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Effects of Litter Carriage Assistive Devices on Soldier Performance and Fatigue During a Simulated Mass Casualty Scenario

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14. ABSTRACT
Service Members must be prepared to manage the physical demands of large-scale combat operations (LSCOs), including mass casualty (MASCAL) events that require rapid casualty evacuation via dismounted litter carriage. This study, conducted with sixteen U.S. Army personnel, evaluated the effectiveness of litter carriage assistive devices—shoulder harnesses and wrist hooks—compared to unassisted carries during simulated MASCAL scenarios. Findings revealed that assistive devices significantly improved litter bearer performance by increasing the number of casualties transported and carry duration while reducing fatigue and discomfort. Shoulder harnesses demonstrated superior outcomes, including reduced rate of fatigue and higher user acceptance ratings, compared to wrist hooks and unassisted carry conditions. These results highlight the potential of assistive devices to enhance evacuation efforts and casualty survivability in operational environments, supporting ongoing research by the U.S. Army Aeromedical Research Laboratory (USAARL) to standardize evaluation methodologies for military casualty transport solutions.

15. SUBJECT TERMS
litter carriage, fatigue, medical evacuation, mass casualty, MASCAL, casualty evacuation, grip strength, multi-domain operations, assistive devices, shoulder harness, wrist hooks, Soldier biomechanics

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Summary

Service Members (SMs) must be equipped to handle the demands of future large-scale combat operations (LSCOs), such as a mass casualty (MASCAL) event. A crucial challenge of a MASCAL situation is the swift movement of casualties from the point of injury to the next level of care via dismounted litter carriage, a task that is physically strenuous on SMs in any environment, let alone with the added stressors of LSCOs. Augmenting SM performance and reducing levels of fatigue can help accelerate evacuation efforts and may increase the survivability of casualties. Previous research has shown that litter carriage assistive devices (LCADs), such as a shoulder harness or wrist hooks, can effectively reduce the need of a four-person litter team to a two-person litter team, and such devices can improve litter bearer performance while reducing the rate of fatigue.

This report presents data findings related to the effects of using the assistive devices on litter bearer performance (number of carries, carry duration, number of rests during carry, litter pick-up duration, litter drop-off duration), fatigue (grip strength), and subjective ratings (perceived exertion, discomfort, fatigue, user acceptance) during an operationally relevant, simulated MASCAL scenario. Sixteen U.S. Army males and females, all 68W Combat Medic Specialists, assigned to the U.S. Combat Capabilities Development Command Soldier Center (DEVCOM SC) Soldier Research Volunteer Program were paired into two-person litter teams and tasked to conduct multiple litter carries on a 50 meter field litter carry course under unassisted, shoulder harness assisted, and wrist hooks assisted carry conditions. Study outcomes found that LCAD use significantly increased the number of casualties transported and the duration of litter carry with fewer rests while not causing significantly higher levels of fatigue, discomfort, or exertion. Wrist hooks enabled the most completed carries across any condition and quick pick-up and drop-offs while reducing average grip strength loss by 50 percent when compared to unassisted carries. Further, shoulder harness use resulted in significantly greater retention of grip strength across all subjects when compared to both wrist hooks and unassisted carry conditions in a simulated MASCAL scenario. Additionally, subjects gave higher user acceptance ratings for the shoulder harness than the wrist hooks or unassisted carry.

This research is part of an ongoing program at the U.S. Army Aeromedical Research Laboratory (USAARL) to investigate the effects of LCADs on dismounted casualty transport across multiple scenarios and experimentations. The outcomes from this and prior efforts demonstrate the ability of LCADs to assist SMs with meeting the dismounted casualty transport needs of current and future operations. Future work at USAARL includes establishing a standardized methodology for evaluating LCADs. This standardized methodology will aid in the future development and deployment of such devices to ultimately ensure SMs are equipped with the necessary technologies to meet the demands of future operations.

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Introduction

In anticipation of the future fight with near-peer adversaries, the need to improve and limit impediments to the operational responsibilities of a Service Member (SM) are of high priority. Beyond the SM contending with various hazards in the field, such as hostile fire, challenging weather, and unique tactical scenarios, the SM must also prepare to adapt to potential challenges with casualty care and transport during future large-scale combat operations (LSCOs), such as a mass casualty (MASCAL) event.

While MASCAL typically refers to a larger number of casualties than can normally be managed, it is not possible to define the scale of a MASCAL event by casualty numbers alone. It is also necessary to consider resources available (Shackelford et al., 2022). Shackelford et al. (2022) defined different scales of mass casualty events: “many casualties” with resources stretched but not exceeded, “MASCAL” with dozens of casualties exceeding resources available, and “Ultra-MASCAL” with hundreds or thousands of casualties greatly exceeding resources. A MASCAL working group made up of first responders and physicians across multiple services and organizations recently published a prehospital response to MASCAL management (Rush et al., 2024). The proposed MASCAL management has three main components: move, treat, and transport. This working group identified that casualties must first be moved out of danger on foot, with treatment provided to the casualty as able, before finally transporting the casualty to a higher level of care in a medical vehicle or vehicle of opportunity (Rush et al., 2024). A common, recurring theme when considering MASCAL scenarios is the need for SMs to move casualties with litters as quickly as possible.

Dismounted litter carriage is a physically demanding task in isolation, apart from the added stressors of LSCOs or a MASCAL scenario. Using a litter carriage assistive device (LCAD) could lessen the physical demands placed on litter bearers and increase their ability to carry the litter faster and for longer distances. Moreover, reducing litter bearer fatigue may help the litter bearers maintain their ability to perform required tasks (e.g., providing security and casualty care) over longer periods of time, which may be a critical component of LSCO. Improvements in these areas will lead to faster evacuation times and may increase the survivability of casualties.

Potential LCADs used in previous studies evaluating dismounted litter carriage transport included a shoulder harness (Tharion et al., 1993; Rice et al., 1999; Ballard et al., 2023; Ballard et al., 2025b) and wrist hooks (Ballard et al., 2023; Ballard et al., 2025b). A shoulder harness can be used to distribute a litter load between the arm and upper body of a SM for easier and more ergonomic transport. Rice et al. (1999) showed that SMs could transport patients on litters for a longer duration when a shoulder harness was used. Additionally, the use of a shoulder harness during transport in same sex teams has been previously shown to increase fine-motor performance, decrease subjective ratings of adverse physical symptoms, and increase the time to fatigue in comparison to not using the assistive device (Rice et al., 1999). Harness use has also been shown to improve shooting accuracy after litter transport compared to not using a harness (Tharion et al., 1993).

Previous efforts at the U.S. Army Aeromedical Research Laboratory (USAARL) have investigated commercial-off-the-shelf LCADs for their affects on dismounted litter carriage and SMs conducting litter carriage tasks. Ballard et al. (2023) demonstrated that a commercially available shoulder harness or wrist hooks could preserve grip strength and reduce litter bearer fatigue in a lab-based, simulated litter carriage scenario. However, additional evaluations were needed in operationally relevant, field-based scenarios to validate laboratory findings and demonstrate their effectiveness in various field environment operations. In long-range, field-based litter carriage, LCADs were found to allow higher carry durations and longer carry distances than unassisted carry while maintaining similar levels of fatigue (Ballard et al., 2025b). These same LCADs (i.e., shoulder harnesses and wrist hooks) were additionally evaluated during military experimentation events, Army Expeditionary Warrior Experiment (AEWE) 2024 and Project Convergence Capstone 4 (PCC4), where SMs found the shoulder harness and wrist hooks could assist with litter carriage tasks; however, results of the studies indicated that improvements are needed before the LCADs would be fully effective in military operational environments (Ballard et al., 2025a). While these efforts identified some benefits and improvable features of LCADs, these event settings did not incorporate the challenges SMs would face in a MASCAL scenario, such as multiple litter pick-ups, drop-offs, and short distance carries within a set amount of time.

To continue our investigations of LCADs in dismounted military casualty transport and build on previous laboratory- and field-based research, USAARL conducted performance, fatigue, and subjective assessments of LCADs in the field during a simulated MASCAL scenario. The goal of this research was to quantify the effects of LCADs on litter carriage and support the deployment of an LCAD to effectively arm SMs to handle the needs of dismounted casualty transport. Additionally, outcomes from this study will provide the foundation for development of standardized evaluation methodologies for military applications of LCADs.

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Methods

To investigate the effects of litter carriage assistive devices (LCADs) under a simulated MASCAL operation scenario, an experimental, repeated measures study was designed. Human research volunteers (HRVs) were tested in two-person litter teams under three different litter carry conditions: shoulder harness (SH), wrist hooks (WH), and unassisted (UA). Study outcomes included the number of completed casualty evacuations, the amount of time spent carrying the litter, and measures of grip strength. Comparisons were made between the three carry conditions: SH, WH, and UA.

Human Research Volunteer Anthropometries and Demographics

The HRVs were recruited from SMs assigned to the U.S. Combat Capabilities Development Command Soldier Center (DEVCOM SC) Soldier Research Volunteer Program. For inclusion in the study, males or females had to be between the ages of 17 and 40, assigned to the DEVCOM SC Research Volunteer Program, and a member of a U.S. military component (Active Duty, National Guard, or Reserves). The SMs were not eligible for participation in the study if they had a profile limiting physical training and/or wear of personal protective equipment, or if they used any nonsteroidal anti-inflammatory drug (e.g., aspirin, ibuprofen, muscle relaxers, etc.) or any other pain medication within 24 hours of participation other than those part of a physician advised/prescribed regimen. Additionally, women who were pregnant were not eligible for participation.

After arriving at the data collection course, anthropometric measurements and demographic responses were collected from the HRVs (Table 1). The anthropometric and demographic responses were measured and recorded in accordance with the methods of the previous litter carry studies (Ballard et al., 2023; Ballard et al., 2025b) and the procedures defined in the U.S. Army Natick Soldier Research, Development, and Engineering Center's anthropometry handbook (Hotzman et al., 2011). The tools that were used to measure the anthropometry include an anthropometer, height measuring stand, a plastic measuring tape from GPM Instruments GmbH (Susten, Switzerland), and a Seca model 876 scale (Seca, Hamburg, Germany). Hand length, shoulder breadth, and hip breadth were measured using the top two sections of the GPM anthropometer as a sliding beam caliper.

Table 1. Human Research Volunteer Anthropometric and Demographic Measures

Anthropometry	**Demographics**
Height (centimeters [cm])	Age (years)
Weight (kilograms [kg])	Sex
Arm Length (cm)	Military Occupational Specialty (MOS)
Hand Length (cm)	Months of Service
Shoulder Breadth (cm)	Number of Deployments
Hip Breadth (cm)	

Carry Conditions

After providing informed consent, the eligible HRVs enrolled in the study watched a training video on proper litter carry techniques in a two-person litter team (including lifting and setting down the litter) and instructions to don, use, and doff the LCADs. Additionally, research staff helped to adjust each LCAD to the HRV as well as provide instruction on use of the LCAD immediately prior to each carry condition. The LCADs used in this study included SH (Figure 1) and WH (Figure 2) used in previous laboratory-based (Ballard et al., 2023) and field-based (Ballard et al., 2025b) prolonged carry efforts. The same LCADs were used to test for efficacy of lifting, carrying, and lowering several simulated casualties over a period of time; this simulated an operational MASCAL evacuation event. In addition to carrying with the SH and WH, each two-person litter team also carried the litter UA (Figure 3).

Figure 1. A litter team is shown carrying the simulated casualty in the SH carry condition. A closeup of the SH device is shown on the bottom right.

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Figure 2. A litter team is shown carrying the simulated casualty in the WH carry condition. A closeup of the WH device is shown on the bottom right.

Figure 3. A litter team is shown carrying the simulated casualty in the UA carry condition.

Litter Carry Procedures

The HRVs were paired into eight two-person litter teams; individuals of similar heights were paired into teams, as is done in operational scenarios to more evenly distribute the litter load and provide level transport of the casualty. The litter teams were scheduled in staggered time slots across three testing days to allow for maximum HRV participation. The front and rear carry positions were assigned at random, and each HRV carried the litter in the same carry position throughout all three carry conditions following a counterbalanced test matrix (Table 2) to mitigate any order effects of carry condition. For each carry condition, the litter teams were asked to pick up a weighted litter with a simulated casualty (185-pound [lb] manikin representative of a 50th percentile U.S. Army male [Gordon et al., 2014]), carry the weighted litter around a 50-meter (m) course (Figure 4) at their own pace, lower the weighted litter to the ground, go through the course again without the litter (simulating a return to the MASCAL area for another casualty), and repeat this process for 20 minutes. Prior to each carry condition, a research team member reviewed the course layout, litter carry procedures, and LCAD instructions (donning, doffing, adjusting, engaging with the litter, etc.) with each litter team. The litter team donned the LCAD (shoulder harness or wrist hooks) and verified proper fit before the test started for the WH and SH carry conditions.

At the beginning of each carry condition, the weighted litter was set up in the pick-up/drop-off zone (Figure 4) in the direction of carry (feet closest to the start/finish line for the course). Each litter team was instructed to carry the litter with the feet of the simulated casualty always in front toward the direction of travel. The litter teams had to re-position the litter for the next carry, either after finishing a carry (before setting the litter down) or before starting the next carry (after picking the litter up) to ensure the simulated casualty was carried in the correct orientation. Between carries, the litter teams were instructed to go through the 50-m course again without a litter to simulate returning to the point of injury to pick up another casualty. These “returns” were also at a self-selected pace. The litter teams tested under each carry condition for 20 minutes, and they repeated the process of picking up, carrying, setting down, and returning the litter to the “point of injury” until the end of the 20-minute timeframe. Additionally, the litter teams were advised to take as many breaks as needed for as long as needed during the 20-minute timeframe, but that the clock would continue running, which could reduce the overall number of casualties transported.

Between each carry condition, the litter teams were given a minimum 20-minute rest period to allow for recovery so that each carry condition would be independent from one another. During one litter team’s rest period, another litter team conducted a litter carry condition per the test matrix in Table 2, as available. During the test period, the resting litter team was asked to rest in a shaded area near the research station so that HRV-borne instrumentation would not disconnect between the carry conditions.

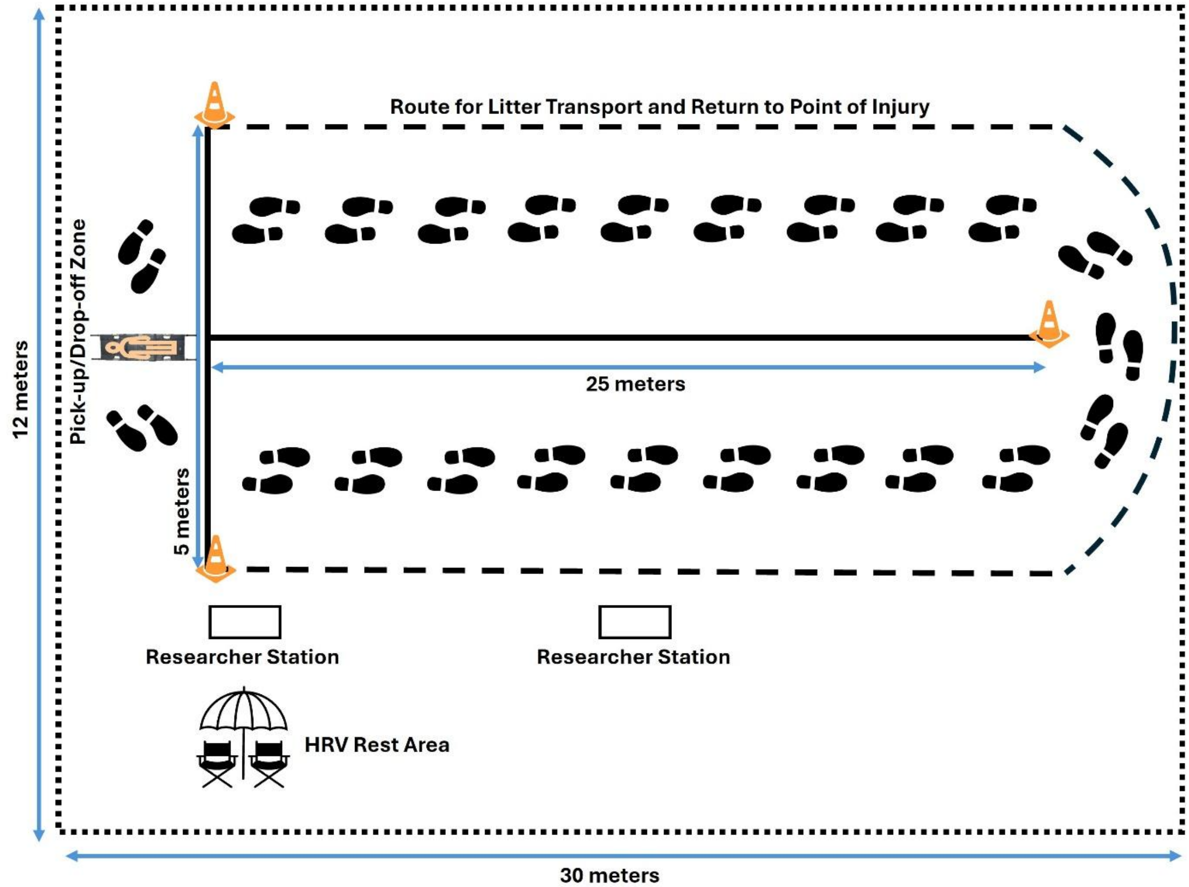

Figure 4. A 50 m course was set up in a grassy field to complete the litter carriage tasks. The two orange cones on the left marked the start and finish line for each lap in the course. The orange cone on the right marked the 25 m point from the start line. The footsteps represent the path the litter teams traveled on the course.

Table 2. Counterbalanced Carry Condition Test Matrix

	Litter Carry Teams							
Carry Conditions	1	2	3	4	5	6	7	8
1	UA	SH	WH	UA	WH	SH	UA	SH
2	SH	WH	UA	WH	SH	UA	SH	WH
3	WH	UA	SH	SH	UA	WH	WH	UA

Grip Strength

Grip strength was recorded pre- and post-carry in all carry conditions for each HRV as an objective measure of fatigue. The grip strength assessment was recorded using two VALD DynaMo Plus dynamometers (VALD, Brisbane, Australia), with the grip strength attachment, in accordance with the methods of the previous field-based litter carry study (Ballard et al., 2025b) (Figure 5). The VALD dynamometers recorded the grip strength wirelessly, and the force data were saved for analysis. The grip strength assessment, taken immediately before and after each carry condition, consisted of three four-second maximum voluntary contractions on each hand, alternating back and forth between hands, with the HRV standing in a neutral position while holding the dynamometer at their side in an orientation similar to holding a litter handle. Grip strength peak force was recorded in Newtons (N). Two research team members, each with a dynamometer, ensured that the litter team conducted the post-carry grip strength assessments within 60 seconds of the end of the carry condition to reduce recovery effects.

Figure 5. VALD DynaMo Plus dynamometers (right) were used to record grip strength before and after each carry condition. One of the litter teams is pictured (left) conducting the grip strength test before a carry condition.

Performance Measures

The following measures were analyzed to assess litter carriage performance: number of carries completed (representative of the number of casualties moved within the 20-minute carry condition time), number of rests (taken during casualty transport), carry duration (total time spent carrying casualties out of the 20-minute carry condition time), litter pick-up duration (time to engage with the litter using the LCAD, pick up the litter, and start the carry), and litter drop-off duration (time from when the carry is finished, the litter is set down, and the LCAD has disengaged with the litter). A custom timing graphical user interface (GUI) (Figure 6) was created using MATLAB (ver. R2023b, Natick, MA) to log event markers and record elapsed time from the start of the carry. The custom timing GUI prepared a Microsoft Excel spreadsheet (ver. 2502, Redmond, WA) in a user-selected file path for saving the data. To prepare the data file, a researcher was prompted to enter the two-digit litter team number and select the carry condition that was being timed. These selections were used in the data file name. The researcher then selected “Start” in the custom timing GUI to start an elapsed time clock that elapsed for either 20 minutes or until “Stop” was selected. While the custom timing GUI was running, the researcher could mark events that were saved to the data file with a timestamp of the elapsed time. The events that could be logged included: litter carry start, litter carry finish, return start, return finish, and other, which allowed the researcher to insert text (i.e., break started, break ended) to indicate the type of event marker being saved.

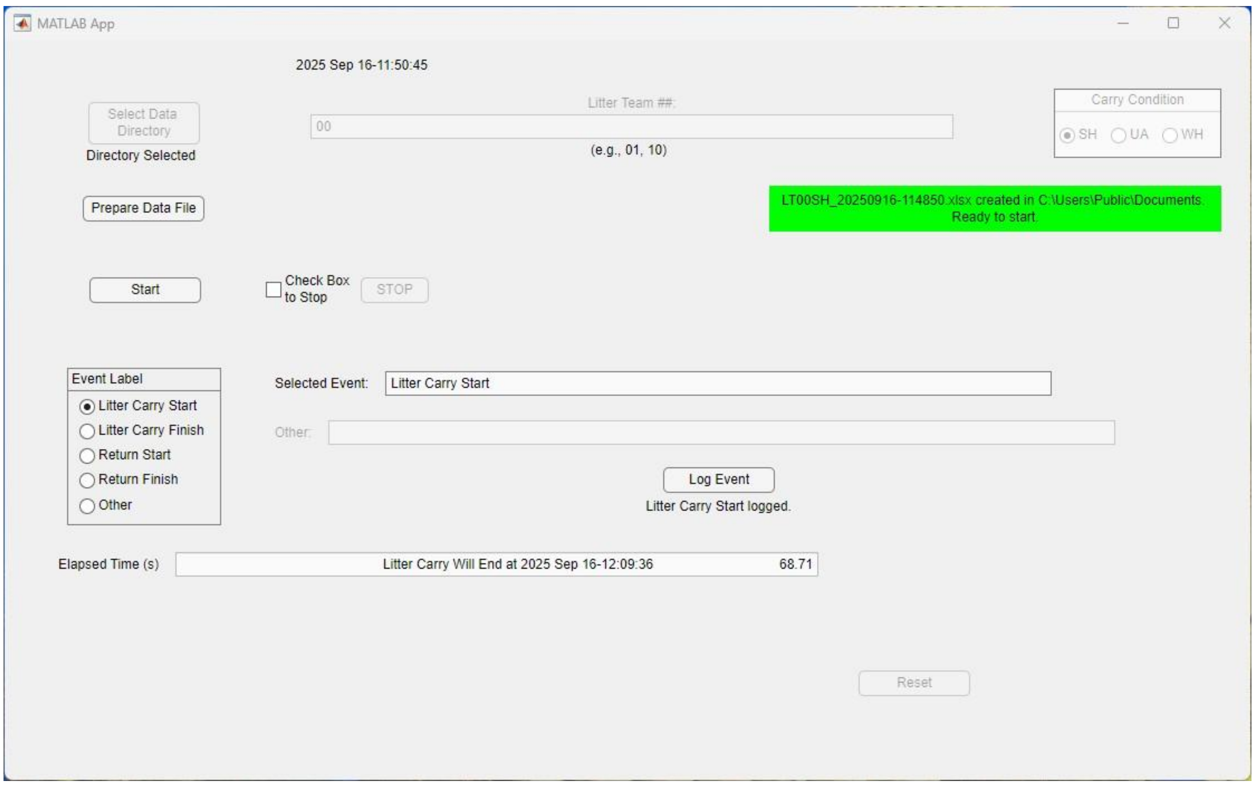

Figure 6. A custom timing GUI was used to timestamp event markers during the simulated mass casualty litter carries for each carry condition. This image was created as an example and does not reflect actual event data recorded during the study.

Before starting each carry condition, the litter team was positioned on the other side of the start line opposite the pick-up/drop-off zone (i.e., to the immediate right of the top of start/finish line illustrated in Figure 4). The research team member running the timing software vocally signaled the start of the carry condition and clicked start on the software, starting the 20-minute time, when the rear litter bearer crossed over the start line of the course for litter pick-up. For each of the primary sections of the litter carry task (litter pickup, start of litter carry, litter drop-off, start of return trip), a timestamp was logged when the last member of the litter team crossed the start/finish line. If the litter team took a break during the carry, custom event markers were logged in the software to signal the start and end of a break when the litter team set down and picked up the litter, respectively. At the end of the 20-minute time, the software would auto-log an event marker to signal the end of the testing. The research team immediately signaled the litter team to stop the test and lower the litter to the ground where they were, even if in the middle of a carry. If the litter was set down during a carry outside of the pick-up/drop-off zone, a research team member would measure the distance from the start/finish line to the top of the head of the simulated casualty to measure the partial distance carried during the last litter carry of the carry condition.

Subjective Measures

The subjective questions asked for this study follow the same procedures of our previous litter carry studies (Ballard et al., 2023; Ballard et al., 2025b). The subjective questions asked pertained to perceived exertion (6 to 20 scale), fatigue (0 to 10 scale), discomfort (0 to 10 scale), and user acceptance (0 to 10 scale) of the HRV (Appendix B). Ratings of perceived exertion, fatigue, and discomfort were recorded pre- and post-carry. The questions quantified subjective measures to characterize the perceived effect of the LCAD from before until after the litter carry condition. The user acceptance ratings, only collected post-carry, indicated the preference of the HRV to conduct the litter carriage task under the respective carry condition.

Data and Statistical Analysis

Data were compiled similarly to the methods outlined in the earlier field-based litter carry study (Ballard et al., 2025b). Metrics were organized by carry condition (SH, WH, and UA); litter team (total number of carries, total duration of carrying the litter, average litter pick-up duration, and average litter drop-off duration); and HRV grip strength and subjective measures (perceived exertion, fatigue, discomfort, and user acceptance). The dependent response variables were total number of carries completed, total carry duration during carry condition, average pick-up and drop-off durations, grip strength, subjective perceived exertion, fatigue, discomfort, and user acceptance. The independent variables were carry condition and carry position; carry position was considered for subjective response variables only. All response variables were treated as continuous as they were all either continuous (e.g., grip strength) or ordered scales that represented an underlying continuous relationship (e.g., a larger score in perceived exertion represents a larger magnitude of perceived exertion than a smaller score). Each of these variables were analyzed using descriptive statistics such as means, standard deviations (SDs), minimum (min) values, and maximum (max) values. An alpha of $p \leq 0.05$ was considered statistically significant for all statistical analyses. Statistical analyses were implemented using R (v 4.5.1) with RStudio (v 2025.5.1.513).

Grip strength.

Analysis of peak grip strength was computed to investigate the effects each carry condition had on litter bearer fatigue. A large decrease in grip strength indicated a greater amount of HRV fatigue. The delta grip strength for both hands (post-carry minus pre-carry grip strength) were averaged together for each HRV to measure the effect of the carry condition on fatigue. Computing the difference between the pre- and post-carry grip strength measures for each HRV also allowed for comparisons between the carry conditions without influence from varying baseline grip strengths.

A one-way repeated measures analysis of variance (ANOVA) was computed for the bilateral delta grip strength (post-carry minus pre-carry) with carry condition as the condition of interest. Carry condition had three levels: SH, WH, and UA. There was a total of three groupings for the dependent variable. Post-hoc analyses, such as pairwise Bonferroni adjusted tests, were evaluated for any significant result in the ANOVA.

Performance measures.

The custom timing software logged the start and finish of every carry by the litter teams per carry condition. From this data, completed carries were tallied for the total number of carries for each litter team by carry condition. Any incomplete carries (such as those in progress when the 20-minute time limit of the test was reached) were not included in the total number of carries. The total number of carries were averaged across carry conditions to represent the average number of casualties successfully transported from point of injury to the next level of care within 20 minutes.

Durations of events were compiled from the time-stamped event markers. The duration between the last litter team member crossing over the start/finish line to pick up a litter and then the rear litter bearer crossing over the start/finish line again to start the carry was compiled as the duration of a litter pick-up. The duration between the rear litter bearer crossing over the start/finish line carrying the litter and until the rear litter bearer crossed over the start/finish line again to set the litter down was compiled as the duration of a litter carry. The duration between the rear litter bearer crossing over the start/finish line to set the litter down and the last litter team member crossing over the start/finish line to start a "return" was compiled as the duration of a litter drop-off. The duration between the last litter team member crossing the start/finish line to start a "return" and crossing over the start/finish line to pick up the litter was compiled as the duration of a return to point of injury. Finally, duration of breaks during each litter carry was compiled from the time at which the litter team sat the litter on the ground within the 50 m course to the time the litter was lifted off the ground to continue the carry.

For each litter team, the amount of time spent carrying the litter for each carry condition was calculated by summing the duration of all active litter carries (which did not include pick-up, drop-off, or rests that may have been taken). All litter teams' total carry duration was then averaged across carry conditions to give an overall carry duration for each carry condition. The percent of time in active litter carry for each carry condition was calculated by dividing the overall carry durations over the 20-minute time limit.

The average pick-up and drop-off durations represent the time it takes to engage or disengage from the litter with and without an LCAD, lift (or lower) the litter, and begin (or end) a litter carry. The average duration for litter pick-up and litter drop-off were calculated for each litter team across all carry conditions by averaging the durations of the first two pick-ups and drop-offs, respectively. Only the first two pick-ups and drop-offs are included in the average durations in order to get an accurate measurement of the time it takes for device engagement and device disengagement without including potential effects from fatigue. These average pick-up and drop-off durations by litter team were then averaged across carry conditions to give average litter pick-up and litter-drop off durations per carry condition.

One-way repeated measures ANOVAs were computed for the number of completed litter carries, number of rests during litter carry, litter carry duration, duration of litter pick-up, and duration of litter drop-off with carry condition as the condition of interest for each analysis. Carry condition had three levels: SH, WH, and UA. Each of the dependent variables had a total of three groupings. Post-hoc analyses, such as pairwise Bonferroni adjusted tests, were evaluated for any significant result in the ANOVA.

Subjective measures.

The deltas (post-carry minus pre-carry) for perceived exertion, fatigue, and discomfort were averaged across the HRV for each carry condition (SH, WH, and UA). The deltas for the subjective measures were calculated to allow for comparison across carry conditions without the influence of HRV baseline measures. The average ratings for user acceptance were compared between the carry conditions. SD and standard error were also calculated for each subjective measure across carry conditions.

One-way repeated measures ANOVAs were computed for four subjective response variables with carry condition as the condition of interest. The four subjective measures are delta (post-carry minus pre-carry) perceived exertion, delta discomfort, delta fatigue, and user acceptance. Carry condition had three levels: SH, WH, and UA. There were a total of three groupings for each dependent variable. Post-hoc analyses, such as pairwise Bonferroni adjusted tests, were evaluated for any significant result in the ANOVAs.

Additionally, one-way ANOVAs were computed for all four subjective response variables with carry position as the condition of interest. Carry position had two levels: front and rear of the litter. Since carry position only had two levels, the post-hoc analyses were equivalent to the ANOVA for any significant result.

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Results

Results for the different response variables did not reveal any extreme outliers when adjusted for carry condition. Additionally, there were no extreme deviations from normality in the data. Due to these characteristics in the data, it was determined that the ANOVA methods were appropriate to determine statistically significant differences due to carry condition.

Human Research Volunteer Anthropometries and Demographics

Seventeen HRVs from the DEVCOM SC Research Volunteer Program consented and enrolled under a protocol approved through the U.S. Army Medical Research and Development Command Institutional Review Board. One HRV decided to withdraw from the study prior to their scheduled testing. Data were collected from 16 HRVs (n = 16; 13 male, 3 female) between the ages of 18 and 28. The HRVs were paired by height into eight two-person teams. Pairing by height, two of the females were paired together as a team and the other female was paired with a male.

The HRV anthropometries and demographics are presented in Table 3. The military occupational specialty (MOS) of all HRVs that participated in the study was 68W Combat Medic Specialist. The range of male HRV heights represented 10th to 98th percentile U.S. Army males and the range of female HRV heights represented 50th to 80th percentile U.S. Army females (Gordon et al., 2014). The overall average HRV height was 173.9 cm, which was representative of a 40th percentile U.S. Army male (Gordon et al., 2014). The average difference in height between the two HRVs in each litter team was 6.3 centimeters (cm) (2.5 inches [in.]). Months of military service for the HRVs ranged from 7 to 12 months, and none of the HRVs had ever deployed.

Table 3. Average (Standard Deviation) HRV Anthropometry and Demographics

Anthropometry						**Demographics**		
Height (cm)	Weight (kg)	Arm length (cm)	Hand length (cm)	Shoulder breadth (cm)	Hip breadth (cm)	Age (years)	Military service (months)	Number of deployments
173.9 (7.5)	77.9 (11.3)	79.0 (4.1)	17.7 (1.3)	34.0 (2.9)	35.0 (2.1)	21.8 (3.4)	8.9 (1.7)	0.0 (0.0)

Note. Average anthropometry was recorded in centimeters (cm) for length and kilograms (kg) for weight.

Grip Strength

Of the 16 HRVs that participated in the study, the WH grip strength data of 1 HRV were excluded from analysis due to a technical error with the device during the assessment. Grip strength data for another HRV in the UA carry condition group were also excluded from analysis due to the subject being withdrawn from the study by the principal investigator (PI) prior to completing the post-carry grip strength assessment. In Table 4 and Figure 7, delta grip strength values that are negative and positive indicate a decrement or improvement in post-carry grip strength, respectively, over the carry condition as compared to the pre-carry grip strength. All carry conditions revealed an overall loss of grip strength after the litter carries. On average, grip strength was retained more in the SH condition and had the greatest loss in the UA condition (Table 4; Figure 7).

The one-way repeated measures ANOVA revealed a statistically significant effect of carry condition on the delta grip strength response (p = 0.007). Pairwise post-hoc analyses, using the Bonferroni adjusted p-value, revealed pairwise statistical significance between carry conditions UA and SH (p_{adj} = 0.004), and between SH and WH (p_{adj} = 0.044). Although not statistically significant, grip strength was retained more for WH than for UA; the grip strength decrement for the WH condition, on average, was less than 50% of the grip strength loss experienced during UA transport.

Table 4. Means of Bilateral Delta Grip Strength per Carry Condition

	UA (*n* = 15)	**SH (*n* = 16)**	**WH (*n* = 15)**
Mean (N)	-122[a]	-33[a,b]	-60[b]
SD (N)	93	41	40
Minimum (N)	-265	-107	-122
Maximum (N)	-3	34	24

[a]A statistically significant difference exists for delta grip strength between SH and UA.
[b]A statistically significant difference exists for delta grip strength between SH and WH.
Note. All grip strengths are expressed in Newtons (N). The number of HRV averaged per carry condition is represented by *n*. Negative values indicate loss of grip strength.

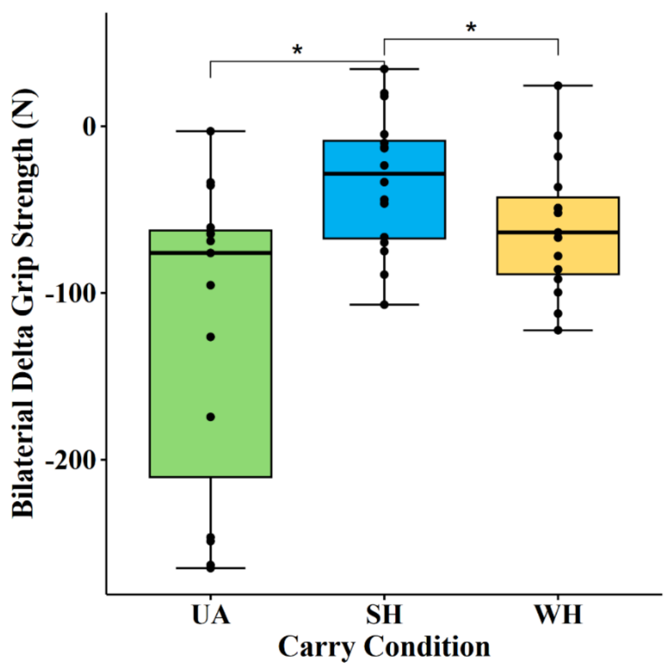

Figure 7. Bilateral delta grip strengths are plotted for UA, SH, and WH carry conditions.
* indicates a statistically significant difference between UA and SH and between SH and WH.

Performance Measures

Number of carries.

Results for the number of completed litter carries per carry condition are presented in Table 5 and Figure 8. The average number of completed litter carries represented the average number of casualties successfully transported from point of injury to the next level of care within 20 minutes for a particular carry condition. The WH carry condition had the highest number of litter carries on average and the greatest number of carries for a single litter team (Table 5). The UA carry condition had the least number of carries on average and the least number of carries for a single litter team. The WH carry condition averaged a 50% increase in the number of casualties evacuated when compared to the UA carry condition while the SH carry condition averaged a 40% increase when compared to the UA carry condition.

A one-way repeated measures ANOVA revealed a statistically significant difference in the total number of carries between carry conditions ($p < 0.001$). Pairwise post-hoc analyses, using the Bonferroni adjusted p-value, revealed pairwise statistical significances between UA and SH ($p_{adj} = 0.006$) and between UA and WH ($p_{adj} < 0.001$). There was no significant difference between SH and WH.

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Table 5. Descriptive Statistics for Number of Completed Carries per Carry Condition

	UA $n = 8$	SH $n = 8$	WH $n = 8$
Mean	8.8[a,b]	12.3[a]	13.1[b]
SD	2.7	2.9	2.7
Minimum	5	8	10
Maximum	13	16	17

[a]A statistically significant difference exists for number of completed litter carries between SH and UA.
[b]A statistically significant difference exists for number of completed litter carries between UA and WH.
Note. Number of litter teams averaged per carry condition is represented by *n*.

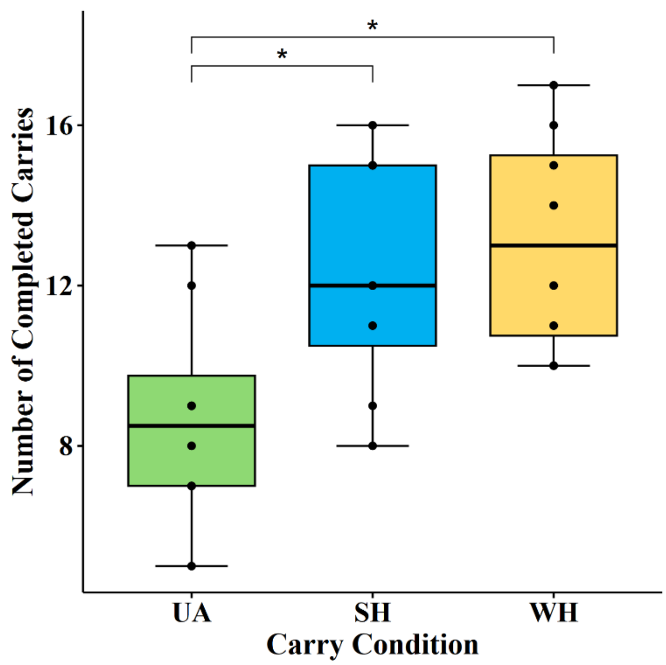

Figure 8. Number of completed carries are plotted for UA, SH, and WH.
* indicates a statistically significant difference between UA and SH and between UA and WH.

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Carry duration and number of rests during litter carries.

The results for the average carry duration by carry condition are presented in Table 6 and Figure 9. In a 20-minute period, the litter teams carried for similar durations with SH and WH (9.00 minutes [min] and 8.65 min, respectively), which were approximately 50% greater than the 5.90 min for UA. The percent of the 20-minute simulated MASCAL task spent carrying the litter was 30% for UA, 45% for SH, and 43% for WH. Carry duration metrics reflected productive time moving casualties, and it was observed that litter teams that carried for less time took more rest breaks, where they sat the litter down on the ground within the 50 m course, during the 20-minute task.

Table 6. Means for Overall Carry Duration Per Carry Condition

	UA $n = 8$		**SH** $n = 8$		**WH** $n = 8$	
	s	**Min**	**s**	**min**	**s**	**min**
Mean	354.11[a,b]	5.90[a,b]	539.97[a]	9.00[a]	518.83[b]	8.65[b]
SD	69.21	1.15	32.59	0.54	39.96	0.67
Minimum	253.64	4.23	494.68	8.24	457.34	7.62
Maximum	464.50	7.74	596.51	9.94	573.51	9.56

[a]A statistically significant difference exists for litter carry duration between SH and UA.
[b]A statistically significant difference exists for litter carry duration between UA and WH.
Note. The number of litter teams averaged per carry condition is represented by n.

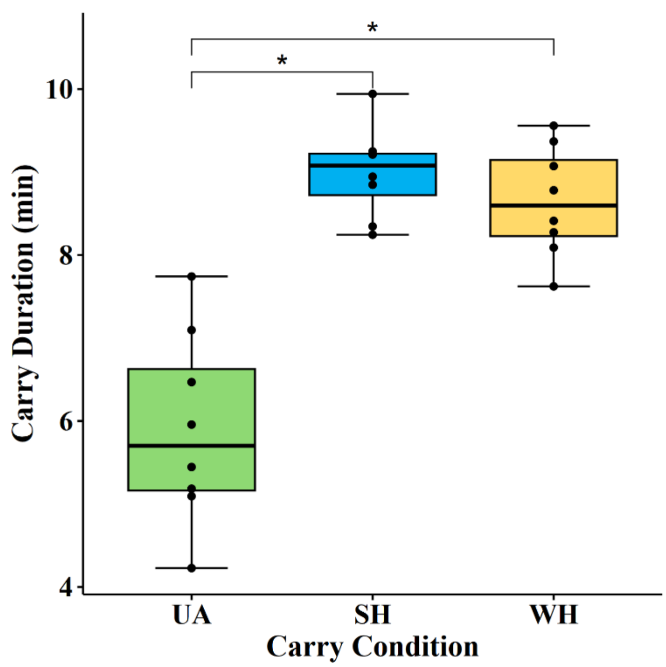

Figure 9. Overall carry duration represented in minutes for UA, SH, and WH.
* indicates a statistically significant difference between UA and SH and between UA and WH.

Results for the number of rests, i.e., rest breaks, taken during the litter carries are presented in Table 7 and Figure 10. On average, litter teams took the most rests with the UA carry condition and averaged only 0.5 rests with the WH carry condition (Table 7). None of the teams rested during the litter carries with the SH carry condition.

The one-way repeated measures ANOVA revealed statistically significant differences in both carry duration and number of rests ($p < 0.001$; $p = 0.002$). Pairwise post-hoc analyses, using the Bonferroni adjusted p-value, revealed pairwise statistical significances for carry duration between UA and SH ($p_{adj} < 0.001$), and between UA and WH ($p_{adj} = 0.003$). Additionally, the pairwise post-hoc analyses revealed statistical significance for the number of rests between UA and SH ($p_{adj} = 0.007$), and between UA and WH ($p_{adj} = 0.006$).

Table 7. Descriptive Statistics for Number of Rests During Litter Carry per Carry Condition

	UA $n = 8$	**SH** $n = 8$	**WH** $n = 8$
Mean	12.9[a,b]	0.0[a]	0.5[b]
SD	7.8	0.0	1.1
Minimum	3	0	0
Maximum	22	0	3

[a]A statistically significant difference exists for number of rests between SH and UA.
[b]A statistically significant difference exists for number of rests between UA and WH.
Note. Number of litter teams averaged per carry condition is represented by n. There were no rests taken during litter carry by any litter team for SH.

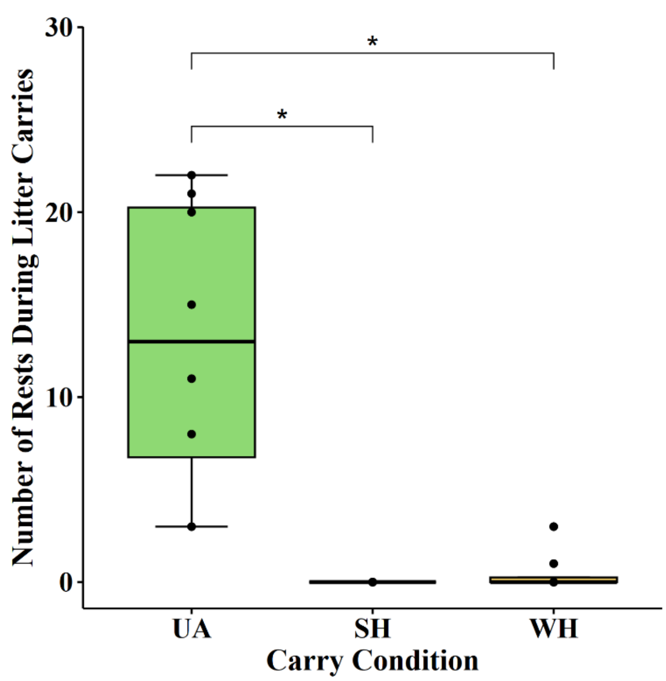

Figure 10. Number of rests during litter carries are plotted for UA, SH, and WH.
* indicates a statistically significant difference between UA and SH, and between UA and WH.

Litter pick-up and litter drop-off durations.

The outcomes for average durations of litter pick-up and litter drop-off are presented in Table 8, Figure 11, and Figure 12. The average durations for litter teams picking up the litters were longer for the SH carry condition, and similar between the UA and WH carry conditions (Table 8). The average duration of dropping off the litter followed the same pattern; the UA and WH carry conditions had similar average drop-off durations, whereas the SH carry condition had a longer average litter drop-off duration. Average pick-up and drop-off durations were the most similar within and between UA and WH carry conditions, and the SDs were similar for litter pick-up and litter drop-off durations across carry conditions.

The one-way repeated measures ANOVA revealed statistically significant differences in carry condition for both litter pick-up and litter drop-off durations ($p < 0.001$; $p = 0.027$). Pairwise post-hoc analyses, using the Bonferroni adjusted p-value, revealed pairwise statistically significant differences in litter pick-up duration between carry conditions UA and SH (p_{adj} = 0.026) and between SH and WH ($p_{adj} < 0.001$); however, the pairwise post-hoc analyses did not reveal statistical significance between any of the carry conditions for litter drop-off duration.

Table 8. Means for Litter Pick-Up and Litter Drop-Off Durations per Carry Condition

	UA $n = 8$		**SH** $n = 8$		**WH** $n = 8$	
	Pick-up (s)	**Drop-off (s)**	**Pick-up (s)**	**Drop-off (s)**	**Pick-up (s)**	**Drop-off (s)**
Mean	9.46^{a}	8.04	15.47^{a,b}	11.73	9.79^{b}	8.77
SD	2.16	3.02	3.38	2.81	1.99	1.99
Minimum	6.94	4.35	10.18	7.25	6.84	6.47
Maximum	14.28	14.02	21.46	15.35	12.09	11.63

[a]A statistically significant difference exists for duration of litter pick-up between SH and UA.
[b]A statistically significant difference exists for duration of litter pick-up between SH and WH.
Note. Number of litter teams averaged per carry condition is represented by *n*.

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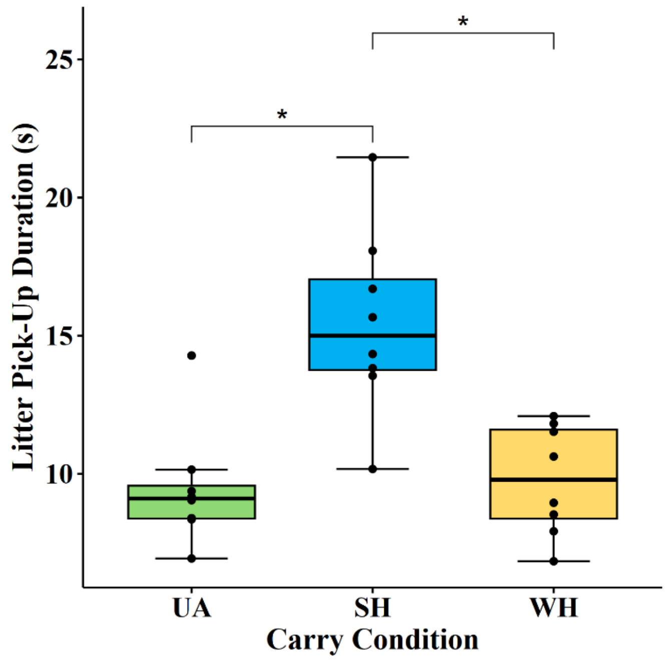

Figure 11. Duration of litter pick-up represented in seconds for UA, SH, and WH.
* indicates a statistically significant difference between UA and SH, and between SH and WH.

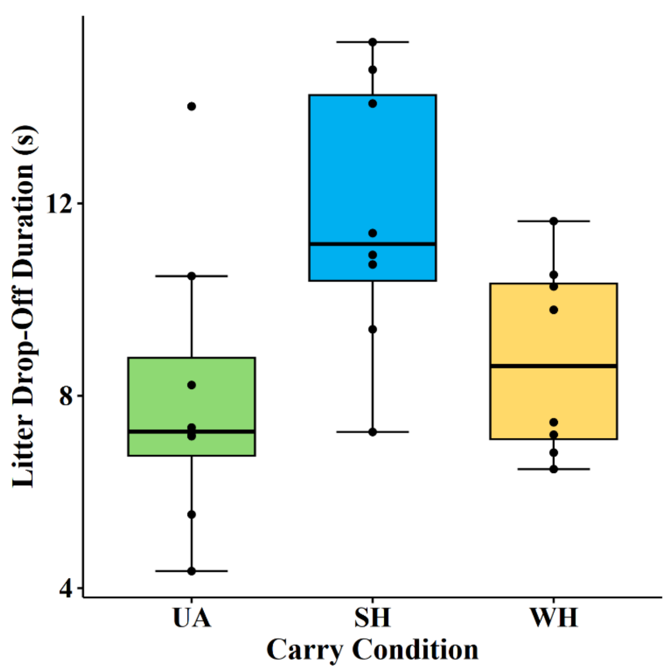

Figure 12. Duration of litter drop-off represented in seconds for UA, SH, and WH.

Subjective Measures

Subjective measures for two subjects were excluded for UA; one subject was withdrawn by the PI before completing the post-carry subjective measures, and the other had an extended delay between completing the UA carry condition and providing the post-carry subjective measures. The one-way repeated measures ANOVA (UA, n = 14; SH and WH, n = 16) did not reveal any significant differences between carry condition and subjective responses for the delta ratings (difference between pre- and post-carry) of perceived exertion, discomfort, or fatigue. Additionally, ANOVA did not reveal any statistically significant differences in any of the subjective response ratings for carry position (front or rear of litter). While the physical act of litter carriage did produce a measurable change in perceived exertion, discomfort, and fatigue between the HRVs' pre- and post-carry responses, the subjective measure deltas were not found to be significantly different between carry conditions. Means, SDs, minimum values, and maximum values for the subjective response variables—perceived exertion, discomfort, and fatigue—are presented in Table 9 through Table 11, respectively.

The one-way repeated measures ANOVA revealed a statistically significant difference in carry condition for the user acceptance subjective response variable (p = 0.009) only (Table 12 and Figure 16). The pairwise post-hoc analysis, using the Bonferroni adjusted p-value, further revealed that carry condition was statistically significant between the SH and UA groups (p_{adj} = 0.010) for user acceptance.

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Perceived exertion.

Mean, SD, minimum, and maximum ratings of delta perceived exertion (6 to 20 scale) are presented in Table 9 and Figure 13; higher number ratings indicate a greater delta perceived exertion. The average delta perceived exertion for UA was slightly higher than for SH and WH (Table 9). Statistical analyses did not reveal significant differences in the average delta perceived exertion ratings between carry conditions, UA, SH, and WH, or between carry positions, front and rear of litter.

Table 9. Descriptive Statistics for Subjective Ratings of Delta Perceived Exertion (6 to 20 Scale) per Carry Condition

	UA *n* **= 14**	**SH** *n* **= 16**	**WH** *n* **= 16**
Mean	5.2	4.4	4.3
SD	2.8	3.0	2.3
Minimum	2	-1	1
Maximum	11	9	8

Note. Number of HRV averaged per carry condition is represented by *n*.

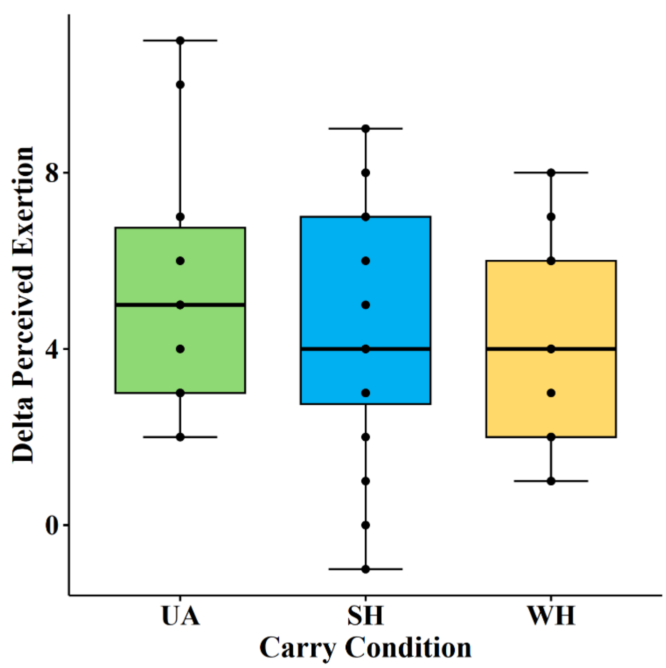

Figure 13. Subjective ratings of delta perceived exertion for the UA, SH, and WH carry conditions.

Discomfort.

Mean, SD, minimum, and maximum ratings of delta discomfort (0 to 10 scale) are presented in Table 10 and Figure 14; higher number ratings indicate a greater delta discomfort. The average delta rating of discomfort for UA was slightly higher than for SH and WH (Table 10). Statistical analyses did not reveal significant differences in the average delta discomfort ratings between carry conditions, UA, SH, and WH, or between carry positions, front and rear of litter.

Table 10. Descriptive Statistics for Subjective Ratings of Delta Discomfort (0 to 10 Scale) per Carry Condition

	UA $n = 14$	**SH** $n = 16$	**WH** $n = 16$
Mean	2.3	1.8	1.9
SD	2.3	1.5	1.6
Minimum	-1	0	-2
Maximum	7	5	5

Note. Number of HRV averaged per carry condition is represented by n.

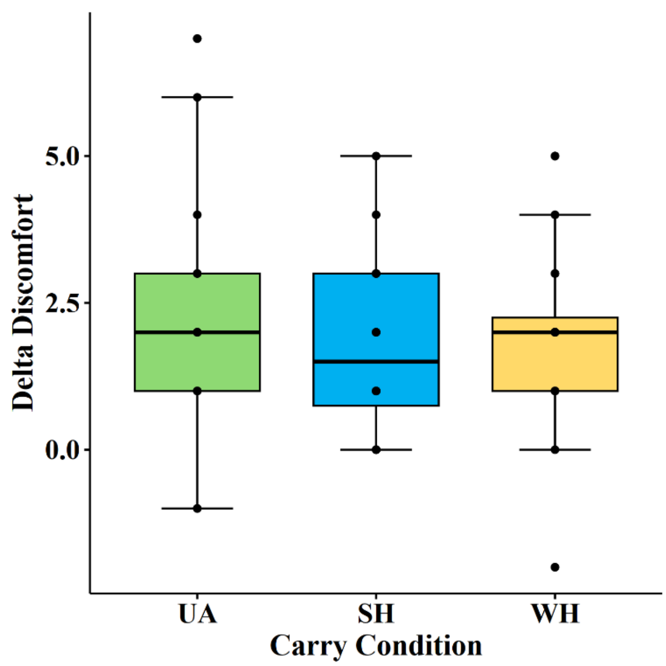

Figure 14. Subjective ratings of delta discomfort for the UA, SH, and WH carry conditions.

Fatigue.

Mean, SD, minimum, and maximum ratings of delta fatigue (0 to 10 scale) are presented in Table 11 and Figure 15; higher number ratings indicate a greater delta fatigue. The average delta rating of fatigue for WH was slightly higher than for UA and SH (Table 11). Statistical analyses did not reveal significant differences in the average delta fatigue ratings between carry conditions, UA, SH, and WH, or between carry positions, front and rear of litter.

Table 11. Descriptive Statistics for Subjective Ratings of Delta Fatigue (0 to 10 Scale) per Carry Condition

	UA ***n* = 14**	**SH** ***n* = 16**	**WH** ***n* = 16**
Mean	2.1	2.0	2.5
SD	1.5	1.3	1.8
Minimum	0	0	-3
Maximum	5	4	5

Note. Number of HRV averaged per carry condition is represented by *n*.

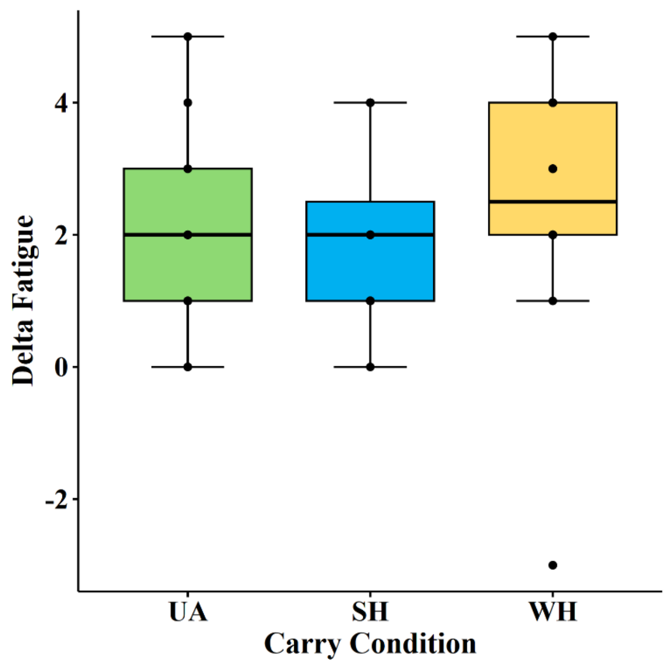

Figure 15. Subjective ratings of delta fatigue for the UA, SH, and WH carry conditions.

User acceptance.

Mean, SD, minimum, and maximum ratings of user acceptance (0 to 10 scale) are presented in Table 12 and Figure 16. User acceptance was an indicator of the preference of an HRV to conduct a litter carriage task in the respective carry condition; therefore, user acceptance was only assessed post-testing for each condition. Mean user acceptance ratings were the highest for SH followed by WH and UA. Statistical analysis resulted in significance between UA and SH (p_{adj} = 0.010) indicating that subjects preferred carrying the litter with the SH over no support. Statistical analyses did not reveal significant differences in the average user acceptance ratings between carry positions, front and rear of litter.

Table 12. Descriptive Statistics for Subjective Ratings of User Acceptance (0 to 10 Scale) per Carry Condition

	UA ***n*** **= 14**	**SH** ***n*** **= 16**	**WH** ***n*** **= 16**
Mean	4.5[a]	7.2[a]	5.1
SD	2.5	2.7	2.4
Minimum	0	1	0
Maximum	9	10	9

Note. [a] A statistically significant difference exists for subjective user acceptance between UA and SH. Number of HRV averaged per carry condition is represented by *n*.

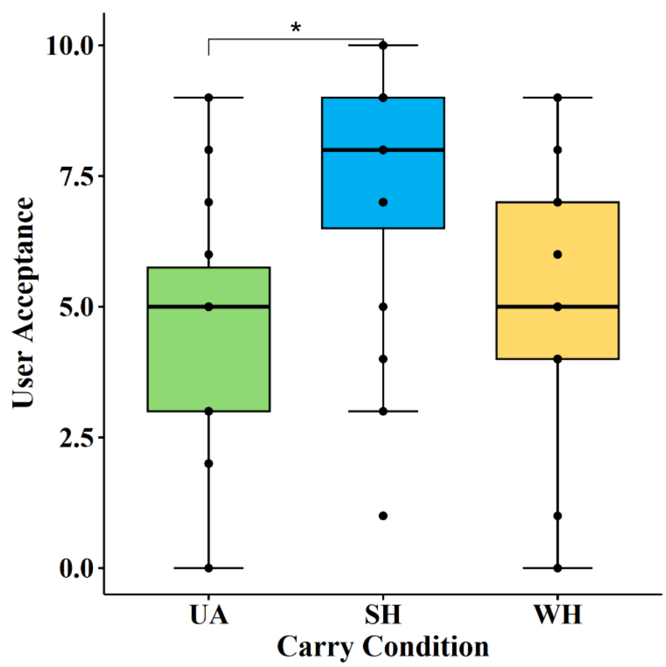

Figure 16. Subjective ratings of user acceptance for the UA, SH, and WH carry conditions. * indicates a statistically significant difference between UA and SH.

Discussion

This study used a simulated MASCAL, field-based litter carriage scenario with a methodology similar to the previous field-based litter carriage study by Ballard et al. (2025b) for direct comparisons to the field-based study and to the earlier laboratory-based simulated litter carriage study by Ballard et al. (2023). The findings of the laboratory-based study demonstrated that the use of an LCAD in a two-person litter team could decrease the number of personnel needed for litter carriage from four to two SMs, SMs could carry casualties longer, and SM could retain grip strength with the use of an LCAD (Ballard et al., 2023). The findings from the field-based, prolonged carry scenario validated that SMs could carry casualties farther and longer with LCADs in a prolonged setting, and a shoulder harness LCAD allowed for HRVs to retain more grip strength than when carrying with wrist hooks or carrying a litter unassisted. To limit variability in this study and maintain consistency with the previous research, two-person litter teams were tested, and carry position (front or rear of litter) was kept the same for all HRVs across the different carry conditions. The effects of LCADs were evaluated based on HRV fatigue (grip strength data and subjective responses) and HRV performance (number of carries, duration of carry, duration of litter pick-up and drop-off, and number of rests during carry). Testing LCADs in various military operational field settings has allowed for investigation into the benefits and shortcomings of different types of LCADs as it relates to human performance and fatigue in current and future operations, like those envisioned during LSCO.

Grip Strength

Grip strength was considered the primary metric for assessing HRV fatigue, confirming results of the previous field-based litter carriage study (Ballard et al., 2025b). In this study, bilateral delta grip strength (the difference between post-carry and pre-carry values) showed a decrease in grip strength for all carry conditions, with the SH carry condition having the lowest decrease and the UA carry condition having the highest decrease (Table 4 and Figure 7). The grip strength for the SH, WH, and UA carry conditions decreased by 33 N, 60 N, and 122 N, respectively. The analysis revealed statistically significant differences in the bilateral delta grip strength between the SH and UA carry conditions and the SH and WH carry conditions. The HRVs in the SH carry condition significantly retained more grip strength than the HRVs in the UA and WH carry conditions, which was expected because the SH helps to transfer the load from the hands to the torso whereas the WH helps to transfer the load from the hands to the wrists and forearms. Although there was not a significant difference in delta grip strength between the UA and WH carry conditions, the average grip strength decrement for WH was half of that for UA with a smaller SD. This indicates that more casualties can be carried with LCADs without the SM becoming more fatigued. Further, the higher SD for the UA carry condition shows that there is much more variance in the delta grip strength for UA than carrying the litter with LCADs. Additional analysis could lead to better understanding of the contribution of carry position and anthropometry to the variance and the large decrements measured in the UA carry condition.

Grip strength results from the laboratory-based study (Ballard et al., 2023) concur with the outcomes in this study as both the simulated two-person SH and WH carry conditions retained more grip strength than the simulated four-person UA carry condition. In this study, the SH carry condition did preserve the most grip strength as compared to the other carry conditions, which also agrees with the results from the previous field-based study (Ballard et al., 2025b); however, HRVs in the WH carry condition in the previous field study did not retain more grip strength than the UA carry condition. A possible reason why the HRVs in the WH carry condition preserved more grip strength in this study is because a WH LCAD may be better suited for multiple short duration carries with intermittent breaks in litter carry (i.e., returning to the point of injury to pick up another casualty) than continuous use of WH in a prolonged litter carry scenario like that simulated in Ballard et al. (2025b).

Performance Measures

Number of carries and carry duration.

In this simulated MASCAL scenario, results revealed that the number of completed carries and carry duration both have statistically significant differences between the UA and LCAD carry conditions (Table 5 and Table 6). The primary performance metric was the number of carries the litter teams were able to complete for each carry condition within the 20 minutes allowed. The results demonstrated that litter teams can not only transport more casualties with LCADs than when carrying litters unassisted (Figure 8), but they also spent more time within the 20-minute time constraint actively carrying the litter with LCADs than with no assistance (Figure 9). On average, the litter teams carried the litter 45% of the time under the SH carry condition, 43% of the time under the WH carry condition, and 30% of the time under the UA carry condition. Additionally, outcomes show that HRVs were able to transport significantly more casualties while also significantly retaining more grip strength for the SH carry condition and on average 50% more grip strength for the WH carry condition compared to UA.

An interesting result from these data is that the WH carry condition averaged more completed litter carries in less active carry time than both UA and SH conditions (Table 5 and Table 6). The number of carries the litter teams could complete and the overall litter carry duration were affected by the HRVs' self-selected pace during the litter carry tasks. It was observed that some litter teams chose to carry the litter through the course as quickly as they could whereas other litter teams would choose to carry the litter at a slower pace. The WH carry condition also averaged shorter pick-up and drop-off durations than the SH carry condition, although the difference in drop-off durations was not found to be statistically significant. More completed litter carries and shorter total carry duration combined with shorter pick-up and drop-off durations suggests that HRVs with WH took more time than SH either resting or on return trips to recover from fatigue before continuing the litter carry; however, this also suggests that SMs using WH might be able to carry casualties slightly faster than with SH.

The performance data from previous USAARL studies (Ballard et al., 2023; Ballard et al., 2025b) suggest that the shoulder harness may be better suited for prolonged carries than the wrist hooks; however, the current study found that both LCADs were more beneficial than unassisted litter carriage in a MASCAL scenario. In the previous laboratory-based study comparing simulated two-person carries with LCADs versus four-person unassisted carries, HRVs with SH demonstrated a significant increase in carry distance and carry duration compared to carrying with WH and UA for the simulated prolonged carries (Ballard et al., 2023). Although the performance differences between HRVs carrying with WH and UA were not significant for the simulated laboratory carries, means for carry distance and duration were higher for the simulated two-person carry with WH than the simulated four-person UA carries. Similarly, the previous field-based study with two-person carries also demonstrated a significant increase in carry distance and duration for HRVs carrying with SH compared to carrying with WH and UA (Ballard et al., 2025b). In the current simulated MASCAL study, there is not only a significant performance increase for HRVs carrying with SH versus carrying UA, but also a significant increase when HRVs carried with WH versus UA for number of completed carries and overall carry duration (Table 5, Table 6, Figure 8, Figure 9).

Rice et al. (1996) also investigated how using a shoulder harness LCAD affected litter bearer performance. Similar to our previous lab study (Ballard et al., 2023), the simulated laboratory-based design of Rice et al. had subjects carry a litter on a treadmill for 50 m for a set amount of time (15 minutes) in simulated two-person and four-person carries. The Rice et al. (1996) study concluded that a shoulder harness did not increase the number of casualties that could be carried; the difference in the number of carries in their data for a simulated two-person team was slightly higher for the SH carry condition (16.1) than the UA carry condition (15.9), whereas they also reported a significantly higher number of carries for their simulated four-person team in UA (17.0) than SH (16.0). Although Rice et al. reported results that were not in agreement with the outcomes in this report, the methods used in the Rice study were very different from the operational field-testing of this study. Participants in the Rice et al. (1996) study transported a simulated casualty on a treadmill alone in simulated two- or four-person teams. These simulations in a laboratory-based setting do not account for differences in litter bearer height or changes in gait when transporting litters on natural, uneven terrain. Additionally, the USAARL laboratory study (Ballard et al., 2023) demonstrated that a two-person team carrying a litter with LCAD was more effective than a four-person team carrying a litter unassisted. While Rice et al. (1996) reported that the difference of transporting one more casualty was significant enough to recommend unassisted four-person teams versus assisted two-person teams, the combined outcomes from our past and current studies do not support this recommendation due to the significant increases in carry with assistive devices versus without. Furthermore, our current study found a significant difference in the number of carries (four and five more casualties transported with shoulder harness and wrist hooks LCADs, respectively, when compared to carrying unassisted) suggesting LCAD use in two-person teams to be highly beneficial for casualty transport during a MASCAL event.

Number of rests during carry.

The number of rests (or rest breaks) during litter carry for the UA carry condition was significantly higher than the SH and WH carry conditions (Table 7), and there was no significant difference for average number of rests between the SH and WH carry conditions. All litter teams rested during the litter carry in the UA carry condition (Figure 10). In contrast, none of the litter teams sat the litter down to rest during litter carry in the SH carry condition, and six out of the eight litter teams did not rest during the litter carry in the WH carry condition. Litter teams were not limited in the number or duration of breaks that they were allowed to take in the carry conditions. It was observed that for the UA carry condition, HRVs were adding more time to rest and recover not only during the carry, but also in the time they spent between carries. More time spent resting means less time for litter carrying (casualty transport); therefore, these observations align with the shorter duration of active carries for UA as compared to the duration of carry with either LCAD. A rest during a litter carry represented the time that a casualty and litter bearers would be stationary—not moving to the next point of care. Operationally, this increases the time that the casualty (and potentially the litter bearer) is in harm's way.

Litter pick-up and litter drop-off durations.

Outcomes for litter pick-up duration demonstrated a significant increase in average duration of picking up the litter between the SH carry condition (15.5 s), the WH (9.8 s), and the UA (9.5 s) carry conditions (Table 8, Figure 11). Although there was no significant difference in the litter drop-off duration between carry conditions, the average duration of setting down the litter in the SH carry condition was higher (11.7 s) than in the WH (8.8 s) and UA (8.0 s) carry conditions (Table 8, Figure 12). The motion of engaging with the litter with WH is the same natural motion of engaging with no assistive device; thus, it was reasonable to expect the findings of no significant difference and similar durations in the litter pick-up and drop-off durations between the WH and UA carry conditions. Engaging with the litter using the SH is a different motion. Rear litter bearers have to lean forward while sliding the loops connected to the harness over the litter handles whereas front litter bearers have to turn toward their sides and shift their torso rearward to slide the loops onto the litter handles. Therefore, it was also reasonable to expect the finding that it would take longer for the HRVs to pick up and set down the litter in the SH carry condition as the motion to do so slightly impedes their natural motion during this task. It is also possible that a larger sample size than tested in this study may show significance in litter drop-off durations between the SH carry conditions and the other carry conditions.

Rice et al. (1996) also reported that use of a harness increased the time it took to pick up a litter. In their simulated, laboratory-based MASCAL study, they presented a significant difference ($p = 0.0009$) between picking up a litter with their shoulder harness device versus without an assistive device. The previous laboratory-based (Ballard et al., 2023) and field-based (Ballard et al., 2025b) litter carry studies at USAARL did not test litter pick-up or drop-off durations, so the agreeance in results with the Rice et al. (1996) study suggests that the increased duration of litter pick-up with SH use (average six-second increase when compared to WH and UA) may impact the number of carries that can be completed as well as the amount of time needed to immediately move a casualty out of harm's way during a MASCAL operational scenario.

Given the potential benefits of SH use in the reduction of fatigue as measured by grip strength retention, number of carries completed, and carry duration combined with the relatively small increase in time to pick up the litter (average six-second increase compared to WH and UA), it is likely worthwhile to employ SHs to aid in dismounted litter carriage; however, it is ultimately a command decision as longer pick-up and drop-off durations can represent delays in operational availability to shoot, move, and communicate. According to Madison et al. (2022), exoskeletons used for casualty evacuation should be designed so that the use of exoskeletons does not impede the natural performance of litter carry tasks (i.e., picking up and setting down a litter). Ideally, durations of litter pick-ups and drop-offs would be the same or lower with LCADs than in the UA carry condition. The results of this study demonstrate that transferring the load from a litter bearer's hands and arms to the torso increases their operational performance—transporting more casualties—and reduces their level of fatigue during dismounted casualty transport. Future LCADs should provide innovative ways for a litter bearer to realize these benefits while minimizing potential shortcomings that would negatively affect picking up and setting down the litter.

Subjective Measures

For subjective ratings of perceived exertion, discomfort, fatigue, and user acceptance, statistical analysis only resulted in significance in the user acceptance ratings between the UA and SH carry conditions with more HRVs preferring to carry with the SH (Table 9 through Table 12). These results were similar to the previous field-based litter carry study in that pre- to post-changes in perceived exertion, discomfort, nor fatigue ratings were significant between the three carry conditions (Ballard et al., 2025b). While not significantly different, trends did show a slight difference between the UA carry condition and the LCAD carry conditions for changes in ratings of perceived exertion and discomfort. The Rice et al. (1996) simulated MASCAL study reported that HRVs had more discomfort ("aches") in the hands, shoulders, and arms during unassisted carries as compared to their shoulder harness device carries; this aligned with the pre- to post-carry changes for subjective discomfort in this study as delta discomfort increased for the UA carry condition and decreased for the SH carry condition. These findings also concur with Ballard et al. (2023) and Ballard et al. (2025b) as they suggest that even though transporting multiple casualties in a simulated MASCAL event is a strenuous, physically demanding activity, LCADs could make a difference in subjective perceived exertion and discomfort of the litter bearer.

While not statistically significant, the average subjective ratings of fatigue were higher for the WH carry condition than for SH and UA. An explanation for this can be gained through examination of the subjective ratings of fatigue (Table 11 and Figure 15) along with the outcomes for delta grip strength (Table 4 and Figure 7) and the number of completed carries by carry condition (Table 5 and Figure 8). In both WH and SH carry conditions, HRVs completed significantly more carries than UA, while not being significantly different from each other; whereas, HRVs in the SH carry condition did retain significantly more grip strength than WH. These outcomes suggest SH may be slightly better than WH at delaying the time to fatigue, likely due to transitioning the litter load to larger muscle groups in the torso.

An interesting observation from the subjective fatigue data is that only one HRV reported decreased fatigue after carrying with the WH as compared to their pre-carry fatigue rating. It is unclear why the HRV felt that carrying during the WH carry condition allowed for subjective recovery. This HRV tested with the SH first followed by the WH, and UA as the last test condition. When looking at the objective fatigue data and grip strength data, this HRV had a larger decrease in grip strength for the SH carry condition than WH and UA between pre- and post-carry. For user acceptance response ratings, this HRV rated SH lower than WH and UA. It appears that this HRV objectively fatigued more when carrying with SH than carrying in the other test conditions, and preferred to carry the litter with WH or UA rather than with SH. The data suggests that the HRV was worn out from the SH carry condition and may have had lingering fatigue effects going into their second carry condition, WH. It is not known why the SH carry condition may have had such a strong subjective effect on the HRV, but this HRV had a unique individualized response and perhaps needed more time to recover from carrying with the SH or may have needed more adjustability due to anthropometry or litter carry position than the SH device offered.

A statistically significant difference was found in the user acceptance ratings between the SH (7.2) and UA (4.5) carry conditions (Table 12). The WH carry condition did not have a significant difference in the user acceptance ratings between UA or SH; however, the average rating for WH (5.1) was slightly higher than UA. These results clearly show that the HRVs preferred using the SH device over the UA carry, but it also shows that the HRVs are open to other LCAD options for litter carriage. Results from the previous USAARL litter carriage studies (Ballard et al., 2023; Ballard et al., 2025b) also demonstrate that regardless of the litter carriage task (single prolonged carry versus multiple short carries), the shoulder harness LCAD device was significantly preferred over carrying the litter without an assistive device.

Furthermore, the ANOVA did not reveal any statistical significance between subjective ratings and carry positions (front or rear of the litter). This is an interesting result because it seemed likely that HRVs carrying in the front of the litter for the SH carry condition may have had increased perceived exertion, discomfort, or fatigue compared to the rear litter bearer due to the awkward postures they have to assume in picking up and setting down the litter. Additionally, the rear carry position is sometimes regarded as the more physically demanding position due to more of the casualty's weight being where the head is positioned (the rear). A limitation of this study in analyzing data from the different carry positions is that the carry position was not an isolated condition of interest. Additional analyses investigating grip strength based on carry position combined with subjective ratings may provide more insight into benefits, or lack of benefits, provided by LCADs based on carry position. Further, it is possible that a study designed around examining the effects of carry position or a larger sample size could reveal significance between carry position, fatigue measures, operational performance, and subjective ratings.

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Conclusion

This study was a follow-on effort, based on previous research completed by USAARL, to investigate the effects of LCADs on litter bearer performance and fatigue in a simulated, operationally relevant MASCAL scenario. To the knowledge of the authors, this unique study is the only published work investigating the effects of LCADs with litter carriage in simulated field-based MASCAL operations. The number of completed litter carries and carry duration were used as primary metrics to evaluate HRV litter carry performance, while grip strength was considered the primary metric for evaluating litter bearer fatigue. Use of a shoulder harness or wrist hooks showed significant increases in the number of casualties transported and duration of litter carriage compared to the unassisted carry condition. Shoulder harness use resulted in significant retention of grip strength when compared to the unassisted and wrist hooks carry conditions.

The use of LCADs in this MASCAL study demonstrated that two-person litter teams are able to transport more casualties up to 50 meters without taking rests while litter teams without assistive devices could not carry that distance without resting at least three times in a 20-minute period. Shoulder harness use took significantly more time to pick up the litter than without the use of an assistive device, but wrist hooks use had similar litter pick-up durations to the unassisted carry conditions. This pattern, although not statistically significant, continued for drop-off, or time to set down and disengage from the litter: SH use took longer than both wrist hooks and unassisted carries, which were extremely similar. Using LCADs resulted in no significant increases in perceived exertion, discomfort, or fatigue compared to unassisted carries, despite HRVs carrying for longer durations and transporting more casualties. Additionally, SMs preferred using a shoulder harness device for multiple, short distance carries as compared to an unassisted carry.

LCADs have been shown to allow SMs to move more casualties, carry casualties longer, and reduce their levels of fatigue. This can increase the number of survivable casualties in a MASCAL event by transporting more to the next level of care. In addition to benefitting the casualty by improving transport, LCAD use could reduce the number of acute or chronic musculoskeletal injuries to litter bearers resulting from overexertion during litter transport, thus reducing costs incurred from lost workdays and disability claims. Furthermore, the devices tested in this study and in the previous USAARL litter carriage studies are commercial-off-the-shelf (COTS) devices tested for their efficacy in military casualty transport. Devices specifically designed for use by the military for dismounted litter carriage could not only increase the benefits realized in these studies but could also mitigate the shortcomings of these devices.

The major findings from USAARL's investigation on the effects of LCADs in a simulated MASCAL scenario are:

- WH averaged more completed litter carries (meaning more casualties moved) in less active carry time than both the UA and SH conditions.
- Both LCADs were more beneficial than unassisted litter carriage in a MASCAL scenario. Previous USAARL studies found the SH may be more beneficial than WH and UA in prolonged carry scenarios.

- Both LCADs resulted in near-zero rests during casualty transport, compared to an average of 13 rests for UA. Rest time means the casualty and litter team are stationary which increases their vulnerability and potential for increased casualties on the battlefield.
- More casualties can be transported with LCADs without increasing the level of fatigue to the SM. HRVs in the SH carry condition retained more grip strength than in the UA and WH carry conditions due to the SH's ability to transfer the litter load from the hands to the torso, whereas the WH help to transfer the load from the hands to the wrists and forearms. The average grip strength decrement for WH was half of that for UA and had a smaller standard deviation.

Recommendations

To assist with dismounted litter casualty transport both in current operations and to meet the challenges of future conflicts, including MASCAL scenarios, and based on the outcomes from this study combined with previous USAARL LCAD research (Madison et al., 2022; Robinette et al., 2023; Ballard et al., 2023; Ballard et al., 2025a; Ballard et al., 2025b), USAARL makes the following recommendations:

- Assistive devices, such as LCADs and exoskeletons, should be developed for military-specific operational needs.
- COTS and military-specific LCADs and exoskeletons should be deployed as soon as possible for evaluation.
- The outcomes from such evaluation should be used to improve the design of assistive devices and exoskeletons for military litter carriage applications.
- Development of a standardized methodology for the evaluation of assistive devices and exoskeletons is needed to ensure the right technologies are developed and deployed.

The USAARL LCAD program, using the experience and outcomes from this and prior efforts, will move forward with development of a standardized methodology for evaluating assistive devices and exoskeletons for use in military casualty transport as well as continue to support the future development of such devices.

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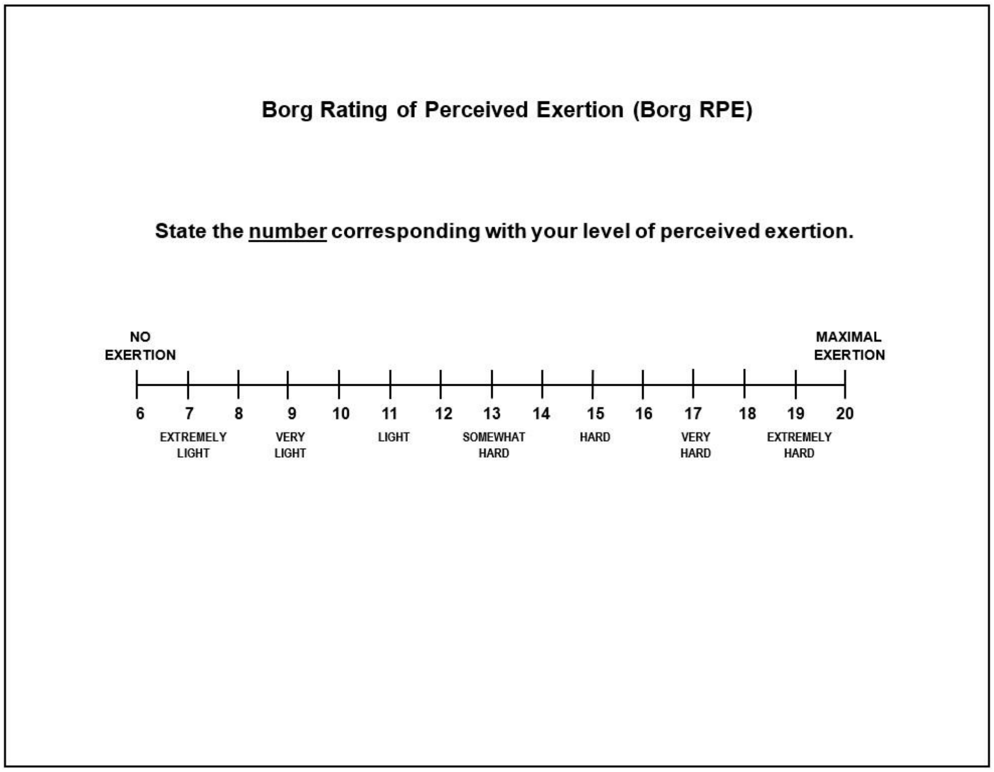
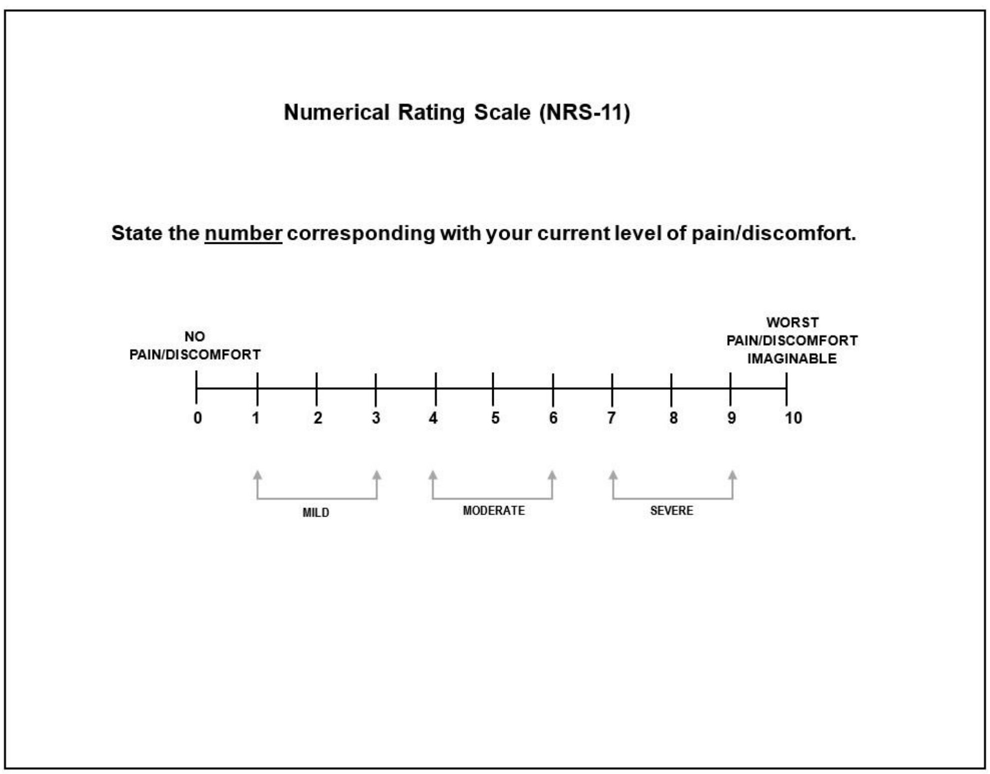
Appendix A. Acronyms and Abbreviations

AEWE	Army Expeditionary Warrior Experiment
ANOVA	Analysis of Variance
cm	Centimeter
COTS	Commercial-Off-The-Shelf
DEVCOM SC	U.S. Combat Capabilities Development Command Soldier Center
DoD	Department of Defense
DTIC	Defense Technical Information Center
EMG	Electromyography
G	Gravitational Constant
GUI	Graphical User Interface
HRDD	Headquarters Research and Development Detachment
HRV	Human Research Volunteer
IMU	Inertial Measurement Unit
in.	Inches
IRB	Institutional Review Board
kg	Kilogram
lb	Pound
LCAD	Litter Carriage Assistive Device
LSCO	Large-Scale Combat Operation
m	Meters
MASCAL	Mass Casualty
Min	Minutes
MOS	Military Occupational Specialty
n	Sample Size
N	Newtons
PCC4	Project Convergence Capstone 4
s	Seconds
SD	Standard Deviation
SH	Shoulder Harness Carry Condition
SM	Service Member
UA	Unassisted Carry Condition
USAARL	U.S. Army Aeromedical Research Laboratory
Ver	Version
WH	Wrist Hooks Carry Condition

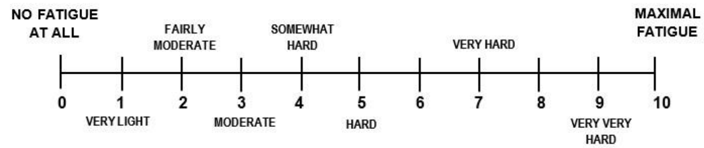
Appendix B. Numerical Rating Scales





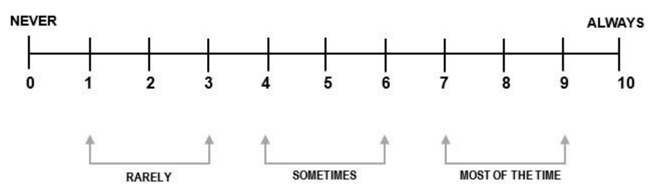
Modified Borg Rating of Perceived Fatigue (CR10 Scale)

State the <u>number</u> corresponding with your current level of perceived fatigue.



Numerical Rating Scale (User Acceptance)

State the <u>number</u> corresponding with your willingness to carry a litter in this fashion.



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