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EVALUATING THE EFFECTS OF CLOTHING AND INDIVIDUAL EQUIPMENT ON MARKSMANSHIP PERFORMANCE USING A NOVEL FIVE TARGET METHODOLOGY

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14. ABSTRACT
Any item of Warfighter-borne clothing and individual equipment (CIE) must not interfere with the Warfighter's ability to quickly and accurately engage targets with their weapon. This paper describes the development of a novel test methodology for evaluating the effect of CIE on marksmanship performance using a weapon simulator system. Eleven military test participants executed the test methodology in a baseline condition and in a CIE test condition which included the M40 Chemical-Biological protective mask. Marksmanship performance variables analyzed included precision, radial error, total engagement time, aiming time, and movement time, as well as subjective interference ratings. There were no significant differences between the No Mask and M40 Mask conditions for precision or radial error; however, participants experienced significantly longer engagement and movement times while wearing the M40 mask. These results suggest the test methodology is sensitive enough to provide valuable insights regarding the effects of CIE on marksmanship performance.

15. SUBJECT TERMS

TARGETS	MARKSMANSHIP	PERFORMANCE(HUMAN)
WEAPONS	PROTECTIVE MASKS	PROTECTIVE EQUIPMENT
M40 MASK	M40 PROTECTIVE MASK	HUMAN FACTORS ENGINEERING
M-40 MASKS	TEST AND EVALUATION	PPE(PERSONAL PROTECTIVE EQUIPMENT)
SIMULATORS		

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Any item of Warfighter-borne clothing and individual equipment (CIE) must not interfere with the Warfighter's ability to quickly and accurately engage targets with their weapon. This paper describes the development of a novel test methodology for evaluating the effect of CIE on marksmanship performance using a weapon simulator system. Eleven military test participants executed the test methodology in a baseline condition and in a CIE test condition which included the M40 Chemical-Biological protective mask. Marksmanship performance variables analyzed included precision, radial error, total engagement time, aiming time, and movement time, as well as subjective interference ratings. There were no significant differences between the No Mask and M40 Mask conditions for precision or radial error, however, participants experienced significantly longer engagement and movement times while wearing the M40 mask. These results suggest the test methodology is sensitive enough to provide valuable insights regarding the effects of CIE on marksmanship performance.

INTRODUCTION

Any item of military clothing and individual equipment (CIE) must not interfere with the Warfighter's ability to quickly and accurately engage targets with their weapon. Marksmanship performance has been used in the evaluation of military CIE to provide insight into how a product will perform in an operational environment (Johnson, McMenemy & Dauphinee, 1990; Johnson & Kobrick, 1997; Bensel, 1997; Carbone, Carlton, Stierli & Orr, 2014). While live fire (firing live rounds on a range) test methods can provide operationally relevant and realistic measures of marksmanship performance, it can be costly (requiring ammunition, specialized facilities, range control personnel, etc.) and can be limited in terms of scenario design (target placement, target height, etc.) due to safety concerns. Weapon simulator systems, on the other hand, can be used to collect marksmanship performance data without the costs and safety concerns that can be associated with live fire evaluations.

Several studies have shown performance using a weapon simulator system is predictive of live-fire qualification scores using M4/M16 series weapon systems (Crowley, Hallmark, Shanley & Sollinger, 2014; Hagman, 2000; Schendel & Heller, 1985; Torre, Maxey & Piper, 1987). Additionally Scribner, Wiley & Harper (2007) found a strong relationship between live fire performance and performance using a weapon simulator system. Weapon simulator systems have also been successfully used in a number of research efforts to measure the effect of postural stability on marksmanship performance (Baca & Kornfeind, 2012; Hawkins & Sefton, 2011), as well as the effects of creatine and caffeine supplementation on marksmanship during stress induced training research (Tharion, Shukitt-Hale & Lieberman, 2003; Warber, Tharion & Patton, 2002). This paper describes the development of a novel test methodology for evaluating the effect of clothing and individual equipment (CIE) on marksmanship performance using a weapon simulator system.

The many studies using weapon simulator systems have required participants to only engage a single target, or simulate a Known Distance (KD) range where the relative angle between targets (i.e., the distance the participant must shift their point of aim) is typically seven degrees or less. Palmer, Bigelow & Van Emmerik (2013) found significant differences in marksmanship performance between CIE configurations while using targets with greater relative angles (50 degrees) and with the inclusion of an elevated target (representing targets in the upper levels of buildings or in mountainous terrain). Based on these results, it was hypothesized that a marksmanship scenario using multiple targets placed at larger relative angles and incorporating elevated targets would be more sensitive to detect the effects of CIE on marksmanship performance as well as representing an operationally relevant task.

The methodology described in this paper required the participants to engage five different targets in succession, which allowed for the analysis of total engagement time, transition time, and aiming time variables in addition to precision (shot group tightness) and radial error from the center of the target (both of which are commonly analyzed in marksmanship performance evaluations). Time as a function of mobility, lethality and situational awareness is considered a critical factor for operational performance and Warfighter survivability (Palmer et al., 2013; Shaw & Kinsella-Shaw, 2007). The speed with which the Warfighter locates, acquires, and engages a threat is just as important as shot accuracy or precision, and CIE should not negatively impact any of these factors. Assessing the engagement time will allow our CIE evaluations to be more operationally relevant and address the key factors for Warfighter performance.

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METHODS

Participants

A total of 11 test participants (TPs) were recruited to take part in this evaluation. Nine TPs were experienced active duty infantry Soldiers (MOS 11B) from the 75th Ranger Regiment. Two TPs were Aberdeen Test Center (ATC) Contractors as Representative Soldiers (CARS). One of the CARS is currently an infantryman in the US Army Reserves, and the other was a former infantryman in the United States Marine Corps (USMC) and a competitive shooter.

All TPs were experienced military shooters, and ranged in age from 21 to 50 years old (M = 26.54, SD = 8.37). One of the 11 TPs was left-handed and left-eye dominant, the other 10 were right-handed and right-eye dominant. All participants were male, and all except one, had qualified within the last year using the M4 carbine. Ten of the TPs had last qualified at the *Expert* level (score of 36+ out of 40 on the standard weapons qualification course), while one ATC CARS participant last qualified as a *Sharpshooter* (30 to 35 out of 40) the last time they had taken the course, three years earlier.

Equipment Configurations

Each participant executed the weapon simulator test methodology in a test condition (with the M40 chemical-biological (CB) protective mask) and in a baseline condition (no M40 CB mask).

In both conditions TPs wore a helmet, a plate carrier body armor system, and a combat load of ancillary pouches filled with items such as ammunition. The helmet, body armor, and pouches were all provided by the TPs and represented the equipment they typically train with and wear in combat, therefore, there were some variations from individual to individual. However, all ancillary equipment remained the same within an individual between the baseline condition (No Mask) and the test condition (M40 CB Mask). The only difference between the baseline and test conditions was the addition of the M40 CB mask.

Measures and Apparatus

A Fabrique National (FN America, formerly Noptel Oy) ST-2000 MilTrainer weapon simulator system and NOS4 software was used for this evaluation. The MilTrainer optical unit was mounted on the barrel of a de-militarized M4 carbine with an integrated carbon dioxide (CO_2) recoil simulation system (de-militarized weapon and recoil simulation system were manufactured by LaserShot) (Figure 1). The M150 Advanced Combat Optical Gunsight (ACOG) sight was also used in conjunction with the weapon (Figure 2). After mounting the ACOG on the de-militarized weapon, the MilTrainer optical unit was adjusted to ensure the hit position recorded by the simulator was aligned with the settings on the ACOG. A paper ring target was used, which was scaled to represent a full-sized “E” type silhouette target at 75-meters when placed 5-meters from the shooter (Figure 2). Such targets are commonly used when confined space precludes training on full-sized ranges.

Figure 1. LaserShot weapon with integrated CO_2 recoil simulation system (left), FN MilTrainer optical unit mounted to barrel of the weapon (right) (Courtesy of McNamara, Burcham, Ortega & Hennessy, In Press).

Figure 2. M150 ACOG sight (left), paper ring target used with weapon simulator system (right) (Courtesy of McNamara et. al., In Press).

Five target positions were used (Figure 3), one located directly in front of the shooter at a height of 1.57 m, two targets located 50 degrees to the right and left of the center target also 1.57 m high, and two targets located directly above the right and left targets at a height of 2.77 m. All targets were located 5 m away from the shooter, and the targets were scaled such that they simulate a full size E-type silhouette at 75 m when placed at that distance.

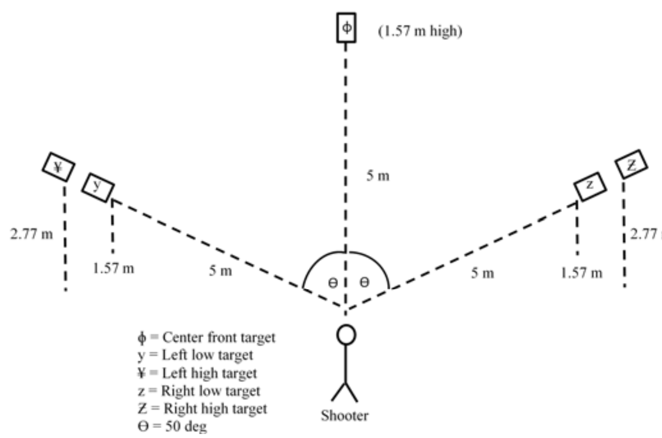

Figure 3. Target locations, distances, and heights (Courtesy of McNamara et. al., In Press).

Procedures

The TPs engaged the targets from two different firing positions (standing unsupported and kneeling unsupported). These are standard firing positions, and the TPs were experienced with engaging targets from each of these firing positions. Each of the firing positions evaluate CIE in different ways, as it changes the positioning of the body.

For this evaluation, a repeated measures experimental design was used, where the order of presentation was counterbalanced. This allowed participants to serve as their own control and helped negate the effects of environmental, time-of-day, and order effects.

Prior to data collection all TPs participated in a weapon simulator practice/qualification protocol. The familiarization training included a briefing of the study procedures, followed by a qualification period consisting of software zeroing the weapon (5 shots), and 10 shots in each firing position for a total of 20 shots at a single target located directly in front of the shooter at a distance of 5 m. The shooter would be considered qualified when 70% of the 10-shots from the standing unsupported firing position and 80% of the 10-shots from the kneeling unsupported firing position were within the "6" ring (black area) of the target. Qualification percentages varied between firing positions in order to account for varying degrees of difficulty associated with each firing position. Normal breathing in the standing unsupported position can cause the rifle muzzle to displace ½ inch from inhale to exhale (Chung et al., 2006) and represents a less stable and potentially less accurate firing position than the kneeling unsupported firing position (Dees, 1971).

After completing the qualification procedure, TPs executed the five target firing sequence. The TPs were instructed in what order to engage the targets (e.g., center, right low, right high, left low, left high), and to fire a single shot at each target. TPs were instructed to move from one target to the next as quickly as possible without sacrificing accuracy. The TPs completed the five target scenario in two different firing positions (Standing Unsupported and Kneeling Unsupported), and in each firing position they completed five series of five shots in each direction (i.e., left-to-right and right-to-left, for a total of 100 shots, see Table 1). The order of presentation of firing position and target sequence were also randomized to control for order of exposure.

Table 1. Five target sequence description

Firing Position	Order of Targets Engaged	Total No. Shots
SU	C => R_{low} => R_{high} => L_{low} => L_{high}	25
SU	C => L_{low} => L_{high} => R_{low} => R_{high}	25
KU	C => R_{low} => R_{high} => L_{low} => L_{high}	25
KU	C => L_{low} => L_{high} => R_{low} => R_{high}	25

SU = Standing Unsupported; KU = Kneeling Unsupported

After completing all shots in a given firing position, the TPs were asked to rate the degree of interference they experienced from the equipment while performing that task using the five-point rating scale presented in Table 2.

Table 2. Subjective rating scale for interference.

No Interference	Slight Interference	Moderate Interference	Severe Interference	Extreme Interference
1	2	3	4	5

Data Analysis

Both precision and accuracy variables were measured using calculations derived from outputs generated by the FN NOS4 weapon simulator software. Precision, or shot group tightness, was calculated by measuring the averaged Euclidian distance of each shot from the calculated center of a five-shot series (Figure 4). Euclidian distance is calculated using the following formula:

$$\text{Distance}\ ((x, y), (a, b)) = \sqrt{(x-a)^2 + (y-b)^2} \quad (1)$$

Radial error from the center of the target was used to assess shot accuracy. This measurement was calculated by measuring the averaged Euclidian distance of a five-shot series to the center of the target (Figure 4).

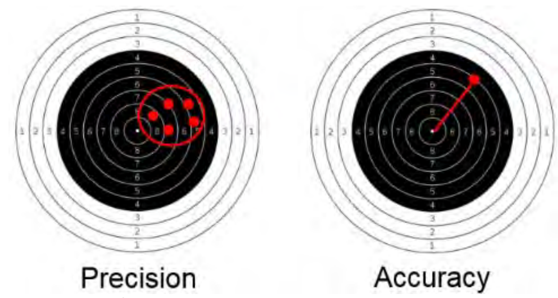

Figure 4. Images of dependent variables Precision (shot group tightness) and Accuracy (radial error) (Courtesy of McNamara et. al., In Press).

Three additional dependent variables were analyzed: engagement time (the total time between two shots), aiming time (the time a TP spent aiming at the target prior to firing, with the time starting when the system detects the weapon is aimed at the target), and movement time (calculated by subtracting aiming time from engagement time, and represents the time required to physically transition between targets) (Figure 5).

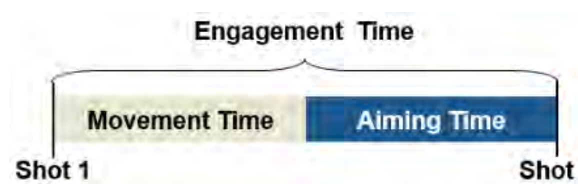

Figure 5. Image of dependent variables engagement time, aiming time, and movement time.

Precision and accuracy variables were analyzed using a three-way repeated measures analysis of variance (ANOVA) which compared the test configurations across firing positions and target location for a 5 (target location) x 2 (mask condition) x 2 (firing position) design. Engagement time, aiming time, and movement time variables were analyzed using a three-way repeated measures ANOVA which compared the test configurations across firing positions and movement arc for a 6 (movement arc) x 2 (mask condition) x 2 (firing position) design. The subjective rating data was analyzed using matched pairs Wilcoxon Signed Rank tests. Tests of multiple comparisons were conducted using the Tukey Honestly Significant Differences (HSD) test; confidence intervals were set at 95% (alpha = .05). All analyses were performed using Microsoft Excel and IBM's Statistical Package for the Social Sciences (SPSS). Excel and/or SPSS were used to perform data reduction, analyses on the data and to create table and chart summaries of the results.

RESULTS

While the data was analyzed using three-way repeated measures ANOVAs, this paper will only report results for main effects of mask condition as the main interest of this methodology is to compare the configuration effects and space is limited in this submission.

Precision and Accuracy

No significant differences between mask conditions were found for either precision (shot group tightness), $F(1, 10)=1.01$, $p=.34$, or accuracy (radial error), $F(1, 10)=1.98$, $p=.19$. TPs tended to have more precise (tighter) shot groupings in the No Mask condition (M=144 mm, SD=34 mm) than in the M40 CB Mask condition (M=155 mm, SD=35 mm) and tended to hit closer to the center of the target in the No Mask condition (M=178 mm, SD=38 mm) than in the M40 CB Mask condition (M=205 mm, SD=53 mm); however, the differences did not reach statistical significance.

Engagement Time, Aiming Time, and Movement Time

A significant effect of mask configuration was observed for both engagement time $F(1, 10)=6.27$, $p=.03$, and movement time $F(1, 10)=4.99$, $p=.05$, and approaching significant effect for aiming time, $F(1, 10)=3.43$, $p=.09$. Engagement time values were significantly faster in the No Mask condition (M=2.82 s, SD=0.97 s) than in the M40 CB Mask condition (M=3.43 s, SD=1.68 s), and TPs also transitioned between targets significantly faster in the No Mask condition (M=1.62 s, SD=0.42 s) than in the M40 CB Mask condition (M=1.96 s, SD=0.85 s). Aiming time values also tended to be faster in the No Mask condition (M=1.20 s, SD=0.56 s) than in the M40 CB Mask condition (M=1.47 s, SD=0.96 s); however, the differences did not reach statistical significance (Figure 6).

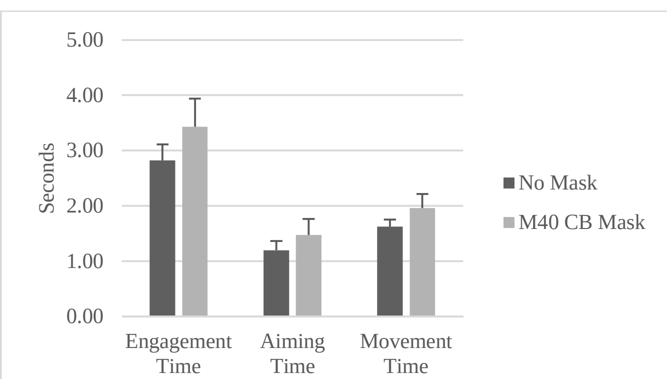

Figure 6. Comparative mean (and standard error) plots for engagement time, aiming time, and movement time for mask condition.

Subjective Ratings

A matched pairs Wilcoxon Signed rank test was performed to investigate the difference in subjective interference ratings across mask condition. TPs' subjective rating on M40 Mask condition (Mdn=3.0) was significantly higher, more interference, than No Mask condition (Mdn= 2.0), Z=-3.96 p<.01 (see Table 2 for detailed rating scale information). Figure 7 shows the M40 CB Mask condition imposed a greater degree of interference (standing: M=2.91, SD=0.70, kneeling: M=3.27, SD=0.47) than the No Mask condition (standing: M=1.73, SD=0.65, kneeling: M=1.73, SD=0.65) for both firing positions.

Interestingly, the test participants' perceived interference from wearing the mask was not correlated with the actual marksmanship performance observed during the mask condition (Spearman correlation; **Precision:** r_s =.30, p=.18; **Accuracy:** r_s =.34, p=.13; **Engagement Time:** r_s =-.01, p=.98; **Aiming Time:** r_s =-.01, p=.96; **Movement Time:** r_s =.01, p=.95).

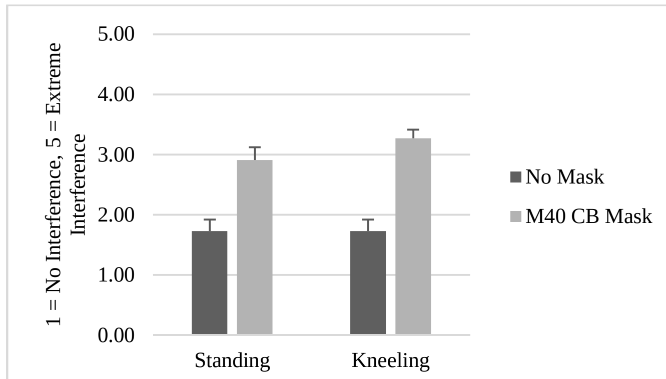

Figure 7. Comparative mean (and standard error) plots for subjective interference ratings.

DISCUSSION

This paper describes a novel test methodology developed to evaluate the effect of CIE on marksmanship performance. In this study the test methodology was able to distinguish performance differences between two equipment conditions (wearing an M40 CB protective mask in addition to baseline Warfighter equipment versus not wearing a mask).

While no statistically significant differences were found between the two mask conditions in terms of precision (shot group tightness) or accuracy (radial error), statistically significant differences in engagement time and movement time were found. Additionally, all of the TPs subjectively reported difficulties in shooting with the M40 CB mask. For example, the mask made it difficult for the TPs to achieve the proper angle/sight picture with the ACOG sight. Furthermore, TPs reported that they were required to turn their head further (almost laying it sideways) or cant/tilt the weapon in order to see through the sight. Once TPs adopted this position, they were able to engage targets with only slight decrements in accuracy, however all of the TPs reported this position was more difficult to hold for an extended period of time.

The significant differences in engagement time and movement time are likely due to the restricted field of view caused by the addition of the M40 CB mask. When transitioning between targets the TPs typically locate the next target with their eyes, and then bring the weapon and the rest of their body to the target, without lowering the weapon. With the M40 CB mask TPs reported they could not see the next target without turning their entire head, which also required them to lower the weapon, locate the next target, and then raise the weapon and re-set into a stable firing position. This delay in locating, acquiring, and engaging a threat could be critical in an operational environment.

Interestingly, the subjective ratings were not correlated with the actual marksmanship performance metrics. Recommendations for design changes based solely on subjective ratings may not reveal true effects of equipment and their impact on marksmanship performance. This test methodology allows for objective clothing and individual equipment evaluation that provides a more complete picture of actual performance degradations.

The results of this study indicate that the test methodology described in this paper can effectively be used to evaluate equipment and detect differences in marksmanship performance due to the interference of CIE (in this case, the M40 CB mask). The test methodology was able to detect this difference partly due to the greater relative angle between targets (50 degrees to the right and left) than is typically used in weapon simulator evaluations.

Some limitations of using weapon simulators to evaluate equipment include a lower force of recoil than is experienced when shooting live rounds, limited muzzle-rise, the lack of psychological effects (such as noise and flash) which can cause some shooters to flinch in anticipation of shot, and outdoor atmospheric conditions (wind velocity, barometric pressure, temperature) are not taken into account with this software. However, the advantages of using simulator systems for human system integration research are that simulators can collect controlled information regarding the impact of CIE on marksmanship performance without the costs (e.g., specialized facilities, range-control personnel, ammunition, etc.) and the safety concerns (e.g., a simulator has more flexibility regarding target locations, target spread, high angle targets, etc. because there are no range restrictions) that can be associated with live-fire testing.

While this test methodology is not intended to replace live-fire evaluations, which are currently the most operationally relevant metric and indicative of real-world performance, it does allow for quick feedback on marksmanship performance with both qualitative and quantitative metrics to address gross incompatibilities of CIE and their ability to impact marksmanship. Further validation and refinement of this test methodology is currently in process. The study described in this paper used the FN MilTrainer weapon simulator system, which is tethered to a computer via a cable while collecting data. The newest version of the system (FN Expert) has the ability to wirelessly collect data, making more dynamic data collection scenarios possible (e.g., participants run between multiple firing locations and/or quickly transition between firing positions within a scenario). Additionally, efforts are underway to develop a Military Operations in Urban Terrain (MOUT) room-clearing scenario with integrated cognitive decision making tasks. These dynamic components may uncover additional information regarding the impact of equipment on marksmanship performance.

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