kg) | Range (kg) | Mean (kg) | SD (kg) | Range (kg) |
| **Baseline** | 45.2 | 7.9 | 36.1-56.2 | 44.8 | 6.4 | 34.8-51.5 | 45.5 | 6.2 | 39.8-55.6 | 45.7 | 6.8 | 38.9-56.7 |
| **1** | 43.7 | 7.2 | 38.0-55.7 | 44.3 | 6.7 | 37.6-53.3 | 37.3[b] | 8.3 | 28.1-50.7 | 43.2[b] | 8.1 | 35.8-55.7 |
| **2** | 37.0 | 7.9 | 31.7-50.9 | 40.9 | 4.0 | 34.1-43.8 | 32.2[b] | 7.3 | 23.8-43.3 | 42.0[b] | 7.1 | 32.6-52.4 |
| **3** | 35.8 | 7.7 | 31.3-49.4 | 41.7 | 4.1 | 36.9-47.7 | 31.3[b] | 7.9 | 25.0-44.9 | 41.9[b] | 7.8 | 34.9-55.2 |
| **4** | 34.6[a] | 8.5 | 27.6-48.6 | 42.6[a] | 5.0 | 38.5-48.9 | 32.7 | 10.0 | 21.4-48.1 | 39.8 | 10.2 | 32.8-57.6 |
| **5** | 30.5[a] | 9.3 | 21.0-41.0 | 45.0[a] | 6.4 | 38.4-53.0 | 28.3[b] | 8.3 | 20.9-42.5 | 39.8[b] | 10.0 | 33.1-57.0 |

*Note.* Unassisted shoulder harness (SH-U4), shoulder harness (SH-A2), unassisted wrist hooks (WH-U4), and wrist hooks (WH-A2). Range equals minimum to maximum values recorded. [a] denotes stastically significant difference in the Shoulder Harness group between conditions SH-U4 and SH-A2 for Carry Attempts 4 and 5. [b] denotes stastically significant difference in the Wrist Hooks group between conditions WH-U4 and WH-A2 for Carry Attempts 1, 2, 3, and 5.

*Table B2*. Mean, Standard Deviation, and Range of Grip Strength at Baseline and per Carry Attempt for Each Participant in Shoulder Harness Group

| Attempt | V001 | | V003 | | V005 | | V007 | | V014 | |
|---|---|---|---|---|---|---|---|---|---|---|
| | SH-U4 (kg) | SH-A2 (kg) | SH-U4 (kg) | SH-A2 (kg) | SH-U4 (kg) | SH-A2 (kg) | SH-U4 (kg) | SH-A2 (kg) | SH-U4 (kg) | SH-A2 (kg) |
| **Baseline** | 45.8 | 46.8 | 56.2 | 51.5 | 36.1 | 34.8 | 48.6 | 48.0 | 39.4 | 42.8 |
| **1** | 40.6 | 45.5 | 55.7 | 53.3 | 44.9 | 37.6 | 39.5 | 47.3 | 38.0 | 37.7 |
| **2** | 34.5 | 42.9 | 50.9 | 43.2 | 32.5 | 34.1 | 35.5 | 43.8 | 31.7 | 40.4 |
| **3** | 31.3 | 39.2 | 49.4 | 47.7 | 32.4 | 41.5 | 33.2 | 43.1 | 32.6 | 36.9 |
| **4** | 27.6 | 38.5 | 48.6 | 48.9 | 29.0 | 38.8 | 36.8 | 47.1 | 31.2 | 39.7 |
| **5** | 26.5 | 41.8 | 39.9 | 50.6 | 21.0 | 38.4 | 41.0 | 53.0 | 24.3 | 41.5 |
| **Mean** | 34.4 | 42.5 | 50.1 | 49.2 | 32.7 | 37.5 | 39.1 | 47.1 | 32.9 | 39.8 |
| **SD** | 7.6 | 3.3 | 5.9 | 3.5 | 7.9 | 2.8 | 5.4 | 3.5 | 5.4 | 2.2 |
| **Percent Difference Between Baseline and Attempt 5 (%)** | 42.2% | 10.9% | 29.0% | 1.9% | 41.8% | -10.3% | 15.7% | -10.3% | 38.5% | 3.1% |

*Note*. Unassisted shoulder harness (SH-U4) and shoulder harness (SH-A2). Participants received a unique alphanumerical label starting with “V” and followed by three numbers. Values are represented in kilograms except for percent differences, which are represented in percentages.

*Table B3.* Mean, Standard Deviation, and Range of Grip Strength at Baseline and per Carry Attempt for Each Participant in the WH Group

| Attempt | V004 | | V006 | | V008 | | V011 | | V013 | |
|---|---|---|---|---|---|---|---|---|---|---|
| | **WH-U4 (kg)** | **WH-A2 (kg)** | **WH-U4 (kg)** | **WH-A2 (kg)** | **WH-U4 (kg)** | **WH-A2 (kg)** | **WH-U4 (kg)** | **WH-A2 (kg)** | **WH-U4 (kg)** | **WH-A2 (kg)** |
| **Baseline** | 55.6 | 56.7 | 46.4 | 38.9 | 41.5 | 46.3 | 44.3 | 45.4 | 39.8 | 41.4 |
| **1** | 50.7 | 55.7 | 36.8 | 43.2 | 37.2 | 44.8 | 28.1 | 36.4 | 33.9 | 35.8 |
| **2** | 43.3 | 52.4 | 31.8 | 41.1 | 34.0 | 40.8 | 28.1 | 32.6 | 23.8 | 43.0 |
| **3** | 44.9 | 55.2 | 27.1 | 41.3 | 28.9 | 40.5 | 30.8 | 34.9 | 25.0 | 37.8 |
| **4** | 48.1 | 57.6 | 21.4 | 38.6 | 29.0 | 32.8 | 29.4 | 34.5 | 35.7 | 35.5 |
| **5** | 42.5 | 57.0 | 20.9 | 39.9 | 27.2 | 33.1 | 24.8 | 34.7 | 26.1 | 34.3 |
| **Mean** | 47.5 | 55.8 | 30.7 | 40.5 | 33.0 | 39.7 | 30.9 | 36.4 | 30.7 | 38.0 |
| **SD** | 5.0 | 1.9 | 9.8 | 1.7 | 5.6 | 5.7 | 6.8 | 4.6 | 6.6 | 3.5 |
| **Percent Difference Between Baseline and Attempt 5 (%)** | 23.6% | -0.6% | 54.9% | -2.6% | 34.5% | 28.5% | 43.9% | 23.7% | 34.4% | 17.1% |

*Note*. Unassisted wrist hooks (WH-U4) and wrist hooks (WH-A2). Participants received a unique alphanumerical label starting with "V" and followed by three numbers. Values are represented in kilograms except for percent differences, which are represented in percentages.

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## Appendix C. Marksmanship Assessment Supplemental Data

*Table C1.* Mean, Standard Deviation, and Range of Marksmanship Assessments at Baseline and Post-Carry

| Posture | Group (*n* = 6) | Test Condition | Baseline | | Post-Carry | |
|---|---|---|---|---|---|---|
| | | | Mean | SD | Mean | SD |
| **Prone Supported Hits (Max: 20)** | **Shoulder Harness** | SH-U4 | 15.33 | 3.88 | 15.00 | 3.29 |
| | | SH-A2 | 15.67 | 2.80 | 14.67 | 3.44 |
| | **Wrist Hooks** | WH-U4 | 16.33 | 4.32 | 15.33 | 3.67 |
| | | WH-A2 | 16.83 | 3.66 | 17.33 | 2.34 |
| **Prone Unsupported Hits (Max: 10)** | **Shoulder Harness** | SH-U4 | 7.33 | 1.86 | 6.33 | 2.07 |
| | | SH-A2 | 6.67 | 2.07 | 7.83 | 2.04 |
| | **Wrist Hooks** | WH-U4 | 7.00 | 2.00 | 6.83 | 1.60 |
| | | WH-A2 | 8.33 | 2.16 | 7.33 | 1.03 |
| **Kneeling Hits (Max: 10)** | **Shoulder Harness** | SH-U4 | 7.67 | 2.07 | 7.5 | 1.05 |
| | | SH-A2 | 7.00 | 1.67 | 6.33 | 2.16 |
| | **Wrist Hooks** | WH-U4 | 6.00 | 1.90 | 6.67 | 1.97 |
| | | WH-A2 | 6.67 | 1.75 | 5.67 | 1.03 |
| **Total Hits (Max: 40)** | **Shoulder Harness** | SH-U4 | 30.33 | 6.12 | 28.83 | 5.85 |
| | | SH-A2 | 29.33 | 5.61 | 28.83 | 5.42 |
| | **Wrist Hooks** | WH-U4 | 29.33 | 6.86 | 28.83 | 4.26 |
| | | WH-A2 | 31.83 | 7.14 | 30.33 | 2.16 |

*Note*. Unassisted shoulder harness (SH-U4), shoulder harness (SH-A2), unassisted wrist hooks (WH-U4), and wrist hooks (WH-A2). Range equals minimum to maximum values recorded.

## Appendix D. Subjective Assessment Supplemental Data

*Table D1.* Mean (Standard Deviation) of Subjective Rating of Perceived Exertion at Baseline, After Each Carry Attempt, and Post-Carry

| Attempt | Shoulder Harness ($n$ = 6) | | Wrist Hooks ($n$ = 6) | |
|---|---|---|---|---|
| | SH-U4 | SH-A2 | WH-U4 | WH-A2 |
| **Baseline** | 7.0(1.3)[a] | 6.5(0.8)[a] | 6.7(1.0) | 6.8(1.3) |
| **1** | 10.3(1.0)[a] | 8.7(1.2)[a] | 11.0(2.5) | 10.2(1.9) |
| **2** | 11.3(1.2) | 9.8(1.2) | 12.2(3.4) | 11.0(2.4) |
| **3** | 11.7(2.0) | 10.5(1.6) | 13.7(2.9) | 12.8(2.3) |
| **4** | 12.0(1.9) | 10.2(2.0) | 14.5(2.2) | 13.5(3.4) |
| **5** | 12.3(1.6) | 10.3(3.0) | 13.8(3.4) | 12.7(3.4) |
| **Post-Carry** | 8.8(3.4) | 7.5(1.5) | 7.3(1.8) | 7.0(1.3) |

*Note*. Rating of Perceived Exertion (RPE) assessed on 6-20 scale for unassisted shoulder harness (SH-U4), shoulder harness (SH-A2), unassisted wrist hooks (WH-U4), and wrist hooks (WH-A2) at the beginning of the litter carry sequence (Baseline), the end of each Carry Attempt, and Post-Carry. Higher numbers are indicative of greater subjective feelings of RPE. [a] indicates statistically significant difference in RPE between carry conditions (SH-U4 and SH-A2) for the Shoulder Harness group.

*Table D2.* Mean (Standard Deviation) of Subjective Discomfort at Baseline, After Each Carry Attempt, and Post-Carry

| **Attempt** | **Shoulder Harness (*n* = 6)** | | **Wrist Hooks (*n* = 6)** | |
|---|---|---|---|---|
| | **SH-U4** | **SH-A2** | **WH-U4** | **WH-A2** |
| **Baseline** | 0.0(0.0) | 0.3(0.8) | 0.2(0.4) | 0.8(1.3) |
| **1** | 2.0(1.5) | 2.5(1.4) | 4.7(2.9) | 4.5(2.0) |
| **2** | 3.5(0.8) | 4.2(1.2) | 5.3(2.9) | 5.8(1.7) |
| **3** | 4.2(1.2) | 5.5(1.6) | 6.2(2.6) | 7.0(1.4) |
| **4** | 4.5(1.0) | 5.0(1.4) | 6.3(2.7) | 6.8(2.1) |
| **5** | 4.2(1.0) | 5.0(1.1) | 6.5(3.0) | 6.8(2.7) |
| **Post-Carry** | 2.5(2.7) | 1.2(1.6) | 2.3(1.6) | 2.2(1.8) |

*Note*. Discomfort on 0 to 10 scale for unassisted shoulder harness (SH-U4), shoulder harness (SH-A2), unassisted wrist hooks (WH-U4), and wrist hooks (WH-A2) at the beginning of the litter carry sequence (Baseline), the end of each carry attempt, and Post-Carry. Higher numbers are indicative of greater subjective feelings of discomfort.

*Table D3.* Mean (Standard Deviation) of Subjective Fatigue at Baseline, After Each Carry Attempt, and Post-Carry

| **Attempt** | **Shoulder Harness (*n* = 6)** | | **Wrist Hooks (*n* = 6)** | |
|---|---|---|---|---|
| | **SH-U4** | **SH-A2** | **WH-U4** | **WH-A2** |
| **Baseline** | 0.5(0.8) | 0.8(1.3) | 0.3(0.8) | 0.7(1.2) |
| **1** | 3.2(0.8) | 2.8(0.8) | 5.0(3.2) | 3.7(2.3) |
| **2** | 4.0(1.3) | 4.0(0.9) | 5.7(3.1) | 4.8(2.1) |
| **3** | 4.8(1.5) | 4.2(1.0) | 6.5(2.5) | 5.7(2.3) |
| **4** | 5.2(1.9) | 4.5(1.2) | 7.0(2.3) | 6.3(2.0) |
| **5** | 5.3(1.8) | 4.7(1.0) | 7.8(1.7) | 6.2(2.6) |
| **Post-Carry** | 3.2(2.2) | 1.5(1.6) | 3.3(1.5) | 3.3(2.0) |

*Note*. Fatigue on 0 to 10 scale for unassisted shoulder harness (SH-U4), shoulder harness (SH-A2), unassisted wrist hooks (WH-U4), and wrist hooks (WH-A2) at the beginning of the litter carry sequence (Baseline), the end of each carry attempt, and Post-Carry. Higher numbers are indicative of greater subjective feelings of fatigue.

*Table D4.* Mean (Standard Deviation) of Subjective User Acceptance assessed Post-Carry

| | Shoulder Harness ($n$ = 6) | | Wrist Hooks ($n$ = 6) | |
|---|---|---|---|---|
| | **SH-U4** | **SH-A2** | **WH-U4** | **WH-A2** |
| **Post-Carry** | 2.8 (2.2) [a] | 4.8 (3.1) [a] | 3.8 (1.2) | 4.8 (3.8) |

*Note*. User Acceptance on 0 to 10 scale for unassisted shoulder harness (SH-U4), shoulder harness (SH-A2), unassisted wrist hooks (WH-U4), and wrist hooks (WH-A2) assessed at Post-Carry. Higher numbers indicate greater user acceptance. [a] indicates statistically significant difference in User Acceptance between carry conditions (SH-U4 and SH-A2) for the Shoulder Harness group.

## Appendix E. Fine Motor Skills Assessments Supplemental Data

*Table E1.* Fine Motor Skills Assessments: Steadiness

| **Attempt** | **Test Condition (*n* = 6)** | **Errors** | | | **Non-Errors Percent Duration (%)** | | |
|---|---|---|---|---|---|---|---|
| | | **Mean** | **SD** | **Range** | **Mean** | **SD** | **Range** |
| **Baseline** | SH-U4 | 5 | 8 | 0-21 | 99 | 2 | 94-100 |
| | SH-A2 | 5 | 8 | 0-20 | 98 | 5 | 88-100 |
| | WH-U4 | 11 | 15 | 0-38 | 98 | 3 | 93-100 |
| | WH-A2 | 9 | 12 | 0-33 | 98 | 4 | 90-100 |
| **1** | SH-U4 | 9 | 10 | 0-22 | 98 | 4 | 91-100 |
| | SH-A2 | 6 | 5 | 0-14 | 99 | 2 | 96-100 |
| | WH-U4 | 16 | 16 | 1-42 | 96 | 4 | 90-99 |
| | WH-A2 | 7 | 8 | 0-20 | 98 | 2 | 95-100 |
| **2** | SH-U4 | 11 | 10 | 3-27 | 97 | 3 | 91-99 |
| | SH-A2 | 13 | 10 | 1-27 | 96 | 4 | 88-99 |
| | WH-U4 | 17 | 16 | 5-42 | 96 | 4 | 90-99 |
| | WH-A2 | 12 | 12 | 0-28 | 97 | 3 | 93-100 |
| **3** | SH-U4 | 10 | 12 | 2-33 | 97 | 4 | 90-99 |
| | SH-A2 | 16 | 14 | 1-35 | 97 | 3 | 93-99 |
| | WH-U4 | 16 | 10 | 5-31 | 96 | 3 | 91-99 |
| | WH-A2 | 12 | 10 | 0-24 | 97 | 2 | 94-100 |
| **4** | SH-U4 | 10 | 8 | 2-21 | 97 | 3 | 91-99 |
| | SH-A2 | 10 | 7 | 2-17 | 97 | 4 | 90-99 |
| | WH-U4 | 15 | 14 | 2-32 | 96 | 4 | 91-99 |
| | WH-A2 | 11 | 13 | 0-32 | 97 | 4 | 89-100 |
| **5** | SH-U4 | 9 | 5 | 1-16 | 98 | 1 | 97-99 |
| | SH-A2 | 9 | 9 | 1-26 | 97 | 4 | 89-99 |
| | WH-U4 | 15 | 14 | 1-39 | 96 | 4 | 89-99 |
| | WH-A2 | 15 | 16 | 0-39 | 96 | 6 | 85-100 |

*Note*. Unassisted shoulder harness (SH-U4), shoulder harness (SH-A2), unassisted wrist hooks (WH-U4), and wrist hooks (WH-A2). Range equals minimum to maximum values recorded. Non-error percent duration is the percent of time a participant was performing the task without error.

*Table E2*. Fine Motor Skills Assessments: Line Tracing

| Attempt | Test Condition ($n$ = 6) | Errors | | | Total Duration (s) | | |
|---|---|---|---|---|---|---|---|
| | | Mean | SD | Range | Mean | SD | Range |
| Baseline | SH-U4 | 26 | 7 | 18-38 | 24.87[a] | 11.64 | 14.61-45.94 |
| | SH-A2 | 23 | 7 | 16-35 | 20.26[a] | 9.36 | 10.38-35.77 |
| | WH-U4 | 29 | 9 | 17-40 | 28.43[b] | 4.85 | 22.34-34.52 |
| | WH-A2 | 25 | 7 | 17-36 | 24.48[b] | 3.37 | 20.67-30.54 |
| 1 | SH-U4 | 30 | 9 | 20-42 | 20.35 | 6.55 | 12.44-29.53 |
| | SH-A2 | 26 | 5 | 20-32 | 19.32 | 9.36 | 11.18-34.88 |
| | WH-U4 | 33 | 4 | 28-38 | 28.41 | 5.78 | 22.52-36.62 |
| | WH-A2 | 29 | 6 | 19-36 | 25.66 | 4.93 | 18.59-32.58 |
| 2 | SH-U4 | 34 | 11 | 23-52 | 22.14 | 9.72 | 12.14-35.86 |
| | SH-A2 | 24 | 3 | 20-28 | 19.57 | 7.43 | 10.88-30.33 |
| | WH-U4 | 35 | 7 | 24-44 | 26.82 | 4.56 | 21.23-31.64 |
| | WH-A2 | 32 | 7 | 21-41 | 26.67 | 5.36 | 22.39-34.76 |
| 3 | SH-U4 | 37 | 13 | 19-57 | 23.49 | 11.29 | 11.82-38.98 |
| | SH-A2 | 25 | 7 | 20-38 | 17.70 | 7.50 | 8.98-26.74 |
| | WH-U4 | 37 | 13 | 21-58 | 28.42[b] | 4.75 | 25.32-37.74 |
| | WH-A2 | 33 | 6 | 25-40 | 23.89[b] | 4.67 | 19.61-30.41 |
| 4 | SH-U4 | 28 | 8 | 18-39 | 22.41 | 11.39 | 12.64-42.84 |
| | SH-A2 | 26 | 5 | 18-32 | 18.12 | 6.94 | 10.39-27.18 |
| | WH-U4 | 33 | 7 | 23-44 | 27.37[b] | 4.03 | 23.13-34.84 |
| | WH-A2 | 33 | 10 | 20-47 | 24.94[b] | 4.73 | 20.22-33.23 |
| 5 | SH-U4 | 31 | 11 | 19-42 | 21.48 | 10.65 | 12.16-39.36 |
| | SH-A2 | 28 | 4 | 24-34 | 18.00 | 6.38 | 9.54-25.36 |
| | WH-U4 | 34 | 9 | 25-49 | 26.40 | 2.49 | 24.38-31.08 |
| | WH-A2 | 27 | 9 | 16-38 | 23.32 | 3.34 | 19.52-28.33 |

*Note*. Unassisted shoulder harness (SH-U4), shoulder harness (SH-A2), unassisted wrist hooks (WH-U4), and wrist hooks (WH-A2). Range equals minimum to maximum values recorded. [a] denotes stastically significant difference in the line tracing total duration Baseline test conditions for the Shoulder Harness group (SH-U4 versus SH-A2). [b] indicates a statistically significant difference in line tracing duration Baseline, after Carry Attempt 3, and after Carry Attempt 4 between unassisted and assisted carry for the Wrist Hooks group.

*Table E3.* Fine Motor Skills Assessments: Aiming

| Attempt | Test Condition ($n$ = 6) | Hits | | | Total Duration (s) | | |
|---|---|---|---|---|---|---|---|
| | | Mean | SD | Range | Mean | SD | Range |
| Baseline | SH-U4 | 20 | 1 | 18-20 | 6.29 | 0.88 | 5.23-7.72 |
| | SH-A2 | 20 | 0 | 19-20 | 6.13 | 0.76 | 5.03-7.16 |
| | WH-U4 | 20 | 1 | 18-20 | 7.24 | 1.30 | 5.60-8.67 |
| | WH-A2 | 20 | 1 | 19-20 | 6.75 | 1.51 | 5.33-8.98 |
| 1 | SH-U4 | 19 | 1 | 17-20 | 6.28 | 0.79 | 5.30-7.41 |
| | SH-A2 | 20 | 0 | 19-20 | 6.24 | 1.07 | 4.94-7.93 |
| | WH-U4 | 19 | 1 | 17-20 | 7.49 | 1.98 | 5.71-10.61 |
| | WH-A2 | 20 | 0 | 19-20 | 6.93 | 1.19 | 5.74-8.69 |
| 2 | SH-U4 | 20 | 1 | 18-20 | 6.42 | 0.87 | 5.57-7.69 |
| | SH-A2 | 20 | 0 | 19-20 | 6.33 | 1.33 | 4.92-8.15 |
| | WH-U4 | 20 | 1 | 18-20 | 7.21 | 1.69 | 5.65-9.86 |
| | WH-A2 | 20 | 0 | 19-20 | 6.97 | 1.19 | 5.50-8.71 |
| 3 | SH-U4 | 20 | 0 | 20-20 | 6.54 | 0.92 | 5.24-7.71 |
| | SH-A2 | 19 | 1 | 18-20 | 6.27 | 1.11 | 4.94-8.01 |
| | WH-U4 | 20 | 0 | 19-20 | 7.41[a] | 1.64 | 5.90-10.00 |
| | WH-A2 | 20 | 1 | 18-20 | 6.66[a] | 1.19 | 5.54-8.51 |
| 4 | SH-U4 | 20 | 0 | 20-20 | 6.57 | 1.00 | 5.10-8.03 |
| | SH-A2 | 20 | 0 | 19-20 | 6.26 | 1.18 | 5.00-8.03 |
| | WH-U4 | 20 | 1 | 19-20 | 7.22[a] | 1.06 | 6.20-8.86 |
| | WH-A2 | 20 | 1 | 19-20 | 6.91[a] | 1.07 | 5.97-8.60 |
| 5 | SH-U4 | 20 | 1 | 19-20 | 6.37 | 0.96 | 5.03-7.72 |
| | SH-A2 | 19 | 2 | 14-20 | 6.43 | 0.99 | 5.21-7.96 |
| | WH-U4 | 20 | 0 | 20-20 | 7.02 | 1.02 | 6.21-8.76 |
| | WH-A2 | 20 | 0 | 19-20 | 7.07 | 1.11 | 5.80-8.74 |

*Note.* Unassisted shoulder harness (SH-U4), shoulder harness (SH-A2), unassisted wrist hooks (WH-U4), and wrist hooks (WH-A2). Range equals minimum to maximum values recorded.
[a] indicates a statistically significant difference in aiming total duration after Carry Attempt 3 and after Carry Attempt 4 between unassisted and assisted carry for the Wrist Hooks group.

*Table E4*. Fine Motor Skills Assessments: Tapping

| Attempt | Test Condition ($n$ = 6) | Hits | | |
|---|---|---|---|---|
| | | Mean | SD | Range |
| Baseline | SH-U4 | 223 | 19 | 201-250 |
| | SH-A2 | 218 | 15 | 201-239 |
| | WH-U4 | 214 | 22 | 191-246 |
| | WH-A2 | 209 | 21 | 190-244 |
| 1 | SH-U4 | 220 | 14 | 204-242 |
| | SH-A2 | 217 | 20 | 194-249 |
| | WH-U4 | 212 | 20 | 191-240 |
| | WH-A2 | 213 | 25 | 191-251 |
| 2 | SH-U4 | 221 | 12 | 201-233 |
| | SH-A2 | 218 | 18 | 194-246 |
| | WH-U4 | 208 | 22 | 186-241 |
| | WH-A2 | 215 | 24 | 196-255 |
| 3 | SH-U4 | 216 | 15 | 202-240 |
| | SH-A2 | 220 | 18 | 197-248 |
| | WH-U4 | 205 | 19 | 179-227 |
| | WH-A2 | 214 | 29 | 183-253 |
| 4 | SH-U4 | 221 | 14 | 206-239 |
| | SH-A2 | 221 | 13 | 206-235 |
| | WH-U4 | 205[a] | 24 | 180-244 |
| | WH-A2 | 212[a] | 23 | 191-248 |
| 5 | SH-U4 | 223 | 11 | 211-245 |
| | SH-A2 | 216 | 13 | 195-234 |
| | WH-U4 | 207 | 18 | 187-234 |
| | WH-A2 | 216 | 26 | 187-262 |

*Note*. Unassisted shoulder harness (SH-U4), shoulder harness (SH-A2), unassisted wrist hooks (WH-U4), and wrist hooks (WH-A2). Range equals minimum to maximum values recorded.
[a] indicates a statistically significant difference in tapping hits after Carry Attempt 4 between unassisted and assisted carry for the Wrist Hooks group.

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## Appendix F. Motion Capture Supplemental Data

*Table F1.* Mean and Standard Deviation (SD) of Torso Anterior-Posterior (A-P) Angles at the Beginning and End of Each Carry Attempt

| Carry Attempt | Capture | Shoulder Harness ($n$ = 5) | | | | | | Wrist Hooks ($n$ = 6) | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | SH-U4 | | | SH-A2 | | | WH-U4 | | | WH-A2 | | |
| | | Mean | SD | Range | Mean | SD | Range | Mean | SD | Range | Mean | SD | Range |
| 1 | First | 14.0 | 5.8 | 8.3-23.6 | 11.6 | 3.8 | 6.3-15.9 | 15.2[a] | 2.8 | 11.9-19.2 | 9.8[a] | 2.0 | 7.7-12.4 |
| | Last | 16.3 | 6.8 | 9.3-25.8 | 13.3 | 2.3 | 10.1-16.4 | 16.4 | 3.4 | 11.0-20.3 | 13.4 | 3.6 | 8.2-17.4 |
| 2 | First | 13.6 | 4.9 | 7.1-18.9 | 12.8 | 5.1 | 7.7-20.3 | 14.2[a] | 3.5 | 10.2-19.6 | 10.2[a] | 2.9 | 6.8-14.5 |
| | Last | 14.4 | 5.3 | 8.7-22.8 | 13.1 | 3.7 | 8.7-16.1 | 16.9[a] | 4.1 | 13.0-23.6 | 12.5[a] | 3.1 | 8.6-16.3 |
| 3 | First | 13.7 | 4.7 | 7.0-19.2 | 13.0 | 5.0 | 9.0-21.4 | 14.5[a] | 3.0 | 11.1-19.4 | 10.5[a] | 2.7 | 7.3-14.9 |
| | Last | 16.2 | 4.2 | 11.7-21.3 | 12.9 | 2.8 | 9.3-16.1 | 16.9 | 3.2 | 14.0-22.8 | 13.8 | 2.3 | 10.8-16.9 |
| 4 | First | 12.9 | 4.1 | 7.7-17.8 | 11.7 | 4.5 | 5.8-17.4 | 14.3[a] | 2.4 | 11.4-17.5 | 10.9[a] | 2.4 | 8.4-14.8 |
| | Last | 15.9 | 4.2 | 11.2-21.6 | 12.8 | 2.1 | 10.7-15.7 | 16.2[a] | 3.4 | 14.0-22.9 | 14.1[a] | 2.1 | 12.2-18.1 |
| 5 | First | 14.2 | 5.1 | 7.2-19.2 | 11.7 | 5.2 | 7.4-20.6 | 15.2[a] | 3.0 | 12.8-20.9 | 11.0[a] | 2.4 | 7.6-13.9 |
| | Last | 17.2 | 4.7 | 12.5-23.5 | 13.3 | 3.7 | 7.5-17.2 | 15.6 | 3.3 | 10.4-20.2 | 12.8 | 3.2 | 8.6-17.2 |

*Note*. Unassisted shoulder harness (SH-U4), shoulder harness (SH-A2), unassisted wrist hooks (WH-U4), and wrist hooks (WH-A2). [a] indicates a statistically significant difference in torso A-P angles between carry conditions (WH-U4 and WH-A2) for the Wrist Hooks group.

*Table F2.* Mean and Standard Deviation (SD) of Torso Lateral Angles at the Beginning and End of Each Carry Attempt

| Carry Attempt | Capture | Shoulder Harness (*n* = 5) | | | | | | Wrist Hooks (*n* = 6) | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | SH-U4 | | | SH-A2 | | | WH-U4 | | | WH-A2 | | |
| | | Mean | SD | Range | Mean | SD | Range | Mean | SD | Range | Mean | SD | Range |
| 1 | First | 6.4[a] | 3.6 | 1.1-11.0 | 2.1[a] | 1.8 | 0.5-4.7 | 4.4 | 3.4 | 0.8-9.2 | 2.0 | 1.6 | 0.1-4.0 |
| | Last | 6.2 | 4.8 | 0.2-12.2 | 2.6 | 2.8 | 0.1-5.9 | 3.0 | 2.4 | 0.7-5.4 | 2.1 | 1.4 | 0.8-3.9 |
| 2 | First | 7.7[a] | 4.2 | 3.0-13.0 | 2.8[a] | 2.5 | 0.2-5.9 | 5.1 | 3.5 | 1.2-10.7 | 1.6 | 1.4 | 0.4-4.1 |
| | Last | 5.6 | 4.4 | 2.2-12.4 | 3.5 | 3.4 | 0.5-7.9 | 4.5 | 3.7 | 0.5-11.5 | 2.0 | 1.6 | 0.5-4.1 |
| 3 | First | 6.9 | 2.7 | 4.5-11.1 | 2.7 | 3.0 | 0.1-6.8 | 4.8 | 3.9 | 2.0-12.3 | 2.0 | 1.7 | 0.7-4.9 |
| | Last | 6.5 | 4.2 | 2.0-11.4 | 3.0 | 3.1 | 0.0-7.1 | 5.6 | 2.7 | 1.5-8.2 | 2.1 | 1.4 | 0.1-3.9 |
| 4 | First | 8.5[a] | 2.8 | 4.6-11.5 | 2.8[a] | 3.0 | 0.0-6.7 | 4.6 | 3.4 | 1.3-9.1 | 2.6 | 1.6 | 1.1-5.4 |
| | Last | 5.8 | 4.0 | 2.0-12.1 | 3.3 | 3.0 | 0.5-6.8 | 4.3 | 2.5 | 0.9-8.1 | 2.2 | 1.2 | 0.9-4.0 |
| 5 | First | 7.6[a] | 3.6 | 2.7-11.1 | 1.9[a] | 2.3 | 0.1-5.0 | 3.7 | 3.3 | 0.8-8.2 | 2.0 | 1.8 | 0.4-5.1 |
| | Last | 6.5 | 5.1 | 0.2-11.1 | 2.8 | 3.4 | 0.0-7.4 | 4.1 | 3.0 | 0.5-9.0 | 2.2 | 1.3 | 0.3-4.0 |

*Note*. Unassisted shoulder harness (SH-U4), shoulder harness (SH-A2), unassisted wrist hooks (WH-U4), and wrist hooks (WH-A2). Range equals minimum to maximum values recorded. [a] indicates a statistically significant difference in first torso lateral angles between carry conditions for the Shoulder Harness group, Carry Attempts 1, 2, 4, and 5 only.

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