Lower-body muscular power and exercise tolerance predict susceptibility to enemy fire and cognitive performance during a simulated military task

by

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Abstract

Physical fitness and performance measures are predictive of Special Forces Assessment and Selection and performance during combat-specific tasks. In combat, approximately 50% of casualties are lost to direct-fire engagements, which requires resiliency to fatigue during repeated high-intensity sprints (under combat load) and delivering suppressive fire while under duress. Currently, the US Army does not have a physical fitness test that is predictive of combat survival. This study examined the predictive ability of field-expedient physical fitness/performance tests on a simulated military task (SMT) that mimicked a direct-fire engagement. Healthy subjects (N = 39, age = 25.3 ± 6.8 years) completed upper- and lower-body strength (i.e., handgrip, isometric midthigh clean pull) and power (i.e., seated power throw, standing broad jump) tests and a 3-minute all-out running test to determine critical velocity. Subjects returned to the laboratory to complete a simulated military task (SMT) that consisted of marksmanship with cognitive workload assessment (CWL) and a fire-and-move simulation (16 6-m bounds) while wearing a vest simulating a combat load (25-kg). Susceptibility to enemy fire was modeled on bound duration during the fire-and-move simulation. Stepwise linear regression identified predictors for the tactical combat movement simulation components. Significant regression models were identified for both susceptibility to enemy fire ($R^2 = 0.755$, $p < 0.001$) and cognitive performance ($R^2 = 0.162$, $p < 0.05$). Critical velocity predicted both susceptibility to enemy fire ($\beta = 0.40$, $p < 0.01$) and cognitive performance ($\beta = -0.30$, $p < 0.05$), and standing broad jump predicted susceptibility to enemy fire ($\beta = -7.20$, $p < 0.001$). All variables demonstrated poor relationships with marksmanship accuracy (r = -0.03-0.24, ps > 0.05) and no statistically significant regression model was identified. These data demonstrate the importance of exercise tolerance (i.e., critical velocity) and lower-body power (standing broad jump) in performance during a simulated direct-fire engagement and provide potential targets for interventions to monitor and enhance performance and support soldier resiliency.

Key Words: marksmanship, combat survivability, susceptibility to enemy fire, cognitive performance, critical velocity, direct-fire engagements

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Dedication

This research is dedicated to the women and men who put themselves in harm's way in support of our nation.

Chapter 1 - Introduction

Direct-fire engagements accounted for approximately half of all US combat casualties during the Global War on Terror (2001-Present, Department of Defense, 2021). The ability to navigate ballistic threats, psychological duress, heavy physical demands, and the harsh environments of asymmetric battlefields is crucial to a soldier's survival in combat. Research efforts regarding combat survival are predominately focused on the emergency on-site or in-patient care near the battlefield (Mabry & DeLorenzo, 2014; Penn-Barwell et al., 2015). The authors address all other efforts to survive combat outside of military medicine as "injury prevention", and include tactical training and personal protective equipment such as body armor.

Eastbridge and colleagues (2011) analyzed combat casualties from October of 2001 through June 2011 and found that most of the battlefield casualties from Operation Iraqi Freedom and Operation Enduring Freedom died of their injuries before ever reaching a surgeon. The authors further concluded that mitigating injury exposure before being wounded would have had the greatest impact in surviving combat (Eastbridge et al., 2011). The use of tactics and wearing of protective body armor are some of the mitigation strategies currently employed. A further potential solution for mitigating casualties could be the development of predictive models for combat survivability. While some survivability models focused on soldier speed and reducing exposure time to enemy fire exist (Billing et al., 2015; Silk et al., 2013), larger efforts have focused on employability and are designed to ascertain if a soldier has the physiological profile to meet the physical demands of the seven military occupational specialties (MOS) that are referred to as "Combat MOSs".

Physically demanding tasks conducted in combat zones are repeatedly identified in military documents such as field and training manuals that have been validated by expert panels

(Research and Technology Organisation, 2009, p. 31). Soldiers encounter a myriad of physical challenges in combat including marching long distances with heavy loads; running, sprinting, and crawling under direct fire; jumping in and out of craters and trenches and over obstacles; lifting and carrying heavy objects—all of which contribute to the superb physical conditioning and resiliency demands of warfare (Hauschild et al., 2017; Hepler et al., 2017; Jette et al., 1989). The military relies on tests of physical fitness (e.g., strength, stamina, agility, and coordination) to assess soldier ability to meet the physical demands of a combat military occupational specialty (Foulis et al., 2015 Knapik & East, 2014). Commanders have historically relied on these same assessments, combined with results from separate marksmanship evaluations, and tactical training as surrogate ratings for combat survivability (Boye et al., 2017). However, it is important to discern between being physically capable to complete a military task such as loading tank ammunition and surviving a dynamic direct-fire engagement. The high rates of casualties from direct-fire engagements deserve increasing attention for combat survivability.

Movement velocity and total time exposed to enemy fire directly correspond to a soldier's probability of being hit (Billing et al., 2015; Blount et al., 2013; Hunt et al., 2016). Rushing (i.e., sprinting all-out from places of cover and concealment successively) is an essential battlefield task for reducing a soldier's exposure to enemy fire (Barringer & Rooney, 2016; Blount et al., 2013). Researchers have used simulated combat rushes to predict a soldier's survivability based on their sprint duration and the predicted number of shots anticipated from enemy forces (Blount et al., 2013). Yet, according to tactical training manuals, after a soldier has successfully found cover or concealment during the combat rush, they then deliver suppressive fire at enemy forces, so other friendly units can move on the battlefield (Department of the Army, 2016).

While marksmanship accuracy and fidelity (not shooting non-combatants or friendly forces) during stressful events likely factor into a soldier's survivability, no previous survivability model has accounted for this. Marksmanship accuracy also deteriorates under situations of mental duress and has been previously studied by confounding fidelity with the cognitive workload while engaging targets (Scribner & Harper, 2001) making the sterile marksmanship evaluations currently used as surrogates of combat survivability questionable and lacking in ecological validity (Pihlainen et al., 2018).

Physical fitness likely moderates marksmanship accuracy and fidelity under duress as shuttle run, grip strength, and leg strength have been predictors of performance during various shooting scenarios in police officers (Muirhead et al., 2019). Together, physical fitness measures may be used to predict both rushing and marksmanship capabilities; and, in turn, combat survivability. To the best of our knowledge, no study has aimed to use field-expedient physical fitness measures to determine soldier survivability during a direct-fire engagement simulation. Our study tested the combination of a unique direct-fire engagement simulation developed by combining the current testing paradigm from the Australian Army (Silk & Billing, 2013) and a marksmanship assessment from the US Army Research Laboratory (Scribner & Harper 2001). Similar to previous research in combat personnel, we hypothesized that measures of muscular strength and cardiorespiratory endurance would predict soldier survivability and marksmanship. We also intended to explore the effects and relationships involved with the cognitive workload as presented simultaneous to marksmanship.

Chapter 2 - Methods

Experimental design

Subjects attended two laboratory visits separated by at least 2 but no more than 14 days. Body composition and physical fitness performance measures were obtained on the first laboratory visit. Physical fitness/performance testing commenced after the body composition assessment. The testing order of physical fitness/performance measures was the seated power throw, the standing long jump, the grip strength test, and the isometric mid-thigh clean pull; all of which were preceded by a standardized warm-up. All subjects were familiarized with the 3-minute all-out running test (Burnley et al., 2008; Hoffman et al., 2016) and the tactical combat movement simulation immediately after the first session measures to mitigate any potential learning effects. During the second laboratory visit, subjects completed the 3-minute all-out running test to determine critical velocity and the tactical combat movement simulation. The testing order of the second laboratory measures was randomized and counterbalanced.

Subjects

Nine female and 30 male volunteers (mean ± SD; age = 25.3 ± 6.8 yrs; height = 177.1 ± 21.6 cm; mass = 75.1 ± 13.1 kg; body fat = 20.8 ±8.2 %) qualified to participate in this study. Subjects were recruited from military-affiliated community resources including the Kansas State University Army Reserve Officers Training Corps program, veteran organizations, and the local civilian community. Subjects completed a health history questionnaire to confirm the absence of any adverse medical condition, tobacco-use, and color blindness. Subjects provided evidence of a military Basic Rifle Marksmanship qualification within the last year (n = 8) or engaged targets with at least 75% accuracy on the marksmanship simulator before the familiarization period (n = 31). Visual acuity, of at least 20/30, was verified using the Snellen Visual Acuity Test due to its expediency and sensitivity to the most common sources of visual impairment (McGraw et al., 1995). Subjects were informed of testing procedures and potential risks of participation prior to providing written informed consent. All experimental procedures were approved by the Institutional Review Board of Kansas State University (#9821). Anthropometric measures were taken following qualification and consenting to participate in the study. Height was measured in centimeters using a stadiometer (Charder HM 200p, Taichung, Taiwan). Body mass, body fat percent, fat mass, and fat-free mass were determined via bioelectrical impedance analysis using standard mode (TBF-310A; Tanita, Japan).

Measures

Seated Power Throw

The seated power throw is a medicine ball put that tests upper-body power (Harris et al., 2011). Procedures used were adopted from the development of the Occupational Physical Assessment Test by the Military Performance Division of the U.S. Army Research Institute of Environmental Medicine (2015). Subjects began in a seated position on the floor with a small foam block (9” long, 6” wide, 3” deep) between their lower back and the wall. The subjects rested a 2-kg medicine ball on their chest and extended their arms to throw the ball as far forward as possible while maintaining contact between their back and the wall. Subjects could practice as many times as they needed before completing three successive attempts to throw the ball as far as possible. The distance was recorded from the closest landing spot with a measuring tape and recorded to the nearest 10^{th} centimeter. The average of the three attempts was calculated and recorded.

Standing long jump

Subjects were instructed to stand with both approximately shoulder-width apart and jump forward as far as possible (Miller, 2012). Both feet were behind a chalk line which was used for the starting position. The horizontal displacement of the jump was measured to the nearest cm from the starting position to the closest heel. Jumps were not scored if any part of the body other than the feet touched the ground or if the feet moved after landing and before scoring. Subjects were given time to practice before attempting three jumps for record. Horizontal displacement was averaged across the three trials.

Grip strength testing

Maximal grip strength was recorded for each subject's dominant and non-dominant hand using a Jamar Plus+ dynamometer (Patterson Medical, Warrenville, IL) to determine upper-body maximal strength (Hamilton et al., 1992). Subjects were instructed to sit in a chair with their elbow resting with 90-degrees of flexion and squeeze the handgrip dynamometer with their dominant hand as hard as possible for 5-seconds. Each subject was given 3 attempts with 30-seconds of rest between. The highest generated force in kg was recorded for each of the attempts and then averaged for analysis.

Isometric mid-thigh clean pull

Lower-body maximal strength was determined using a strain gauge load cell (Jackson Strength Evaluation System, Model #32628, Lafayette Instrument, Lafayette, IN). Subjects secured the bar – connected to a load cell by a metal chain – across the middle of their thigh while flexing the hips and knees at approximately 175 and 125-135 degrees, respectfully. Subjects were instructed to pull against the bar as forcefully as possible. Two warm-up attempts were performed prior to maximal attempts to ensure that the subject was comfortable with the procedures and could adjust the bar height if necessary. Subjects were provided 60-seconds of rest after each warm-up attempt. Three maximal attempts were performed for 5-seconds and followed by 2-minutes of rest. The average force and maximal force were recorded in kg during each maximal effort. The average of the three attempts were used for the statistical analysis.

3-minute all-out critical velocity

Subjects performed the 3-minute all-out test using an established protocol (Burnley et al., 2008; Hoffman et. al, 2016). Subjects began warming-up with walking or light jogging and familiarized themselves with the conditions of the 400-meter outdoor rubberized track. Subjects were instructed to begin running from a stationary position and run as fast as possible for 3-minutes. Individual velocity was recorded using a wrist-worn GPS (Polar V800, Polar Electo Inc., Kempele, Finland). Masking tape was used to cover the watch face to prevent subjects from seeing the elapsed time. Critical velocity was determined as the average velocity over the final 30 seconds of the test.

Simulated military task

The simulated military task (SMT) simulates tactical movements performed in combat and combines adaptations from previous studies by the United States Army Research Laboratory (2001), United States Army Research Institute of Environmental Medicine (2003), and the Australian Defense Institute (2012). The SMT was performed indoors and consisted of repeated sprints, marksmanship, and cognitive workload assessment (CWL), and has been previously described (Stein, 2020). Each subject performed the simulated military task wearing a 25-kg weighted vest designed to replicate a soldier’s combat load (Billing et al., 2015). Subjects wore exercise attire during the familiarization session and performed the SMT in military-issued combat uniform, boots, and the weighted vest. The SMT was conducted in three parts:

marksmanship with CWL assessment on the control target set; sprinting portion; marksmanship with CWL on randomized target set. The protocol was designed so that the subjects would transition to the second marksmanship trial from sprinting as quickly as possible.

The SMT began with a marksmanship protocol integrated with a cognitive workload (CWL) assessment that was modified from live-fire protocols at the Army Research Laboratory (2002). An M4 rifle (Palmetto State Armory, 16-inch Nitride M4, Carbine chambered 5.56 NATO) with iron sights was modified by removing the bolt-carrier group rendering the weapon unable to fire live ammunition. The M4 was then fitted with a shot indicating resetting trigger automatic rifle bolt (SIRT-AR, Next Level Training, Ferndale, WA), which emitted a laser from the barrel with each trigger squeeze. Subjects were instructed on how to calibrate the SIRT-AR before each session. A USB camera focused on the target area acted as a sensor for the emitted laser. A Laser Activated Shot Reporter (L.A.S.R., Shooter Technology Group, Lincoln, NE) acquired, analyzed, and compiled marksmanship data directly to a laptop computer. Four colored targets (E-type target silhouettes) were mounted on the wall to simulate standoff distances of 18-, 100-, 150-, and 200-meters. The computer software was customized to randomly announce target colors (i.e., red, blue, yellow, green) every 4-seconds until 12 targets were called out. The subjects were instructed to engage targets as quickly and accurately as possible. Basic math problems (addition/subtraction of single-/double-digit numbers) were announced between target call-outs to increase CWL similar to the protocol used by the Army Research Laboratory (2001). Answers to math problems were recorded to evaluate cognitive performance during the simulation. The L.A.S.R. software reported the number of correctly engaged targets (i.e., marksmanship accuracy) and time-series data for each target engagement. Four configurations of the target layout were randomized to prevent memorization of the target locations across shooting sessions.

After the first marksmanship with CWL assessment, subjects transitioned to the fire-and-move simulation that was modified from Silk and Billing (2013). The subjects performed 16 6-meter sprints, which were designed to mimic individual movement techniques used by military personnel while conducting a tactical drill known as "break-contact." Each 6-meter sprint started every 20 seconds from the prone position and subjects carried a separate M4 training device during the sprints to mitigate calibration deterioration of the M4 used during the marksmanship assessment. An infrared timing gate system (Position Fitness, Boston, MA) was used to record sprint duration. The average sprint duration was determined for the second testing session. Subjects returned to the marksmanship and cognitive workload assessment after completing the 16^{th} sprint and repeated the marksmanship protocol as previously described.

Statistical Analysis

Complete data for 36 subjects were available and analyzed using SPSS version 25 (SPSS Inc., Chicago, IL). All independent and dependent variables were assessed for normality using a Kolmogorov-Smirnov test and box plot analysis. Stepwise linear regressions were conducted to determine if physical fitness and performance variables predicted performance on cognitive performance, marksmanship accuracy, and susceptibility to enemy fire during a tactical combat movement simulation. Multicollinearity violations were identified if tolerance coefficients were less than 0.10 or VIFs were greater than 10. Outliers were re-evaluated after stepwise linear regression with a scatterplot and confirmed if standardized residuals were $\geq|3.3|$. Values for independent variables were reported as standardized coefficient β and statistical significance was set at $p < 0.05$.

Chapter 3 - Results

Table 3-1 displays the subject anthropometric characteristics and fitness performance results from the first session. Table 3-2 shows the intercorrelations between the simulated military tasks and both fitness performance and body composition measures. Significant ($p < 0.001$) correlations with susceptibility to enemy fire included seated power throw ($r = -.630$), standing broad jump ($r = -.833$), grip strength (dominant, $r = -.533$), isometric mid-thigh pull (peak, $r = -.598$), and critical velocity ($r = -.566$). However, there was no intercorrelation between susceptibility to enemy fire and marksmanship, and all physical fitness variables demonstrated non-significant relationships with marksmanship score ($r = -0.03$-0.212).

Table 3-1. Average Participant Characteristics and Fitness Scores (N = 39)

Variable	Mean ± SD
Age (years)	25.3 ± 6.8
Height (cm)	177.1 ± 21.6
Mass (kg)	75.1 ± 13.1
Body Mass Index (kg/cm^2)	24.6 ± 3.6
Percent Body Fat	20.8 ± 8.2
Fat Mass (kg)	15.8 ± 7.2
Fat Free Mass (kg)	59.3 ± 10.7
Seated Power Throw (cm)	599.6 ± 132.6
Standing Broad Jump (cm)	202.4 ± 40.9
Grip Strength (kg) [Dominant hand]	45.7 ± 12.1
Grip Strength (kg) [Non-dominant hand]	43.0 ± 11.5
Isometric Mid-thigh Pull Peak Force (kg)	153.8 ± 42.6
Isometric Mid-thigh Pull Average Force (kg)	129.1 ± 37.5
Critical Velocity (m/s)	3.8 ± 0.8

Table 3-2. Intercorrelations of the Fitness Measures and Simulated Military Tasks

Variable	Cognitive Performance (# correct)	Marksmanship Accuracy (Hits)	Susceptibility to Enemy Fire (%)
Marksmanship Accuracy (Hits)	0.070		
Susceptibility to Enemy Fire (%)	-0.025	-0.149	
Seated Power Throw (cm)	-0.035	0.220	-0.630**
Standing Broad Jump (cm)	-0.051	-0.023	-0.833**
Grip Strength (kg) [Dominant hand]	-0.061	0.258	-0.533**
Grip Strength (kg) [Non-dominant hand]	-0.116	0.268	-0.580**
Isometric Mid-thigh Pull Peak Force (kg)	0.026	0.161	-0.598**
Isometric Mid-thigh Pull Average Force (kg)	0.023	0.140	-0.638**
Critical Velocity (m/s)	-0.212	0.168	-0.566**
Body Fat (%)	0.327	-0.014	0.682**
Fat Mass (kg)	0.357*	0.082	0.466**
Fat Free Mass (kg)	-0.052	0.145	-0.497**

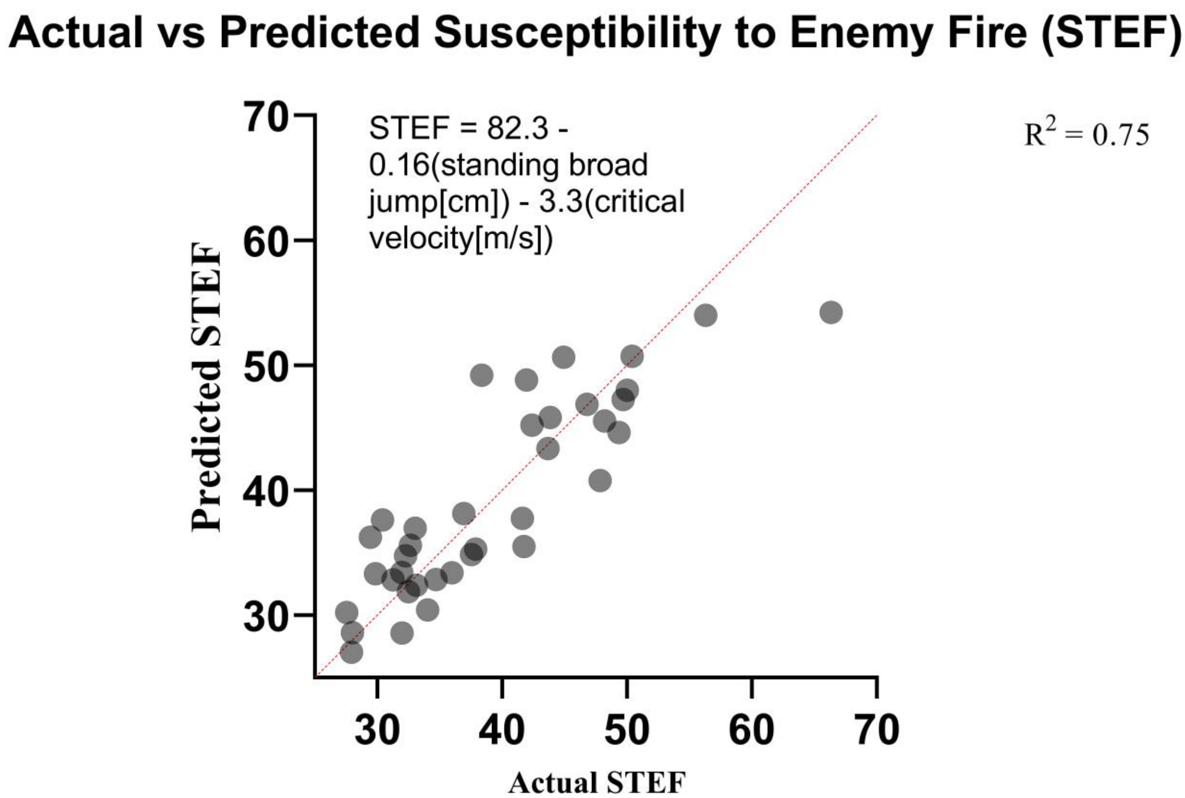
* $p < 0.05$, ** $p < 0.001$

Incorporating statistically significant variables from the correlation analysis, we conducted a series of stepwise multiple linear regressions to determine the variables that best predicted performance for each part of the simulated military tasks (SMT, Table 3-3). Standing broad jump and critical velocity predicted 75% of the variance in susceptibility to enemy fire, $F(2,32) = 48.0$, $R^2 = 0.75$; $p < 0.001$. Subjects' predicted susceptibility to enemy fire as a percent was equal to 82.3 – [0.155 (standing broad jump (cm))] – [3.275 (critical velocity (m/s))]. The equation therefore suggests that susceptibility to enemy fire decreased 0.16% for each cm increase in standing broad jump ($p < 0.001$) and by 3% for each m/s increase in critical velocity ($p = 0.008$).

Table 3-3 Stepwise Linear Regression Coefficients for Susceptibility to Enemy Fire

	Unstandardized Coefficients		Standardized Coefficients		
Variable	B	Standard Error	β	t	*p*
Constant	82.3	4.70		17.40	< 0.001
Standing Broad Jump	-0.16	0.02	-7.20	-7.20	< 0.001
Critical velocity	-3.30	1.20	-0.30	-2.83	0.008

Table 3-4: Actual vs Predicted Susceptibility to Enemy Fire



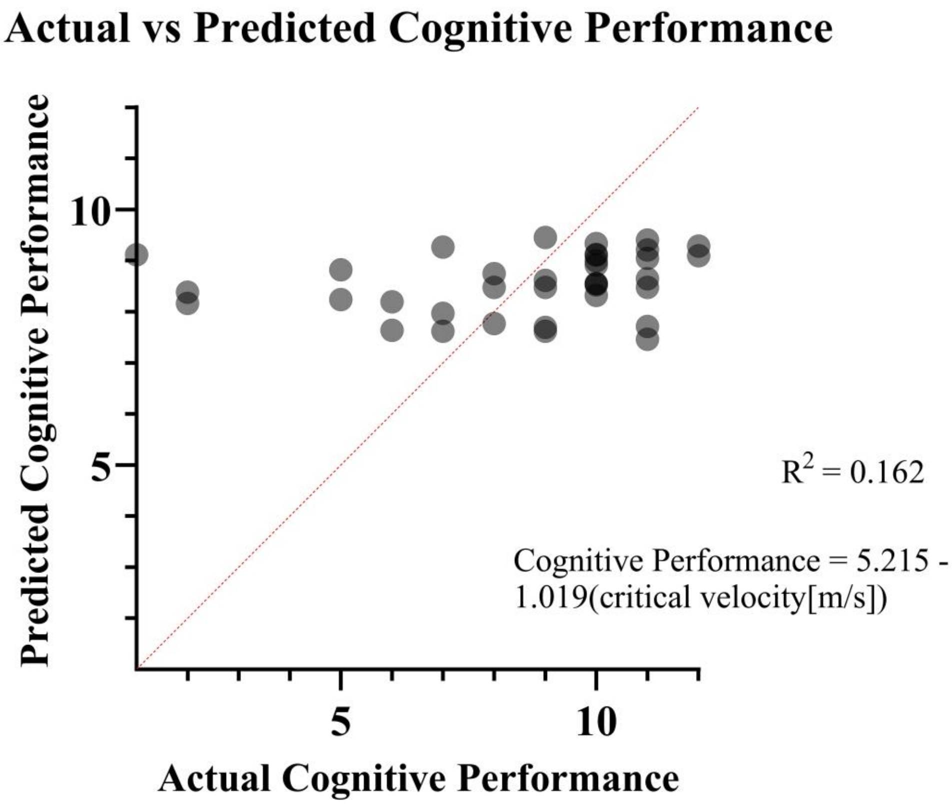
No physical fitness variables remained in the stepwise linear regression analysis as predictors for marksmanship score after the fire-and-move simulation. All physical fitness variables demonstrated poor relationships with marksmanship score (r = -0.023-0.268).

A statistically significant regression equation was found for cognitive performance after the fire-and-move simulation (Table 3-4), F(1,30) = 4.886, p = 0.022); R^2 = 0.162. Subjects predicted cognitive performance was equal to 5.215– [1.019(critical velocity (m/s))]. Subjects' cognitive performance was increased by 1 point for every m/s increase in critical velocity (p = 0.022).

Table 3-5: Stepwise Linear Regression Coefficients for Cognitive Performance

	Unstandardized Coefficients		Standardized Coefficients		
Variable	B	Standard Error	β	t	*p*
Constant	5.2	1.7		3.2	0.004
Critical velocity	1.019	0.423	0.40	2.4	0.022

Table 3-6: Actual vs Predicted Cognitive Performance



Chapter 4 - Discussion

This study investigated the predictive capacity of physical fitness on performance during a simulated military task (SMT) that mimicked tactical procedures used to react to direct-fire engagements. We hypothesized that measures of upper and lower body power would predict soldier survivability and marksmanship. The primary findings of this study indicated that standing broad jump and critical velocity was predictive of susceptibility to enemy fire, critical velocity was predictive of cognitive performance, and physical fitness was not predictive of marksmanship accuracy.

The fitness measures included in this investigation were chosen based on several factors including: field expedience, relevance to previous or existing physical tests used by the US Army, and previous research in military populations. The seated power throw and standing long jump events were chosen because of their inclusion in military assessment trials such as the US Army Occupational Physical Assessment Test (OPAT, Foulis et al., 2015). The OPAT was developed by the United States Army as a screening test for employment in the seven Combat Arms Military Occupational Specialties. The isometric mid-thigh clean pull and hand-grip were chosen because the reduced range of motion during this test is perceived to be safer for study participants compared to maximal exercise tests. The simulated military task (SMT) combined an evaluation of repeated sprinting that is predictive of susceptibility to enemy fire, and a marksmanship and cognitive workload (CWL) evaluation that simulates the complexity of returning fire on the battlefield.

Individual movement techniques (IMT) such as low crawling and repeated rush-sprinting from positions of cover are known to reduce a soldier's exposure and susceptibility to enemy fire. IMTs have been trained in the military and are described in Army field manuals covering infantry tactics as far back as 1940 (Department of the Army, 1940, pp. 156-166). Susceptibility to enemy fire during direct-fire engagement simulations is reported to increase across successive combat rushes (Hunt et al., 2016). Critical velocity/power measures are predictive of endurance performance and repeated sprints with "rush" shooting in Special Forces personnel (Hoffman et al., 2016). Soldiers who can repeatedly sprint short distances quickly have a higher survivability rate and have a greater chance at mission success (Silk & Billing, 2013). Our results are similar to the US Army OPAT, which demonstrated that performance on a beep test (i.e., shuttle runs) and standing long jump performance were significant predictors of performance on a move-under-fire simulation (Foulis et al., 2015) and confirm the relationship between jumping and sprinting performance (Lockie et al, 2019).

The marksmanship protocol was adapted from previous research conducted by the Army Research Laboratory (ARL, 2001). Their study used live ammunition on a "pop-up" firing range and included elementary addition and subtraction problems. The math problems present an assessment of cognitive workload (CWL) to the subjects that allow investigators to assess cognitive function and is analogous to the split decisions that soldiers must make on the battlefield when deciding whether to engage a perceived threat. Using live ammunition was not possible in our study, thus we attempted to replicate the ARL "pop-up" firing range protocol by visually scaling the target sizes to replicate distances from the ARL study and assigning a random order of target exposures audibly dictated to the participant and designated by color.

To the best of our knowledge, this is the first study that attempted to predict marksmanship performance with physical fitness and performance measures under physically and cognitively demanding conditions. We did not find physical fitness and performance measures to predict marksmanship accuracy. These findings were surprising but not unexpected given that marksmanship research is a separate research field. Prior research provides little specific guidance on which variables to measure to predict performance on marksmanship (Chung et al., 2011). Chung and colleagues had earlier reported that as knowledge of marksmanship principles increases, so do their scores on record-fire ranges and that combining knowledge assessments with rifle simulators, scores may also be predicted (2004). One more recent study that utilized an immersive virtual reality environment and a treadmill to simulate a marksmanship task predicted performance via subject gait and features of their speech cadence (Rao et al., 2020). The design used by Rao and colleagues incorporated what the authors termed "cognitive load conditions" and asked subjects to memorize 3- and 6-digit number strings while walking and engaging specific targets only.

One study that is close in design to ours and uses critical velocity determined by a 3-minute all-out test found that body mass index (BMI) and critical velocity predicted only the time to complete repeated rush shooting (Hoffman et al., 2016). However, their design incorporated a single target at 30 meters and did not incorporate CWL or a fidelity challenge. For these reasons we believe Hoffman and colleagues' study not to be informative to marksmanship accuracy.

Similar in design to our investigation, Muirhead (2019) employed a dynamic shooting task where law enforcement personnel completed a 3-minute submaximal step test before a fire-and-move scenario. Their report identified a weak negative relationship between marksmanship accuracy (handgun) and grip strength but lacked a regression model to predict marksmanship performance (Muirhead et. al, 2019). Marksmanship protocols, collectively, have wide variability, and different protocols may require different aspects of physical fitness for success (Muirhead et al, 2019, Scribner & Harper, 2001). Determining models of success under a variety of conditions may be of utility for tactical personnel preparing for missions; especially Special Forces or SWAT units who execute tightly controlled tactics, techniques, and procedures to gain superiority.

Chung and colleagues called predicting marksmanship performance a "deceptively complex task sensitive to variations in the individual, equipment, and environment" (2009). Our data demonstrate that we could not agree more with this statement.

These results suggest that exercise tolerance, as determined by a 3-minute all-out critical velocity test, can predict cognitive performance during a simulated direct-fire engagement. Direct-fire engagements require soldiers to continuously assess whether to deploy lethal fire at moving targets on the battlefield. The decision to shoot, or not to shoot, consumes cognitive resources that are simultaneously depleted by maintaining situational awareness and environmental scanning (i.e., distinguishing as friend or foe targets) (Rao et al., 2020). This immense psychophysiological stress that soldiers undergo during these tasks degrades cognitive performance to an extent as alcohol intoxication, sedating drugs, or clinical hypoglycemia, which, undoubtedly, threatens mission success (Lieberman et al., 2005).

While beyond the scope of our investigation, it is possible physiological explanations underpin our predictive model: specifically, the relationship between cerebral blood flow and cognitive processing and executive function (Poels et al., 2008). Total cerebral blood flow increases with exercise intensity until ~60% of maximal oxygen uptake (Ogoh & Ainslie, 2009). Thereafter, vasoconstriction ensues upon hyperventilation and reduces cerebral blood flow (Ogoh & Ainslie, 2009). A higher exercise tolerance, in theory, may delay the accumulation of fatigue associated metabolites (i.e., hydrogen ions), which stimulate the ventilatory response evoking hyperventilation and causing concomitant decrements in cerebral blood flow (Wang et al., 2005). To elucidate this, future investigations should evaluate the impact of exercise-intensity domains (i.e., moderate versus severe) on cognitive performance during simulated military tasks.

Study Considerations

A key limitation to our study was not being able to fire live ammunition on a pop-up style target range. Live fire pop-up style target ranges allow administrators to present targets to the shooter that vary by distance and could be marked as either friendly or foe. Participants shooting at a live-fire pop-up range typically do not know the exact location of the target until it presents itself. When the target is presented on these ranges, participants must quickly identify, aim, then fire within the programed target exposure time or the target will reset back in the down position. This study was limited in using laser simulation software that required static target displays to operate effectively. Therefore, we were not able to simulate friendly and foe target exposures and could not hide the targets prior to the system designating to the shooter which targets to engage. We attempted to mitigate this possible learning effect by producing 4 separate target arrangements to ensure that participants were not presented with the same organization of targets at any subsequent visit, and by preventing participants from viewing the target boards until the last possible moment prior to their first engagement.

Since <25% of participants were women, we were unable to explore sex differences for our findings. Women have long been integral to battlefield success and frequently are involved in combat situations despite being relegated to support roles for much of history. Seventeen countries within NATO have women assigned to combat positions with Norway and Israel being the first to integrate in 1988. The United States had an official ban on women in combat roles until 2013. Despite this official ban, women typically served in vital support roles potentially exposing them to combat. This involvement culminated in 2005 when Army Sergeant Leigh Ann

Hester became the first woman awarded the Silver Star for bravery in action while in direct-fire combat (Fainaru, 2005). Future investigations into combat survivability must include as many women as possible to explore sex differences.

The strengths of our study include the design of the SMT and both the measures and methods used. We based most of our measures in our investigation to be purposely similar to the events of the Occupational Physical Assessment Test (OPAT) which was novel when we were designing our study. The development of our protocols coincided with the development of the Army Combat Fitness Test (ACFT) that is currently being phased in for use in the US Army (US Army, 2021). The events of the ACFT had not been finalized and officially approved by the Department of the Army by the time we were seeking institutional review board approval. Therefore, we were unable to use any ACFT events. Subsequent investigations using simulated military tasks combining elements of combat survival, marksmanship, and cognitive workload evaluations should evaluate relationships with individual elements of the ACFT. Specifically, future studies of combat survival that incorporate a simulated military task should aim to examine if the different methods of physical fitness measures like the standing power throw, hand release pushups, leg tuck, and the two-mile run are predictors of SMT performance.

Practical Implications

Military individuals may be deployed to hostile forces and be required to respond to direct-fire engagements because of their deployment situations. By developing a unique simulated direct-fire engagement that measured susceptibility to enemy fire, marksmanship, and cognitive performance, this investigation provides a potential model to ascertain soldier survivability. The results of this investigation revealed the predictive capacity of critical velocity and standing broad jump in simulations of direct-fire engagements. Critical velocity and standing broad jump significantly predicted susceptibility to enemy fire, while critical velocity was predictive of cognitive performance. These findings suggest that unit training might benefit by incorporating events that develop lower-body power. The 3-minute all-out critical velocity test and the standing broad jump are field-expedient measures and can be conducted on large groups of individuals in a short amount of time.

The SMT was safe to implement and can be replicated by units in a relatively cost-effective way. Military units have access to M4 rifles and with a modest investment, they can purchase similar devices to replace the inner workings to emit traceable lasers. Software training companies license their customizable programs for much cheaper than it would cost to take an entire unit to an off-site location to conduct training.

Chapter 5 - Conclusions

Our study was designed to combine dynamic elements of battlefield engagements with enemy forces. When under direct fire soldiers must be able to employ several tactics, elemental of which is repeated rush sprinting from and to positions of cover. Soldiers must also accurately return fire from these positions. No previous Army physical fitness assessments combined those two elements of combat in any appreciable way. Our results revealed the predictive capacity of critical velocity and standing broad jump in simulations of direct-fire engagements such that critical velocity and standing broad jump significantly predicted susceptibility to enemy fire, while only critical velocity was predictive cognitive performance (i.e., ability to correctly communicate answers to math problems between target engagements). However, marksmanship was not predicted by any physical fitness performance variables. By developing a unique simulated direct-fire engagement that measured susceptibility to enemy fire, marksmanship, and cognitive performance, this investigation provides a potential model to ascertain soldier survivability. The ability to “shoot, move, communicate, and survive” is vital on the battlefield. These findings provide military leaders with field expedient predictors of how individuals react under cognitive and physically demanding workloads with operationally relevant outcomes.

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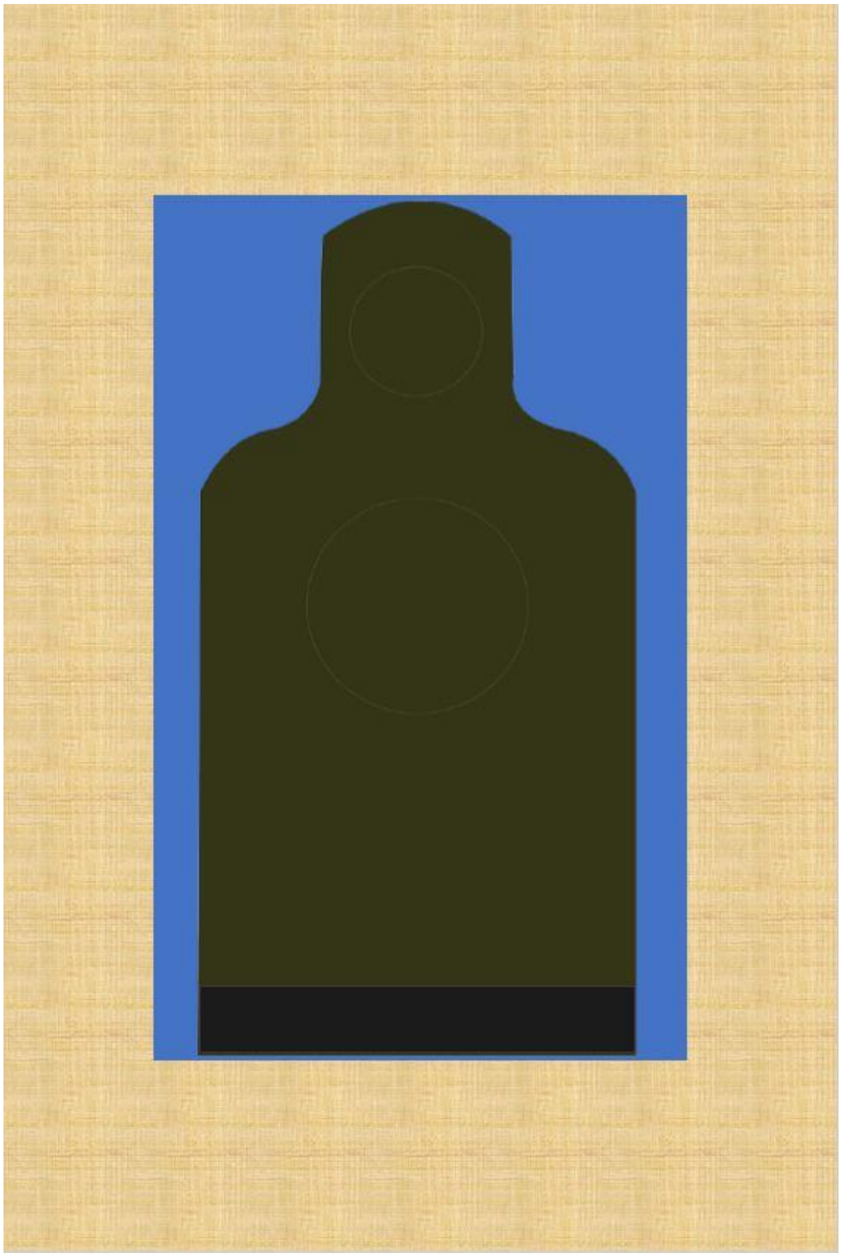
Appendix A - Target Photos

These posters were fixed at 18 feet from the participants and scaled down to represent similar stand-off distances found to be typical in combat and on qualification ranges as described by previous research (Scribner & Harper, 2001). The targets are identical to the E-type silhouettes used at military pop=up live fire ranges. Colored backgrounds

18-meter target



200- meter (yellow), 150-meter (red), 100-meter (green)