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PRELIMINARY DEVELOPMENT OF AN INTEGRATED MOBILITY, LETHALITY, AND SURVIVABILITY SOLDIER PERFORMANCE TESTING PLATFORM

by
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14. ABSTRACT
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Preliminary Development of an Integrated Mobility, Lethality, and Survivability Soldier Performance Testing Platform

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Abstract. There is a desire for an integrated tool to measure the impact of military clothing and equipment on mobility, lethality and survivability. This study was a first step to develop such a test platform. Twenty Soldiers executed the test in three levels of encumbrance. Mobility was measured via obstacle completion timing. Lethality tasks included static and dynamic shooting engagements, with traditional marksmanship measures and cognitive decision-making. Quantification of body exposure and exposure to threat time comprised survivability measures. Preliminary results indicated that as encumbrance increased, mobility, lethality and survivability were altered. Obstacle completion times increased, marksmanship precision and vertical stability during the static elements improved, and shooting efficiency and threat elimination during the dynamic elements decreased. By expanding on this methodology, we create additional capabilities for the US Army and our international partners. Lessons learned from this study will allow for improvements to the test platform as it is developed.

Keywords: Clothing and Individual Equipment (CIE) · Human-systems integration · Human factors · Military · Combat obstacle course · Lethality · Mobility · Survivability · Marksmanship

1 Introduction

In 2017, the US Army announced their modernization priorities as a means of maintaining their military strength. Six specific areas were targeted for focus improvement and development, with the first five being specific technologies or end products. The sixth was “Soldier Lethality” or Soldier’s ability to shoot, move, communicate, protect and sustain by improving human performance and decision making [1]. In an effort to support this priority area for those trying to make clothing and individual equipment (CIE) acquisition and development decisions, there is a desire for an integrated or holistic objective tool to measure Soldier performance, specifically mobility, lethality and survivability incorporating underlying measures of human factors, biomechanics and cognition.

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Defense research organizations from Australia, Canada, Singapore and the United States use the Load Effects Assessment Program (LEAP), a military mission obstacle course originally developed by the US Marine Corps, to assess the impact of CIE on dismounted warfighter performance and specifically, mobility. The standardized LEAP test platform includes a 10-station obstacle course, in addition to static simulated rifle firing, vertical jump and weight transfer activities. Previous studies investigating completion times for military task-oriented obstacles (i.e., jumping, running, crawling, climbing) and obstacles courses have been able to differentiate CIE designs and configurations [2–4]. In the last 5 years, a number of studies have been completed using similar versions of the LEAP obstacle course. That testing has shown that course performance is affected by differences in CIE [5–7]. The LEAP course has also shown to be sensitive to changes in gross weight [8] and in percent body weight carried [9].

Additionally, previous marksmanship performance research had shown sensitivity to CIE encumbrance when using live fire [10–13]. Multiple studies have shown that weapons simulator/training systems are predictive of live-fire qualification scores [14–18]. Moreover, simulated marksmanship has also shown to be sensitive to CIE encumbrance level comparisons [19, 20] and allows testers to assess compatibility and performance degradations in an easy, quick, low cost, and safe manner [21]. The simulated marksmanship tasks have used static and on-the-move shooting at single and multiple targets (varied heights and locations) to demonstrate these differences in performance when wearing CIE products [22]. They have also integrated basic cognitive decision-making elements (go-no-go tasks), but with only high-level mobility differences seen across CIE encumbrance levels [23].

By integrating these mobility and marksmanship methodologies, with additional developmental methodologies in the areas of cognitive decision-making and survivability metrics, the LEAP Mobility, Lethality and Survivability (LEAP-MLS) was conceived. This research provides an initial proof of concept of this developmental test platform. This study is a first step in developing a methodology that incorporates objective measures of performance and is sensitive to changes in Soldier-system equipment, thus helping to inform the Soldier performance trade space during product development and acquisition, using a single, standardized and controlled event.

2 Methods

2.1 Study Participants

Twenty active duty Soldier volunteers executed the course in three levels of CIE encumbrance, in a repeated measures design of experiments. All participants were active duty Army personnel, with a majority (all but three) having an infantry military occupational specialty. The test participants had a mean age of 24.85 $\pm$ 5.11 years. Their years in service ranged from less than a year to over thirteen, with a mean of 4.5 $\pm$ 3.48 years. Five had combat deployment experience. The test participants had a mean weight of 189.15 $\pm$ 27.27 lbs and mean height of 69.68 $\pm$ 1.96 inches.

2.2 Test Configurations

All twenty participants executed the course in three configuration that represented three levels of CIE encumbrance: unloaded, minimal-encumbrance, and maximal-encumbrance. The baseline or natural unloaded body included the participant, their duty uniform (e.g., Army Combat Uniform, duty boots, undergarments), a helmet (i.e., Advanced Combat Helmet) (worn for safety), and a surrogate (training aid) M4 weapon (with sensor and optics). The minimal-encumbrance configuration included all the components of the Unloaded in addition to body armor. The body armor was one of two fielded or soon to be fielded systems based on fit and availability, to include their identified baseline kit for the rifleman duty position. This included magazines, grenades, water, and a first aid kit, weighing approximately 23 kg. The maximal-encumbrance configuration included the components of the minimal configuration kit and additional items that are associated with the Grenadier duty position, such as additional 40 mm grenade, with a weight of approximately 25–30 kg. Although this kit is not much heavier than the minimal-encumbrance, it has the maximum amount of bulk around the torso of the body that a dismounted Soldier could experience when wearing body armor (approximately 17 cm as measured at waist circumference [24]).

2.3 Test Procedures

A repeated measures test design was used for this evaluation, where the participants ran through the scenario one time in each test configuration (three times total, randomized and counterbalanced). The participants were instructed to transverse the course as quickly as possible, while maintaining tactical discipline in their movements and accuracy during threat engagements. Practice of movements was provided during training, focusing on the difficult obstacles and incorporated shooting tasks. When testing commenced, the participant was dressed with the proper equipment and zeroed two weapon simulators in the prone position, one at a 5 m distance (target set to simulate 75-m) for use during the obstacle course portion of the test. The other was zeroed at 6.67-m (target set to simulate 200 m) for use during the static shooting task.

The scenario begins with the static shooting tasks. Participants were instructed to shoot three trials of five shots at a 100-m simulated distance (15 shots) and a 200-m simulated distance (15 shots), with a priority on accuracy over speed. This was completed for two firing position (i.e., standing unsupported and prone unsupported, order randomized). Upon completion of the static shooting, the participants commenced the integrated LEAP-MLS obstacle course (Fig. 1). The course contains standard obstacles for assessment of mobility, and fourteen dynamic (on-the-move) shooting engagements for assessment of lethality, including cognitive decision making (go/no go) and threat discrimination measures. At five locations, videos were captured to quantify bodily exposure and time of exposure to threats during engagements (survivability metrics). Finally, participants completed a post-static marksmanship session (firing position order same as pre-LEAP).

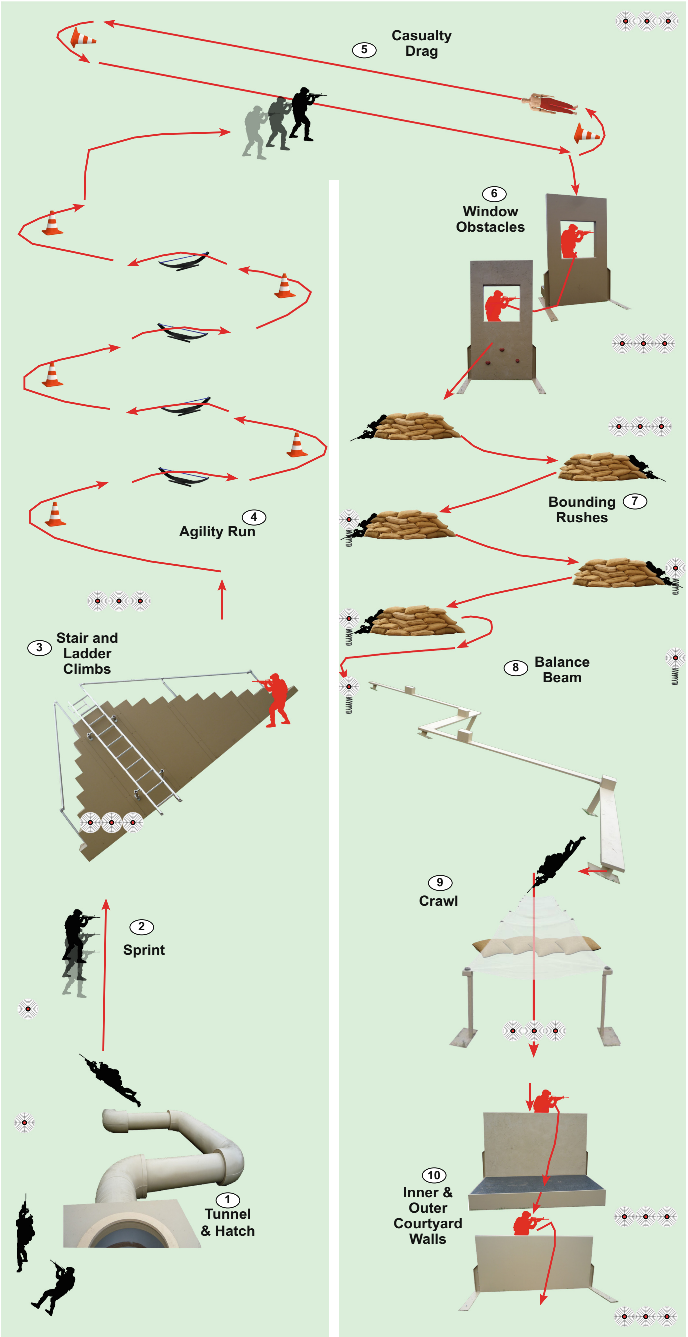

Fig. 1. Diagram of the LEAP-MLS test platform layout, starting in the lower left with the static shooting. The soldiers depicted in red indicate the survivability assessment points.

2.4 Test Apparatus

The LEAP-MLS course was set up according to the diagram above (Fig. 1). Each component and associated equipment will be discussed in further detail below.

Mobility Tasks. The standard LEAP obstacle course consists of a tunnel/hatch, sprint, ladder and stair climb, agility run, casualty drag, windows, bounding rush, balance beam, low/supine/high crawl, and walls. These obstacles replicate activities Soldiers would execute in a dismounted combat deployment.

Lethality Tasks. All of the lethality tasks utilized the FN Expert marksmanship simulator system in combination with a M4 training aide with an integrated CO2 recoil system (LaserShot, Stafford, TX). The FN Expert Weapon Simulator consists of an optical unit and software package loaded on a computer. The optical unit was mounted on the Picatinny rail system of the M4 training aid, and emits an eye-safe infrared (IR) light emitting diode (LED) beam. Paper ring targets, incorporating FN Expert specific diamond grade reflector rings, were used in the marksmanship activities throughout the scenario. The integrated lethality marksmanship tasks were set up throughout the course. The three major types of shooting incorporated into this event include shooting on the move (SOM), target discrimination tasks (TDT), and go/no go (GNG) reaction time tasks.

Static Tasks. The targets used in the static event were scaled to represent 100-meters (m) and 200-meters when placed at an actual distance of 6.67-m, and were placed at a height of 1-meters and 1.57-m on the same vertical plane.

SOM Tasks. The targets utilized for dynamic portion of the course were all scaled to represent 75-m at an actual distance of 5-m. Most targets were mounted at 1-m height. For those targets engaged while the participant was moving (sprint and agility run), a shooting line approximately 5- to 10-m from the target was provided. Targets requiring shooting in the prone posture (end of tunnel and crawl) were placed .5-m high.

TDT Tasks. A manual target tracker was used to help determine which TDT targets were engaged and number of actual shots executed during the post processing of the marksmanship data. The TDT utilized a camouflage patterned target set, with two camouflage patterns designated as enemy (or threat) and friendly (or non-threat), and a gradation of the two for partial threats and partial non-threats. The test had eight sets of targets, with orders selected in a randomized and partially counterbalanced manner for order exposure across the course. Each set had one 100% threat camouflage, one 100% non-threat camouflage, and one of the eight various mixed partial threat/non-threat patterns.

GNG Tasks. The GNG tasks included six pop-up targets placed at a height of 0.5-m and a 5-m distance from the bounding rush sand bags, but scaled to represent 75-m. The same camouflage pattered targets were utilized for this task, but in isolation. Two of the six targets used the two 100% threat or non-threat camouflage patterns, two displayed the 75% partial threat and non-threat patterns, and one showed the 51% partial threat, with randomized exposure order.

Survivability Tasks. Survivability was assessed after the stairs, at the windows, and at the walls. Each of these points had a TDT engagement. Video footage captured from the threat's perspective (i.e., camera attached to the target facing outward) was used to capture the participant's bodily exposure and exposure time prior to threat engagement.

2.5 Data Measures

Mobility Measures. Mobility was measured by timing data during completion of the various obstacles. Overall completion time (time to complete all eleven obstacles) was the primary metric. In addition, time to complete each individual obstacle was also utilized in order to determine which types of movements were compromised when adding various equipment items to the Soldier's load. Inertial measurement unit data was also collected and will be utilized for a more in depth analysis of movement quality.

Lethality Measures. The static shooting task provides information on lethality outcomes in a low stress environment where shooting accuracy is prioritized over speed (untimed), whereas the integrated dynamic marksmanship tasks focused on balancing speed of completion with shooting accuracy. Traditional lethality measures of accuracy (distance from shot to target center), precision (shot group dispersion), probability of hit (percentage of hits), and probability of lethal hit (percentage of hits at center of mass) were utilized across all shooting tasks. In addition, measures based on the weapon handling, stability and time spent aiming during the period prior to engagement were also utilized for analysis across all shooting tasks (i.e., aiming time, trigger control, vertical and horizontal barrel stability, and barrel rotation).

Additional marksmanship mobility measures were assessed only during the dynamic task, to include target acquisition time (move, detect and position), engagement time (aim, shoot, adjust, shoot, etc.), total trial time, and shooting efficiency (number of hits per second). Cognitive measures were assessed for the TDT and GNG tasks utilizing signal detection theory [25, 26]. Reaction time from signal presentation to threat engagement can also be calculated for the GNG task.

Survivability Measures. Survivability was assessed via threat elimination, bodily exposure amount, and exposure time. Threat elimination was calculated based on all target engagements during the dynamic portion of the session. Each target was designated a threat, partial threat, or non-threat based on the camouflage presented. For every target that was presented and engaged correctly, the threat was graded as correctly eliminated (i.e., 1). When a target was not engaged (i.e., no shots were fired), then threat was graded as not eliminated (i.e., 0). The probability of threat elimination was then calculated based on total correct sets of engagements divided by total target sets displayed. Additional refined measure of threat elimination entails identifying critical areas on the body/target that would incapacitate the threat upon engagement and only counting the threat as eliminated when the shots fired have hit those identified zones.

Bodily exposure *amount* was measured by the amount of body not concealed behind the obstacle structure. Video footage from the vantage point of the threat was analyzed to capture the amount of the Soldier's body exposed in pixels up until engagement. Additional refined measure of bodily exposure amount will include critical body parts exposed as opposed to any body part.

Bodily exposure *time* was measured in two manners. First, total exposure time from first exposure to threat through engagement (time of first shot) was captured. Second, the time from last exposure to engagement was captured. The reason for two measures was due to the various manners in which Soldiers can approach and engage threats while maintaining concealment. Some Soldiers look, assess, and engage immediately, while others look, conceal their bodies while assessing, and then re-expose themselves in order to engage the threat.

3 Results

The results reported here are preliminary findings and will only review the high-level measures across each area of the assessment. The statistical analysis was conducted to primarily investigate sensitivity to configuration (unloaded, min-encumbrance, max-encumbrance), while also investigating shooting posture (standing, prone) and fatigue (pre, post), as appropriate depending on the dependent variable. Within-subjects repeated measures analysis of variance (ANOVAs) were utilized to analyze each dependent variable. Tests of multiple comparisons were conducted using the Tukey Honestly Significant Differences (HSD). Confidence intervals were set at 95% (alpha = .05). Further detailed analysis is still required for a comprehensive understanding of this tool.

3.1 Mobility

Repeated measure ANOVA tests were conducted for each dependent mobility timing variable to compare performance across the three configurations. For this report, only the overall course completion time results will be presented. Overall course completion time was significantly different across configuration, $F(2, 26.82) = 23.7$, $p < .0001$. Post hoc analysis indicated that the unloaded configuration ($M = 322.4$ s, $SD = 39.9$) was significantly faster than both the min-encumbrance ($M = 409.3$ s, $SD = 68.9$) or max-encumbrance ($M = 406.9$ s, $SD = 60.2$) configuration as seen in Fig. 2. However, the two encumbrance conditions had comparable completion times.

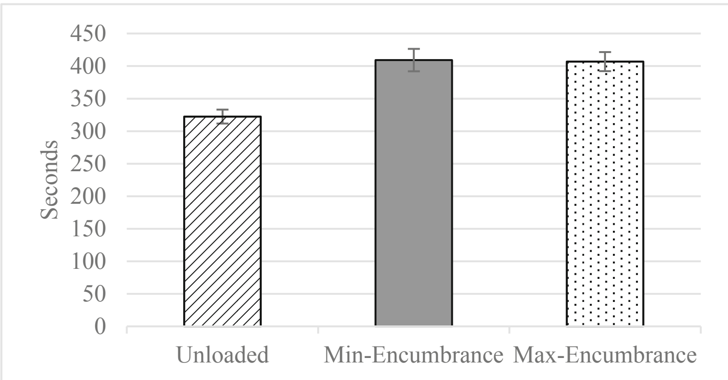

Fig. 2. Mobility as measured by overall course completion times across CIE (error bars represent Standard Error)

3.2 Lethality

Static Marksmanship. All static marksmanship measures were evaluated in this analysis, and only dependent variables that revealed a main effect of configuration will be reported here. A main effect of configuration was found for Precision, $F(2, 38.02) = 4.52$, $p = .017$, and Vertical Stability, $F(2, 38) = 4.24$, $p = .022$. Post hoc analysis indicates that the unloaded configuration (*M* = 161.5 mm, *SD* = 139.9) produced less precise shot groups as compared to the min-encumbrance (*M* = 146.8 mm, *SD* = 128.3) or max-encumbrance (*M* = 144.6 mm, *SD* = 128.0) configuration. In addition, the unloaded configuration (*M* = 174.5 mm, *SD* = 179.6) had significantly more vertical movement during aiming than the min-encumbrance (*M* = 152.7 mm, *SD* = 158.9) or max-encumbrance (*M* = 156.3 mm, *SD* = 159) configuration, as seen in Fig. 3.

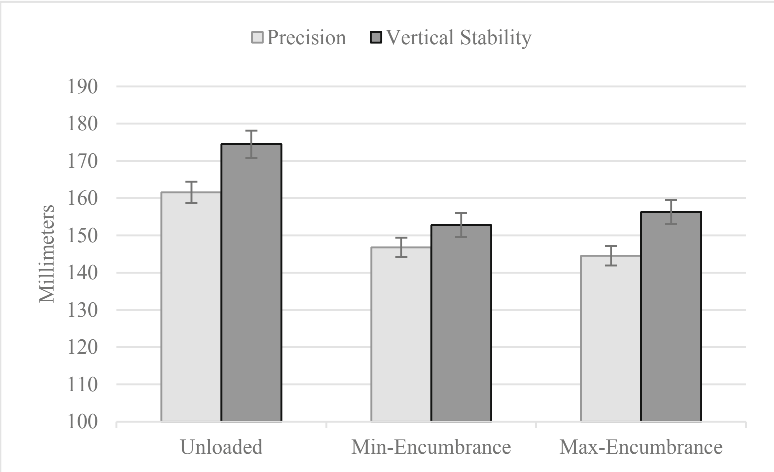

Fig. 3. Differences in Lethality as measured by mean Precision and Vertical Stability across CIE configuration (error bars represent Standard Error)

Integrated Dynamic Marksmanship. The Soldiers were instructed to traverse the course in a tactical manner, with a focus on speed while maintaining tactical movements and eliminating all threats along the route. With this in mind, shooting efficiency (hits/second) was focused on for this initial analysis. A main effect of configuration was revealed for shooting efficiency, $F(2, 38) = 4.24$, $p = .0218$. The unloaded configuration (M = .11 hits/s, SD = .03) was significantly more efficient (greater hits per second on the course) than the max-encumbrance (M = .086 hit/s, SD = .04) or min-encumbrance configuration (M = .08 hit/s, SD = .05) as seen in Fig. 4.

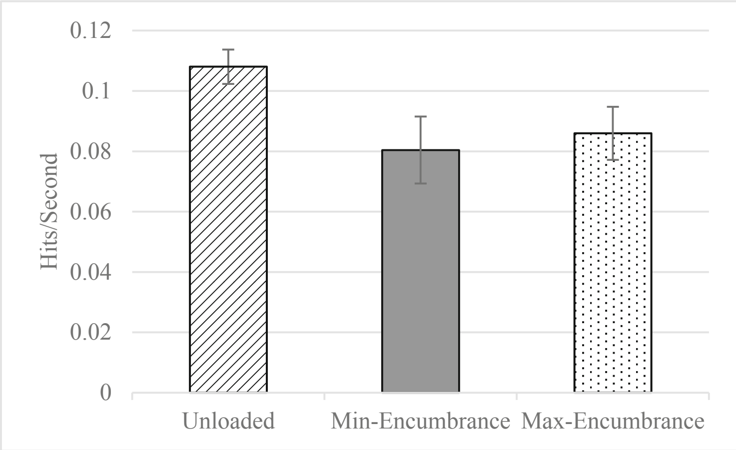

Fig. 4. Differences in Lethality as measured by mean Shooting Efficiency across configuration (error bars represent Standard Error).

3.3 Survivability

These initial results of survivability will only report the basic threat elimination measure based on correct threat engagement. The other measures of survivability (i.e., bodily exposure and exposure time) are still undergoing post-processing and analysis.

Analysis of threat elimination revealed a main effect of configuration, $F(2,34) = 3.98$, $p = .028$. When wearing the max-encumbrance configuration (M = .66, SD = .16), Soldiers had a significantly more difficult time identifying and eliminating all of the threats that were displayed as compared to the min-encumbrance condition (M = .77, SD = .11) as seen in Fig. 5.

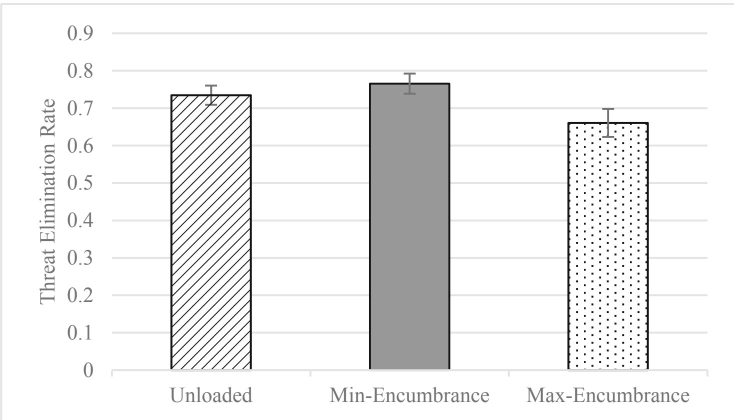

Fig. 5. Differences in Survivability as measured by threat elimination across configuration (error bars represent Standard Error)

4 Discussion

This research is the first proof of concept of an integrated mobility, lethality and survivability test platform for CIE related product evaluation. Although other methods have successfully looked at each individual element in isolation, this test platform provides an opportunity to consider the tradeoffs between these areas in a single assessment. Other research had begun to quantify behavior adaptations (taking cover) in the training environment when facing high or low fidelity simulated threats [27], but this is the first methodology for CIE testing that identifies and quantifies survivability (a critical aspect of lethality) through measurements of threat elimination and bodily exposure to threats when taking cover and engaging targets. Further research is warranted in order to add the appropriate protection level of worn equipment to the survivability scoring model within this test platform. The initial high-level results in the three categories of mobility, lethality and survivability have provided indications that this novel test platform is a good enhancement for integrated performance testing during CIE related product evaluations.

This initial research has provided great lessons learned for further development of the integrated test platform. Some high level benefits include the flexibility of the simulator system, the novel measures of survivability, and the integrated look at metrics for CIE assessment. Additionally, the platform is relatively inexpensive, is easy to set up and is mobile. The initial findings prove that the traditional LEAP system can be enhanced with supplemental operationally relevant tasks that focus on lethality without losing the system's original design intentions of being a comprehensive and sensitive mobility test for CIE product assessments. Further detailed analysis will provide additional information on the areas of enhancement and their value for future CIE product assessments. Future analysis efforts will also work towards a combined weighted index measure for each component area (i.e., mobility, lethality, and survivability) for ease of use and standardization of performance interpretation during CIE product tradeoff assessments.

Some limitations experienced during this initial research include some equipment-based issues. The minimal recoil and muzzle rise of the weapon surrogate as well as the lack of external environmental stressors (i.e., gunfire noise, wind adjustments, etc.) experienced during live-fire can influence the psychological physical performance during the shooting engagements. Also, some of our equipment (i.e., eye tracking glasses and cameras) had unanticipated technical difficulties during testing. Eye tracking could not be used with the close-combat optical sight on the weapon due to the focal point shift of the pupils to the sights rather than the target. Iron sights were attempted during the training period, but the shooting tasks were too difficult without the sights, and performance was falsely degraded due to the weapon configuration rather than the CIE configuration being evaluated. The difficulty level of the cognitive measures (camouflage-based threat images in the TDT and GNG tasks) and their location within the LEAP obstacles should be assessed further in order to determine the appropriate size and display required to capture the decision-making processes with minimal potential learning effects and acuity issues. Additionally, the eye tracking devices used was not field grade and overheated after one set of runs (approximately 20 participant completions).

Multiple military research and acquisition groups, within the US and internationally, use LEAP as a standardized assessment of mobility. By expanding on this test platform to create this alternative methodology, we create additional capabilities for the US Army and our international partners. Lessons learned from this study will allow for improvements to the test platform as it is developed.

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