CAN TARGET EFFECTS OR DISCOMFORT RATINGS DISCRIMINATE BETWEEN SMALL-ARMS WEAPON CONFIGURATIONS?

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1.1. ABSTRACT

Defence acquisitions use accuracy measures as a discriminating factor in weapon purchases, but assessments are generally completed in static, supported postures at static targets with few differences being seen between configurations. The aim of this study was to investigate whether an assessment requiring repositioning between shots could reveal differences. Participants shot at a static target under four conditions: an unweighted rifle and the addition of a mass fixed at three different positions. Accuracy and timing as well as discomfort measures were captured and compared. Hit percentage, consistency and timing varied over time, and timing increased with the addition of mass in two out of the three conditions. There was an increase in discomfort with the addition of mass further from the participant. The results showed that relying on accuracy and consistency measures alone to make acquisition decisions could have the consequence of purchasing equipment not fit for the human.

Keywords: acquisition, accuracy, weapon, design

Practitioner summary:

This research shows that relying on accuracy and consistency measures alone to make weapon-system acquisition decisions could have the consequence of purchasing equipment not fit for the user. Further research should focus on 'upstream' issues such as muscle fatigue and aim point stability in order to better understand human-weapon-system interactions.

1.2. INTRODUCTION

In the Australian military context, ancillaries (e.g. accessories such as sights, target designators, ballistic computers or suppressors) may be purchased and added to a weapon without human usability testing due to the perceived capability improvement (such as increasing speed of engagement or accuracy). The addition of any ancillary increases the system mass and will likely change the centre of gravity and moment of inertia of the weapon-system. These changes may exert a negligible influence on performance when considering combat situations that feature supported fire on static targets (e.g. static shooting from the prone position without the requirement for sight re-alignment or reshouldering of the weapon), but could result in performance degradation when considering requirements for the shooter to interact with the target dynamically (e.g. shooting on the move or at moving targets). In these instances, a heavier weapon system that has been shown to be superior in controlled static range conditions may degrade human-weapon-system performance within a dynamic combat environment.

Ergonomics principles have shown that better designed industrial equipment can improve work efficiency and reduce fatigue as well as fatigue-related musculoskeletal disorders (Kluth, Pauly, Keller, & Strasser, 2004; Lewis & Narayan, 1993). These principles likewise apply to weapon systems carried by dismounted soldiers, as well as ancillaries and the ammunition that is fed into such systems. However, the engineering requirements documents for small arms systems largely focus on measures of effectiveness., such as shot accuracy, and hits and misses, as well as shot timing to validate weapon design, often without due consideration for the burden associated with carrying and employing the system within agile and dynamic battlefield contexts. This latter scenario arguably comprises the bulk of combat operations in terms of time spent on the battlefield; however, there are few examples of requirements and assessments of performance in these scenarios, and acquisition reporting tends to have commercial sensitivities and is hence not referable in the open literature.

Few open-literature published studies have investigated the effect of systematically varying weapon mass or centre of gravity on speed and accuracy of the human-weapon-system in a dynamic assessment. Yuan and Lee (1997) showed that in a static, unsupported standing position, a rifle with a shorter handling length (distance between shoulder to trigger finger) and lower mass resulted in fewer aiming point fluctuations, better acceptability, tighter shot groups (precision), and groups closer to the target centre (accuracy) as compared to a rifle with a longer handling length. Whilst statistically significant, the distance of each group to target centre differences were only in the magnitude of 2 mm.

Kemnitz, Johnson, and Merullo (2001) assessed the effect of handling length and weapon mass on static, unsupported standing marksmanship performance using the M16 rifle and M4 carbine (shorter barrel and lighter in mass by 600 g than the M16). A reduction in handling length resulted in improved scores (a less-precise measure of accuracy), shorter distance to target centre (by 0.5 mm) but no differences in group spreads (distance between furthest shots). The lighter mass of the M4 resulted in no differences in scores or distance to target centre but did result in tighter group spreads (by 39 mm).

A study by Stone et al. (2014) compared the effects of two conventional and two bullpup (where the magazine is located behind the trigger and therefore the centre of gravity is closer to the user) weapon systems and found that the bullpup allowed participants to maintain better whole body balance as measured by a force platform, with better balance being associated with an increase in scores. Based on the target effects measures alone, there is unlikely to be any practical capability differences between weapon systems.

The accuracy differences in the aforementioned studies are very small to non-existent for discrete static marksmanship assessments at static targets and represent a shooting task being performed under optimal conditions. The effects may be amplified in a more dynamic assessment, such as with the addition of upper body repositioning, shooting on the move, or cognitive complexity. The different configurations used in the studies did not allow researchers to understand systematic differences that could be expected to be seen on a single platform.

Dynamic assessment of marksmanship performance would be an intuitive step in the assessment of weapon-system design and modification. The effect of additional intrinsic and extrinsic factors on marksmanship performance has been completed in the past, such as the effect of the addition of external load (Tenan, LaFiandra, & Ortega, 2017; Thomas, Pohl, Shapiro, Keeler, & Abel, 2018), aerobic exercise (Evans, Scoville, Ito, & Mello, 2003; Frykman, Merullo, Banderet, Gregorcyzk, & Hasselquist, 2012; Ito, Sharp, Johnson, Merullo, & Mello, 2000), and mental fatigue (Head et al., 2017). However, when investigating dynamic marksmanship it is important to ensure the movement patterns used are repeatable and within the participants current skillsets. A room clearance drill, whilst operationally relevant and externally valid, can introduce too much variability depending on the layout of rooms and targets, or is subject to a learning effect over multiple repeats. Differences in standard operating procedures may mean a lengthy familiarisation period. Assessments that take into account subjective feelings can add valuable information to assessments (Taverniers & Suss, 2019), however the issue of brand recognition and a desire to emulate elite regiments as well as other nation's armies can sometimes contradict objective measures (Stone et al., 2014).

A new assessment, or suite of assessments that adequately taxes the human-weapon-system, whilst teasing out physical versus cognitive aspects would be valuable. This is especially true for government-based acquisition projects where experimental control and rigor cannot be expected. The aim of this study therefore was to investigate the effect of systematically changing the weapon mass and centre of gravity and number of shots fired on shot accuracy and timing, and discomfort using an assessment requiring dynamic movement of the upper body, whilst controlling lower body movement. It was hypothesised that the addition of mass as well as moving the centre of gravity of the weapon further away from the shooter will result in poorer accuracy of shot placements in a linear fashion.

1.3. METHODS

1.3.1. PARTICIPANTS

This research was undertaken at the Weapon System Interface Dynamics Laboratory, located at the U.S. Army Research Laboratory (ARL) at Aberdeen Proving Ground, Maryland, U.S.A. Fourteen male participants were sampled from the area local to the Army post, including a mixture of combat and non-combat soldiers who were all qualified marksmen. Participants were 34.1 ± 6.9 years old, 181.4 ± 8.4 cm tall and 91.6 ± 12.9 kg in mass. One participant was left-handed and fired from the left shoulder used their left eye for target sighting, while the remainder were right-handed and shot with their right shoulder and right eye. All participants reported no musculoskeletal soreness or injuries at the time of data collection.

This research complied with the tenets of the American Psychological Association Code of Ethics and was approved by the U.S. Army Research Laboratory Institutional Review Board (ARL 16-154). Informed consent was obtained from each participant.

1.3.2. INSTRUMENTATION

A U.S. Army standard issue M4A1 carbine (3.4 kg) with a 36.8 cm barrel and a fitted 30.5 cm Picatinny Forend afforded the installation of a 1-kg mass (dimension of 1.5 cm x 7 cm x 10 cm) via a Mil-Std 1913 rail grabber to three positions (Pos1 through Pos3) on the top rail (Figure 1). Position 0 (Pos0) was designated as the baseline condition, with no added mass. The 1-kg mass was considered the worst case scenario for future rifle accessory purchases, but may also act as a surrogate measure for future design changes, such as a longer barrel. An unmagnified EO Tech EXPS-3 holographic optic was mounted in the same position for each participant and weapon condition.

Figure 1 caption. M4 baseline (Pos0), and with mass installed in three positions (Pos1-Pos3, highlighted)

Figure 1 alt-text: Four identical M4 rifles showing where the added mass is installed. The top rifle has no mass, the next rifle down has the mass half-way along the top of the rifle, the next down has it further to the right, then the bottom rifle has it to the far right, or barrel end of the rifle.

A single, stationary in-service E-type silhouette target was installed onto an open-air acoustic targetry system (TDCue, AAI Corporation, Hunt Valley, MD), at a position of 50 m from the shooting position. The targetry was a "location-of-misses-and-hits" (LOMAH) system that detects supersonic projectiles as they pass through the scoring area, generating a Cartesian coordinate (i.e. x,y) location relative to the origin within the acoustic detection "window", a virtual space that encompasses the dimensions of the E-type silhouette and also includes a 30 x 30 cm region outside of the physical target (*Figure **2***). The LOMAH system is accurate to within 5 mm (Ortega, Harper, & Morelli, 2015). Misses that hit the ground before or below the target did not pass over the acoustic sensors and were therefore not detected by the targetry system. Misses that passed over the acoustic sensors but were outside the coordinates of the silhouette target were designated as misses for hit percentage data, but the coordinates were included in the accuracy data.

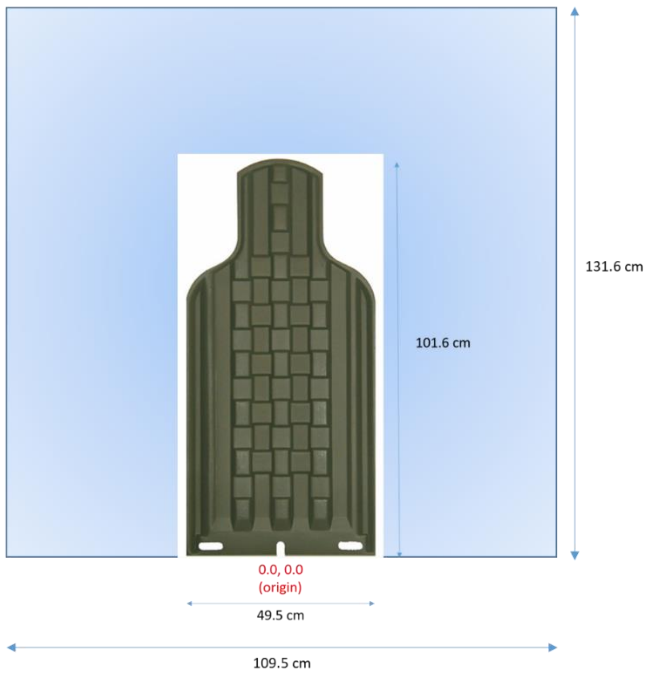

Figure 2 caption. E-type silhouette target showing dimensions (in cm) and x, y axes (in red). Acoustic envelope associated with misses is denoted by the shaded blue box.

Figure 2 alt-text: a green man-shaped plastic target is shown with dimensions of the target as well as a blue-shaded box around the target where near-misses will be captured.

1.3.3. EXPERIMENTAL PROTOCOL

The shooting protocol consisted of individually zeroing (calibrating the sight to the weapon by the user) prior to completing the same shooting task under the four weapon conditions. Participants were instructed to start in the standing unsupported low ready position (Figure 3), and to engage a single static target 50 m away, firing a single shot and returning to the low ready position "as fast as they accurately could" (i.e. giving equal priority to speed and accuracy), but at a self-selected pace, for 60 shots, or until they voluntarily stopped shooting. This process was repeated for each of the four conditions and the magazine changed every 30 rounds by the safety supervisor. The order in which the conditions were tested was quasi-randomised using a Latin-square design to control the carry-over effects of fatigue. All four conditions were completed in one day; each condition took roughly 2 minutes to perform, and a 10-minute rest between conditions was given.

A perceived discomfort questionnaire was administered once at the completion of each condition, using an ARL-specific questionnaire (Figure 4), which was written in an online questionnaire program (Qualtrics, Utah, USA) and administered to the participants immediately on the completion of each shooting task. A screen showed the body map and participants clicked on each of the body parts where they felt discomfort, soreness or fatigue. A second screen was then presented with each of these body parts listed, and a rating scale and a space for listing the reason for their rating. Ratings of discomfort were coded as 1

(Slight) to 4 (Extreme), and a non-rating was assumed to be 0. Bilateral body parts were split into support (majority left hand) and non-supported (majority right hand) body parts, with the left-handed participant's body parts reflected from left to right for the purposes of illustration. The ratings for each body part per weapon condition were averaged and assigned to five arbitrary categories for illustrative purposes.

Figure 3 caption. Low ready pose (left), and shooting (right). Note the configuration of the weapon is Pos1 and any instrumentation visible was not for the benefit of the current study

Figure 3 alt-text: two side-by-side photos of a man holding a rifle. In the left-hand photo the man is holding the rifle with the barrel pointing toward the floor, while in the right-hand photo the man is holding the rifle pointing towards the target.

1.3.4. DATA ANALYSIS

The percentage of hits (hit%) on the target was calculated from the total number of shots that fell within the target's coordinates as a ratio of the number of shots fired for each configuration. Radial error (a measure of accuracy from the target origin) and Bivariate Variable Error (BVE; a measure of consistency) was calculated for each shot that registered with the targetry (i.e. not including ground shots) and combined to form the mean (including Mean Radial Error; MRE) for each participant for each condition (Hancock, Butler, & Fischman, 1995).

Shot interval was considered as the time in seconds between each shot, determined from the shot microphone, which was a part of the range instrumentation. This measure is a combination of movement time and aiming time, as participants were able to briefly pause or modify their posture between shots and were not reacting to a stimulus. The duration of the magazine change was not included in analysis, resulting in a maximum of 58 shot intervals for analysis. If a shot hit the ground (therefore no accuracy data, other than hit%), there was still a shot interval associated with that shot. To investigate the effects of fatigue over time, data was split into four quarters (Q1-Q4), with the final quarter (Q4) being short if the person stopped before their 60th shot. There was an average of 54.5 shots fired for Pos0, 53.9 for Pos1, 52.7 for Pos2 and 54.4 shots for Pos3. One participant retired themselves early from two conditions, leaving missing cases for Q4 in Pos2 and Pos3. The analysis was completed both with the missing cases and with the cases replaced by the group mean, with little differences. The analysis with the missing cases replaced by the group mean is reported here.

Friedman Test was used to compare all conditions on body parts that had more than five participants rating greater than 0, with Wilcoxon Signed Rank Tests used in the case of significant main effects.

Figure 4 caption. Screenshot of the body areas, rating scale and rating reasoning as presented digitally in Qualtrics

Figure 4 alt-text: a pictorial representation of the human body, both front and back, with different areas marked out. To the right the associated rating scale of some of the body parts is pictured.

Quantitative measures were analysed using a series of two-way repeated measures analyses of variance in order to ascertain a difference between weapon conditions and time (IBM SPSS v25). Main effect size statistics (partial Eta squared - η_p^2) were also calculated using SPSS. If a significant main effect was found, *post hoc* comparisons were undertaken using Tukey's corrections, and reported along with effect sizes in the form of Cohen's *d* (Cohen, 1992) between the variables. Violations of sphericity were corrected for using Greenhouse-Geisser where required.

1.4. RESULTS

There was a tendency for participants to shoot to the right and below the target for all conditions (*Figure **5***). There were no significant interactions for any measured variable. There was a significant main effect of time for hit%, BVE and shot interval, and a main effect of position for shot interval (*Table **1***).

Post hoc tests revealed that for hit% Q1 had more hits than Q2 by 0.04% (standard error; SE=0.17, p=0.025, d=0.419), and Q4 by 0.095% (SE=0.24, p=0.001, d=1.100). Q4 had fewer hits than Q2 by -0.054% (SE=0.24, p=0.042, d=-0.568) and Q3 by -0.060% (SE=0.026, p=0.039, d=-0.616), (*Figure **5***).

For BVE, Q4 was more variable than all other quarters; Q1 by 2.599 (SE=0.70, p=0.002, d=0.819), Q2 by 1.783 (SE=0.431, p=0.001, d=0.524) and Q3 by 1.552 (SE=0.62, p=-0.025, d=0.459). Q3 was also more variable than Q1 by 1.047 (SE=0.46, p=0.040, d=0.307).

For shot interval, Pos0 was quicker than all other positions; Pos1 by -0.557 s (SE=0.14, p=0.002, d=-0.707), Pos2 by -0.437 s (SE=0.196, p=0.045, d=-0.545), Pos3 by -0.733 (SE=0.215, p=0.005, d=-0.806). Q4 was slower than each of the other quarters; Q1 by 0.347 s (SE=0.104, p=0.005, d=0.439), Q2 by 0.337 s (SE=0.107, p=0.008, d=0.384) and Q3 by 0.0187 s (SE=0.075, p=0.027, d=0.214).

Table 1. Results of main effects of two-way ANOVA for hit percentage, mean radial error overall and in the x and y direction, bivariate error and shot interval time for each of the four positions, four-time quarters and the interaction between the two

	df	**MS**	**F**	***p***	**η_p^2**
Hit%					
Position	3, 42	0.03	2.0	.125	.126
Quarter	3, 42	0.09	6.2	**.001**	.307
Condition x Quarter	4.5, 63.1	0.01	1.3	.265	.087
MRE					
Position	3, 42	53.18	1.5	.217	.099
Quarter	3, 42	45.98	1.6	.195	.105
Condition x Quarter	9, 126	12.14	0.7	.702	.048
MRE(x)					
Position	3, 42	18.340	1.4	.269	.095
Quarter	3, 42	14.506	0.8	.523	.055
Condition x Quarter	9, 126	26.196	1.7	.102	.114
MRE(y)					
Position	3, 42	.912	1.1	.356	.073
Quarter	3, 42	.734	0.9	.426	.063
Condition x Quarter	9, 126	.264	0.6	.820	.039
BVE					
Position	1.4, 19.6	10.4	0.1	.848	.006
Quarter	3, 42	70.8	8.2	**<0.001**	.371
Condition x Quarter	9,126	10.0	1.3	.222	.088
Shot interval time					
Position	3, 39	5.5	7.0	**0.001**	.351

	df	MS	F	*p*	η_p^2
Quarter	3, 39	1.5	7.5	**<0.001**	.365
Condition x Quarter	4.1, 53.2	0.1	0.7	0.610	.050

Hit% denotes hit percentage; MRE mean radial error; MRE(x,y) mean radial error in the x and y directions; BVE bivariate error; df degrees of freedom, MS mean square, F f-value, p p-value and η_p^2 as partial eta squared

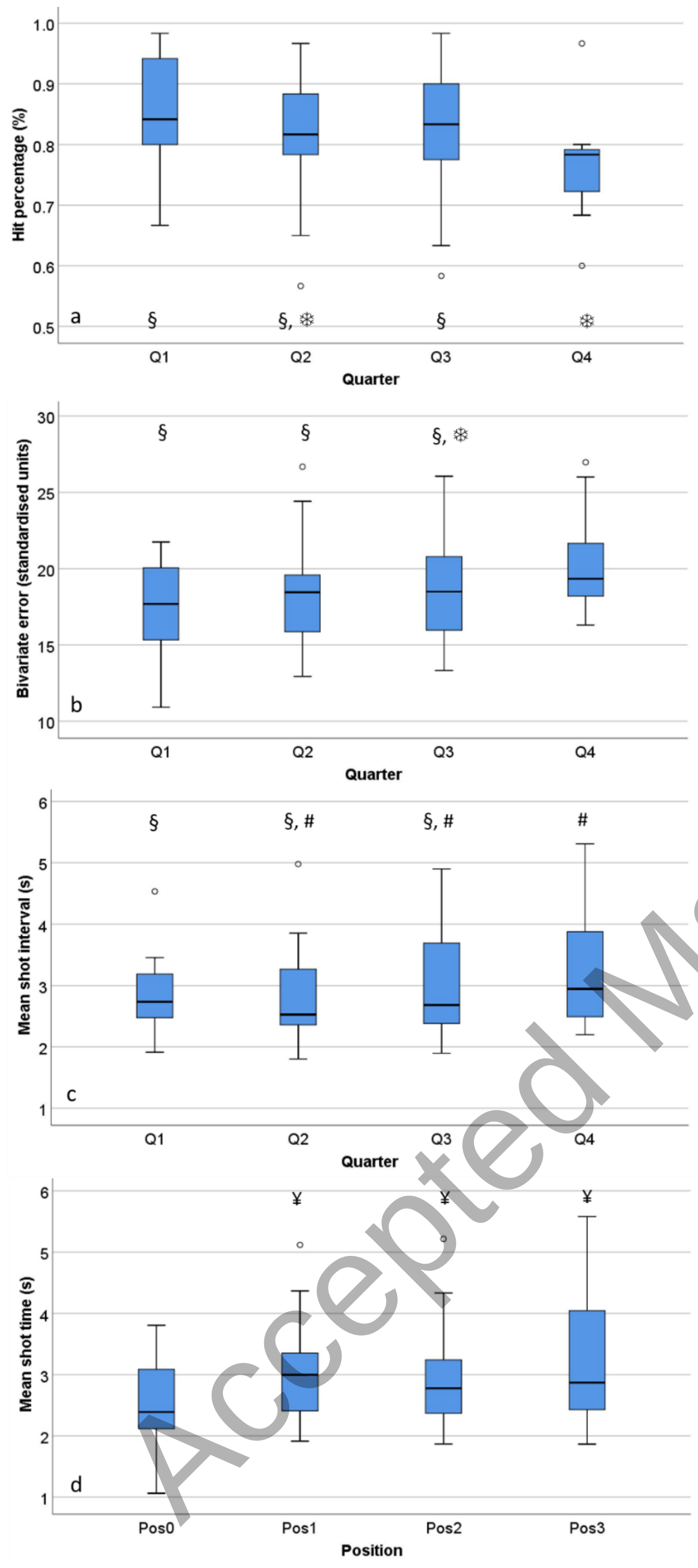

Figure 5 caption. Box plots for variables with significant main effects a) Hit% by quarter, b) BVE by quarter, c) MST by quarter and d) MST by position. § denotes significantly different to Q4, ❄ denotes significantly different to Q1, # denotes significantly different to Pos3, ¥ denotes significantly different to Pos0.

Figure 5 alt-text: four graphs stacked vertically showing box-plots for each of the four positions.

Figure 6 illustrates the average discomfort per body part per condition. There was a main effect for the support front shoulder $x^2(3)=19.05$, $p<0.001$, where Pos3 had significantly greater perceived discomfort than Pos0 (mean rank difference -1.33, $p=0.002$, $d=-0.58$) and Pos1 (mean rank difference -0.86, $p=0.045$, $d=-0.31$) (Table 2). Pos2 had greater discomfort to Pos0 (mean rank difference -1.08, $p=.012$, $d=-0.30$). A main effect was also seen for the support front lower arm $x^2(3)=11.38$, $p=0.010$, where Pos3 had greater discomfort and Pos0 (mean rank difference -1.00, $p=0.020$, $d=-0.69$).

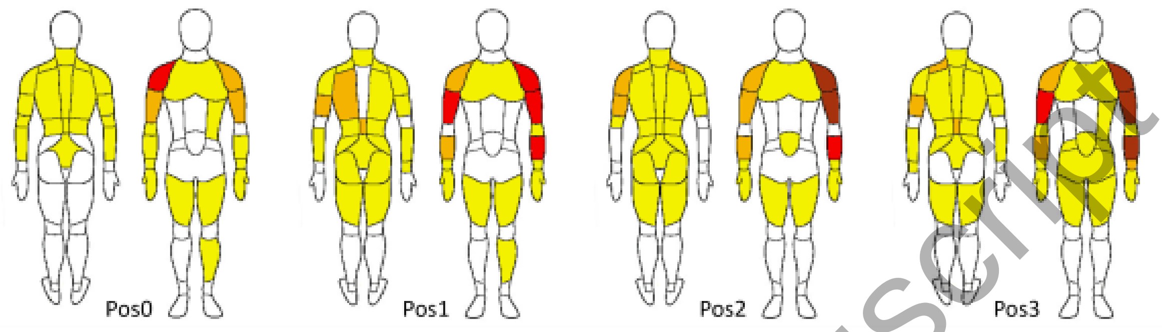

Figure 6 caption. Average discomfort in arbitrary units; white being no discomfort reported, then colours in increasing severity; yellow, orange, red and maroon

Figure 6 alt-text: four sets of pictorial representation of the human body, both front and back, with different areas marked out for each of the four conditions. The body parts are shaded based on the level of discomfort reported.

Table 2. Results of Friedman Test on discomfort per body part

Body part	**x^2**	**p***
Non-support front shoulder	1.93	.586
Support front shoulder	19.05	.000
Non-support back shoulder	2.54	.468
Support back shoulder	1.91	.591
Non-support front upper arm	3.00	.392
Support front upper arm	6.85	.077
Non-support back upper arm	2.08	.557
Support back upper arm	5.94	.115
Non-support front lower arm	7.29	.063
Support front lower arm	11.38	.010
Non-support back lower arm	6.00	.112
Support back lower arm	6.00	.112

*all comparisons had three degrees of freedom

x^2 denotes the chi-square test statistic, and p denotes the p statistic

1.5. DISCUSSION

The aim of this study was to investigate whether there are any differences in accuracy and timing between weapon configurations using an assessment protocol requiring repositioning between each shot, which was designed to physically tax the participant without adding cognitive complexity to the task. Assessments of design changes on accuracy and shot timing have traditionally been undertaken using static postures whilst shooting at static targets, both within civilian (Kemnitz et al., 2001; Yuan & Lee, 1997) and military literature (Kemnitz, Rice, Irwin, Merullo, & Johnson, 1997). This allows the researchers to reduce the movement variation used to undertake a shooting task in order to improve reliability of the assessment but turns the task into a best case scenario for the human-weapon-system.

The current assessment, whilst lacking operational validity (e.g. shooting on the move, utilising moving targets or return fire), had the advantage of adding in repetitive, self-paced movements requiring repositioning between each shot and using different configurations in order to understand the effect of the systematic added mass and mass location on accuracy and shot intervals. Adding mass to the weapon, as well as moving the centre of gravity at incremental distances towards the end of the barrel had no effect on the target accuracy measures and suggests that the participants could maintain accuracy only with a negative effect on the increased time between each shot. Unsurprisingly, Pos0 without the 1-kg mass attached was the fastest condition to shoot overall, likely due to the lighter mass, and the centre of gravity being closest to the user, effectively reducing the moment of inertia. Arguably, any reduction in time to engage a target is sufficient reason not to add mass or change the centre of mass properties of the weapon system as it shows that more targets can be hit during the same time period, or that the target can be neutralised before it neutralises the shooter.

Leaders in Defence are likely to see the benefits of the increased mass that ancillaries bring to the weapon if there is an increase in capability. Adding a suppressor to the end of a rifle adds significant weight and length and changes the centre of gravity of the weapon, but also reduces the acoustic signature of the weapon, both at the ears of the user, as well as masking the direction the round is being fired from. Other ancillaries may be placed on the top, or on the side, of the rifle between the sight and end of the barrel, such as target designators (to point out targets), thermal or image intensifiers (to better detect targets in low light or smoke obscured situations), or magnifiers (to better detect targets at a distance). Again, these add weight and bulk and change the centre of gravity of the weapon. It is important to understand both the extended capabilities the ancillaries afford, as well as what the trade-offs are at the target, in terms of number of shots fired, as well as cumulative fatigue of the user.

All weapon configurations showed a tendency for an average directional bias of shots towards the right-hand, lower portion of the target, without any differences between the weapon configurations. Average MRE of the current study was 22 cm, approximately double that of the same weapon utilised during Morelli et al. (2017) study; however during that study participants shot 10 rounds without any break in their firing position. Accuracy differences (MRE=1.3 cm) were only seen between rifles with the lowest and highest recoil energies (Morelli et al., 2017). The weapon configurations used in the current study, although not measured, would have had similar recoil energies to each other from a first-principles point of view.

An additional advantage of the current study's methods was the inclusion of a higher number of shots used in the analysis to investigate how the number of shots fired affects accuracy and timing. The shots were averaged into four quarters to assess the changes in accuracy, consistency and timing over a period of time, and showed that subsequent quarters resulted in poorer performance. Fatigue is an intuitive effect of a shooting protocol requiring repositioning between shots, as well as with this number of shots fired. Unpublished equipment acquisition projects tend to use the minimum number of shots required in order to verify specification requirements in a condensed time period and budget. Even in published literature the number of shots used for each configuration numbered between 3 and 10 shots (Kemnitz et al., 2001; Stone et al., 2014; Yuan & Lee, 1997). The results of the current study indicate that further analysis could be completed on this dataset to better understand the number of shots required for confidence for this particular shooting task.

The subjective measure of discomfort has previously been correlated to muscle fatigue as measured by electromyography (Bosch, de Looze, & van Dieen, 2007), and therefore a post-task measure of discomfort was administered to understand the utility of such a basic measurement. Discomfort in the current study was significantly different with the addition of mass in two of the body parts; the front of the support shoulder and support lower arm and could not be monitored throughout the 60 shots without introducing safety concerns, and interrupting the shooting. The results indicate that whilst the metric is not a useful measure in understanding how fatigue manifests during the protocol temporally, it does indicate that fatigue is occurring and that monitoring electromyography in the future may help better understand the effects of adding mass or changing the centre of mass properties of the weapon-system.

Shot interval in the current assessment was defined as the time between subsequent shots, and was made up of any rest period the participant gave themselves, movement time from the low ready to align the weapon with the target, and the time spent fine tuning the aim point on the target before shooting. The self-imposed rest period is a function of motivation and fatigue, and now that an effect for timing has been uncovered, future analyses will focus on the individual event timings of gross weapon movement and aim time, similar to that completed by Goonetilleke, Hoffmann, and Lau (2009) and others (Rao et al., 2018; Ripoll, Papin, Guezennec, Verdy, & Philip, 1985).

The limitations of this study include testing the masses on the weapon without their corresponding capabilities; it is likely that a mass that gives a soldier enhanced capabilities for example; night vision would be considered an acceptable mass addition by participants. The mass was only added on the top rail of the weapon, not on the bottom or side rails as this would add too many variables into the mix, such as moving the centre of gravity of the system in the y and z directions rather than limiting it as much as possible in the x direction. Therefore, the positioning of the mass does not exactly equate to where an ancillary may be placed. Pos0 being a kilogram lighter could be seen as a limitation, however it was included as it is a configuration that soldiers may learn marksmanship skills on, and one that may be used at times on operations.

A second limitation was that the use of accuracy measures such as MRE doesn't take into account ground shots or shots outside the acoustic envelope, which will artificially improve accuracy statistics. It was included here as it is commonly used by researchers to allow comparison between future studies and is easily understood by shooters and decision makers. Another limitation to this protocol was the use of self-selected pace. The main aim was to understand the addition of mass and mass placement on the weapon-system on accuracy whilst maximising difficulty in the form of the standing-unsupported posture resetting to low ready between shots. Imposing a time limit on target exposure would have resulted in many more missing data in the form of target misses and ground shots and possibly increased the cognitive burden of the test. Finally, only one type of weapon system was tested in order to limit the number of comparisons being made. Future studies will investigate differences in other weapons, such as the Australian EF88 or another "bullpup" platform.

1.6. CONCLUSION

The results showed that relying on accuracy and consistency measures alone to make weapon-system acquisition decisions could have the consequence of purchasing equipment not fit for the human. Participants in the current study were able to maintain accuracy and consistency with changes in the configuration of the weapon-system, but that came with the sacrifice of shot timing.

An effort needs to be made to understand the interaction between accuracy, consistency and shot timing during a dynamic shooting task. Future research will endeavour to draw together target accuracy and consistency, shot timing, biomechanics and self-reported measures in a more realistic, repeatable military shooting task.

1.7. PRACTICAL RECOMMENDATIONS

Based on the outcomes of this research, a number of practical recommendations are made:

1. Not to rely on target effects alone or completely static shooting postures when making weapon-system acquisition decisions.
2. Include user-specific measures such as discomfort diagrams or investigate the use of including electromyography or biomechanics into user-weapon-system assessments.

3. Better understand how other masses and locations of masses on the weapon system affects target effects, as well as the user. This may include baselining all small-arms and weapon configurations at varying distances.

Further research on this dataset in particular will further investigate temporal changes over the 60 shots, further breakdown the shot interval time into movement and aiming time, as well as further interrogate biomechanical measures that were collected during the current study. The end-goal is to develop a suite of metrics and assessments to add into future small arms engineering requirements documents for future acquisitions.

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