Perceived Difficulty for Seated Reach Motions: Methodologies Developed for Military Armor

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Soldiers seated in military tactical vehicles perform diverse manual tasks while wearing personal protective equipment (PPE) and body borne gear (BBG), which potentially restrict the soldiers’ ability to reach. In this study, participants performed seated reach movements to targets in a wide range of locations around the body, with and without a harness restraint, while donning a range of PPE configurations. The participants then reported perceived difficulty of reach motions on a 10-point scale. A preliminary analysis indicated that difficulty ratings significantly increase with added harness and armor levels. Further, the overhead and left hemisphere areas of the participant’s body show increased difficulty ratings in added armor and harness level conditions due to the restricted torso mobility. These findings will be incorporated into a quantitative model for vehicle design to improve occupants’ performance and comfort.

INTRODUCTION
Soldiers seated in military tactical vehicles perform increasingly diverse manual tasks, including using communications and weapons systems. Personal protective equipment (PPE), including body armor, and body borne gear (BBG) can potentially restrict the soldier’s ability to reach, but the impact of body armor and gear on functional range of motion and task performance is not well understood. Currently available tools used to simulate military vehicle occupants for ergonomics and performance analysis, such as the Siemens Jack or other human modeling software tools, lack the ability to accurately represent the reach restrictions imposed by PPE and BBG.

The current pilot study examined the effects of body armor and body-borne gear on perceived difficulty in seated reach movements that simulate soldiers’ manual tasks in military vehicles. Participants performed a series of seated reach movements to targets in a wide range of locations around the body, with and without the presence of a harness restraint system, and while wearing a range of PPE/BBG configurations. The overall goal of this research is to develop a quantitative model of reach difficulty for use in vehicle design. Ultimately these tools will be used to optimize military vehicle design and improve body armor and harness systems.

METHODS
Participants
In this pilot study, data were gathered from 10 civilian participants (5 females and 5 males), all right-handed and with no history of musculoskeletal disorders. The mean age was 24.3 (SD 5.5) years old. The mean stature of the participants was 171.2 (SD 9.9) cm and the mean body-mass index (BMI) was 25.4 (SD 3.6) kg/m². Participant anthropometry range was designed to span at least the 5th-percentile-female to 95th-percentile male values for current U.S. Army personnel.

Equipment
A mock-up of a squad seat with dimensions that are typical in a military tactical vehicle was used in this study. The seat was equipped with a 5-point restraint (harness) system (Figure 1). During testing the upper restraints were fed back into the retractor with the participant sitting back in the seat. The restraints were then locked to prevent feed-out, which restricted the participant’s torso motions. Participants’ motions were recorded using a 13-camera VICON optical motion capture system. However, the outcome of motion capture analysis is not included in this report.

Figure 1. Laboratory setup illustrating the vertical elevations of the target locations.
Garment and Harness Conditions

Each participant was tested with three levels of armor (Figure 2): minimally clad garment (MCG), wearing PPE alone (PPE), and wearing the PPE and BBG (BBG). The effect of the 5-point harness was also investigated (with vs. without a harness). Test condition order was randomized by level of armor and harness conditions.

![Figure 2. Participant donning 5-point harness in minimally clad garment (MCG: A). Participant in PPE (B) and BBG (C).](image)

Hand Reaching Tasks

During testing, participants performed index-finger pushes on button targets presented on a grid (Figure 3). The reference plane (0°) of the grid was scaled to shoulder height. Targets were presented through a range of azimuth angles, approximately -90° (right) to +60° (left), at 30° interval increments, relative to the mid-sagittal plane. Vertically, the grid design incorporated the presentation of hand targets at five vector directions with respect to horizontal: 0° (reference plane), +30° and 60° above, and -30° and -60° below the reference plane. The horizontal location of the grid was scaled using initial measurements of each participant’s maximum reach performed at the shoulder height. Horizontal target distances were set at 85%, 95% and 105% of the individual participant’s demonstrated maximum reach capability in the particular combination of PPE/BBG and harness. In each trial, the position of the target was displayed on a computer screen using an alphabetic label. Target positions were randomized and balanced.

Prior to the start of each trial, participants assumed a standardized posture with a torso inclination angle of approximately 10-degrees aft of vertical (lower back contact with the seatback), parallel legs (no splay angle), ankles located directly under the knee, and the left, opposing arm lowered to their side with the palm oriented towards the body. The participant depressed a button on the target position using the right index finger for approximately 1 second (Figure 3) and returned to the resting position near the right lap. The participant reported a subjective rating of reach difficulty on a scale from 1 (minimal difficulty) to 10 (maximum difficulty). Reach targets that were not achievable were assigned a rating of 11.

![Figure 3. Participant performing a reach.](image)

Analysis

The general goal of the study is to develop a quantitative model to estimate difficulty rating as a function of reach target coordinates, armor, body-borne gear, and harness conditions, as well as subject attributes.

For this preliminary analysis, target locations were represented either in spherical and Cartesian coordinate systems, with the origin at the mid-shoulder position at the neutral (seated) position of the participant. In the spherical coordinate system, target azimuth was defined as positive leftward from the mid-sagittal plane. Also, target elevation was defined as positive upward from the horizontal reference plane at the mid-shoulder height.

The reach difficulty ratings were analyzed to quantify the main effects and interactions of body size, body armor level, and harness use. Summary statistics were tabulated and the spatial distribution of ratings was also analyzed using contour plots.

RESULTS

As expected, difficulty ratings increase with target distance across all armor and harness conditions (Figure 4). Ratings increase with the magnitude of target azimuth from the mid-sagittal plane, with the right hemisphere associated with higher ratings compared to the left hemisphere. Similarly, ratings increase with target elevation above the horizontal.

The mean linear distances from the seat reference point to targets associated with ratings of 7 or higher are listed in Table 1. The results show the effects of harness and body armor on reach capability. Specifically, wearing BBG significantly decreases the maximum target distance associated with a particular level of difficulty rating. For example, the target distance for a difficulty level of 7 decreased by 16% in comparison with the MCG condition (84.5 cm versus 101.4 cm). Similarly, the harness also decreases target distances at rating level 7, particularly in the MCG (101.4 cm versus 91.5 cm) and PPE (98.2 cm versus...
87.9 cm) conditions. However, such effects were not as evident in the BBG condition (84.5 cm versus 85.2 cm). Wearing a harness tends to reduce the armor-induced variations: in the no-harness condition, BBG versus MCG shows a difference of 16.9 cm (101.4 cm versus 84.5 cm), while in the with-harness condition, the difference was reduced to 6.3 cm (91.5 cm versus 85.2 cm).

![Image](http://doi.org/10.1080/00140139.2011.564312)

Figure 4. Mean difficulty ratings by target distance from the mid-shoulder (A), azimuth (B), and elevation (C). Error bars indicate 95th percentile bootstrap confidence intervals.

<table>
<thead>
<tr>
<th></th>
<th>No Harness</th>
<th>With Harness</th>
</tr>
</thead>
<tbody>
<tr>
<td>BBG</td>
<td>84.5 (1.95)</td>
<td>85.2 (2.7)</td>
</tr>
<tr>
<td>PPE</td>
<td>98.2 (11.7)</td>
<td>87.9 (5.5)</td>
</tr>
<tr>
<td>MCG</td>
<td>101.4 (11.8)</td>
<td>91.5 (5.2)</td>
</tr>
</tbody>
</table>

The spatial distributions of ratings for different body armor and harness conditions are also illustrated in Figure 5. The target coordinates associated with higher difficulty ratings are represented by shaded spots on three horizontal planes at different heights from the origin (mid-shoulder). The results demonstrated that a higher rating (represented as darker spots) is obtained for a given target space coordinate when the subject wore a harness and/or armor. For example, wearing BBG tends to decrease reach capabilities, particularly in the plane above the shoulder height. Further, when the harness conditions are considered (Figure 5A versus D, B versus E, C versus F), wearing a harness significantly reduces the participants’ reach distances, as represented by the shaded zone shifted close to the origin.

**DISCUSSION**

These preliminary results demonstrate that perceived difficulty from seated reach movements increases with target distance, absolute azimuth, and elevation, which is in alignment with previous studies (Reed, Parkinson, & Klinkenberger, 2003; Wang & Trasbot, 2011).

Difficulty ratings significantly increase with added harness and body armor levels. The specific magnitudes of impacts from body armor and harness levels tend to vary across different target areas, as shown in Figure 5, in the planes above the shoulder height and targets at far distance. In general, target areas that require substantial torso motions are more influenced by adding body armor and harness.

Due to practical experimental limitations, the order of presentation of the body armor and harness conditions was not randomized. For example, the with-harness and no-harness conditions were nested within a same body-armor condition, due to the extensive time to equip a subject with PPE and gear. Further, with only 10 subjects in this pilot study the covariance from anthropometry, such as stature and body weight, may not be reliably estimated. A larger scale study now underway will yield more useful results.

**ACKNOWLEDGEMENT**

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**REFERENCES**


A. MCG (No Harness)  
B. PPE (No Harness)  
C. BBG (No Harness)  
D. MCG (With Harness)  
E. PPE (With Harness)  
F. BBG (With Harness)  

Figure 5. Difficulty rating distributions in horizontal planes at 3 different heights from the mid-shoulder (origin).