2021

Influence of Body Composition, Velocity Profiles, and Sex-Related Differences on Army Combat Fitness Test Performance

David Boffey
University of Central Florida

STARS Citation

Boffey, David, "Influence of Body Composition, Velocity Profiles, and Sex-Related Differences on Army Combat Fitness Test Performance" (2021). *Electronic Theses and Dissertations, 2020-*. 650.
https://stars.library.ucf.edu/etd2020/650

INFLUENCE OF BODY COMPOSITION, VELOCITY PROFILES, AND SEX-RELATED DIFFERENCES ON ARMY COMBAT FITNESS TEST PERFORMANCE

by

DAVID BOFFEY
B.A. University of California Santa Cruz, 2009
M.A. Sonoma State University, 2015

A dissertation submitted in partial fulfillment of the requirements
for the degree of Doctor of Philosophy
in the Department of Learning Sciences and Educational Research
in the College of Community Innovation and Education
at the University of Central Florida
Orlando, Florida

Summer Term
2021

Major Professor: David H. Fukuda

ABSTRACT

The Army Combat Fitness Test (ACFT) will become the United States Army's mandatory physical fitness test in March of 2022. The purpose of this study was to determine the relationship between ACFT performance and both body composition and velocity profiles, and to determine sex differences for these variables. Data was collected in November 2020 (Fall) and March 2021 (Spring) from male (n = 55) and female (n = 17) Army Reserve Officers' Training Corps (ROTC) cadets. Body composition was assessed with a bioelectrical impedance spectroscopy (BIS) device, and cadets completed a squat jump (SJ) force-velocity profile (FVP) and a hex bar deadlift (DL) load-velocity profile (LVP). Stepwise multiple regressions were used to explain the maximal amount of variance in ACFT total score and individual event performance. Results revealed that body composition and lower body power production may have a strong influence on ACFT performance. In terms of accounting for variance in ACFT total score, skeletal muscle mass and body fat percentage were able to account for 49% of shared variance, SJ height (unloaded) and SJ maximal force for 64% of shared variance, and DL maximal power and maximal velocity for 67% of shared variance. The 3-repetition maximum deadlift, standing power throw, hand-release push-up, and sprint-drag-carry events favor cadets with more muscle mass, while the leg tuck is influenced by body fat percentage and the two-mile run is affected by fat mass. Men outperformed women on all individual events and had a higher total ACFT score. Sex had greater predictive capability for the two-mile run than body composition, and for the sprint-drag-carry than any SJ metric. The greatest sex differences were on the standing power throw and sprint-drag-carry. It is recommended that Army ROTC cadets taking the ACFT maximize power production and increase muscle mass.

ACKNOWLEDGMENTS

I would like to thank most of all my wife, Elizabeth, and my son, Matthew, for inspiring me to keep pushing through all the obstacles of the last four years, and to keep getting better as a husband and father.

I would also like to thank my parents and my grandmother Mimi for always supporting me and motivating me to keep learning.

I am extremely grateful for Dr. Fukuda’s mentorship. His attention to detail and careful consideration of all variables when making decisions, made a major impact on me. Another big thank you to my committee: Dr. Stout, Dr. Hill, and Dr Kendall, for the great feedback, insights, and conversations.

I would also like to express my thanks to LTC Chris De Ruyter for welcoming me into the ROTC’s culture. I am grateful that I was able to give back to the Army as a subject matter expert. Thank you to Cadets Menjivar and Perkins for their careful attention to making this project run smoothly, and all Cadets with whom I worked and got to know.

Five undergraduate students volunteered and served essential roles during the extensive data collection process: Hannah Bauta, Joseph Diprima, Carson McAbee, Bianka Monis, and Amanda Straus. Their time and effort are appreciated and made this study possible.

Lastly, my experience at UCF would not have been the same without Nicolas Clark and Erica Goldstein. I value their friendship and they made a significant positive impact on my time at UCF.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

LIST OF ACRONYMS

1RM	One-repetition maximum
2MR	Two-mile run (Army Combat Fitness Test event)
APFT	Army Physical Fitness Test
ACFT	Army Combat Fitness Test
BC	Body Composition
BIA	Bioelectrical Impedance Analysis
BIS	Bioelectrical impedance spectroscopy
BF%	Body Fat Percentage
BM	Body Mass
BSPRRS	Baseline Soldier Physical Readiness Requirements Study
BT	Basic Initial Entry Training
CMJ	Counter-Movement Jump
CST	Common Soldier Tasks
CV	Coefficient of Variation
DL	Deadlift
F_0	Absolute Maximal Force
$F_{0\ rel}$	Maximal Force Relative to Body Mass
FFM	Fat-Free Mass
FFMI	Fat-Free Mass Index
FM	Fat Mass
FMI	Fat Mass Index

FVP	Force-Velocity Profile
H2F	Holistic Health and Fitness
HRP	Hand-release Push-up (Army Combat Fitness Test event)
HT	Height
ICC	Intraclass correlation Coefficient
LPT	Linear Position Transducer
LTK	Leg Tuck (Army Combat Fitness Test event)
LVP	Load-Velocity Profile
MDL	Three- repetition Maximum Deadlift (Army Combat Fitness Test event)
MOS	Military Occupational Specialty
MV	Mean Velocity
MVIC	Maximal Voluntary Isometric Contraction
OPAT	Occupational Physical Assessment Test
P_{max}	Absolute Maximal Power
$P_{max\ rel}$	Maximal Power Relative to Body Mass
PRT	Physical Readiness Training
PT	Physical Training
ROTC	Reserve Officers' Training Corps
RT	Resistance Training
SDC	Sprint-Drag-Carry (Army Combat Fitness Test event)
SEE	Standard Error of the Estimate
SJ	Squat Jump

SMM	Skeletal Muscle Mass
SPT	Standing Power Throw (Army Combat Fitness Test event)
TRADOC	Training and Doctrine Command
USACIMT	United States Army Center for Initial Military Training
USARIEM	United States Army Research Institute of Environmental Medicine
WTBD	Warrior Tasks and Battle Drills
WTBC-ST	Warrior Tasks and Battle Drills – Simulation Test

CHAPTER ONE: INTRODUCTION

In March of 2022, the Army Combat Fitness Test (ACFT) will replace the Army Physical Fitness Test (APFT) as the mandatory test-of-record for all United States Army soldiers. The APFT has been the United States Army's standard physical test for 40 years (Myers, 2018). MG Lonnie Hibbard, Commander of the Center for Initial Military Training, stated in the Foreword to the Initial Operation Capability manual for the ACFT in October 2019: "The ACFT will strengthen our fitness culture, our Soldier's fitness for battle and our Army's readiness for war." (Department of the Army, 2019a). The ACFT is an element of Holistic Health and Fitness (H2F), the Army's new physical readiness training (PRT) doctrine (Department of the Army, 2020b). The H2F model is based on five domains of soldier readiness: physical, nutritional, mental, spiritual, and sleep (Department of the Army, 2020b). This represents a major shift for the Army's physical priorities and standards, and the ACFT is a critical gauge of physical readiness in the Army's new system.

Physical assessments have historically been used in militaries across the world to assess occupational physical preparedness as well as underlying health status, risk factors and general physical fitness (Warr et al., 2017). Post-World War I efforts yielded the U.S. Army's first list of standards (minimum, average, above average and superior) on a variety of tests including the 100 yard dash, running vertical jump, running horizontal jump, and push-ups (War Department, 1941). After several overhauls and iterations, in 1980, the Army Physical Fitness Test (APFT) became the Army's test of record (J. J. Knapik & East, 2014). The APFT consists of timed endurance tests of push-ups and sit-ups (2 minutes each), and concludes with a timed two-mile run (Warr et al., 2017). As such, the APFT provides measurements of upper body and trunk muscular endurance, and full-body aerobic endurance (J. J. Knapik & East, 2014). However, these components of fitness may not accurately reflect the breadth and specificity of the soldier's occupational demands (E. A. Harman, Gutekunst, Frykman, Nindl, et al., 2008; E. Harman & Frykman, 1992; J. Knapik et al., 2012; Nindl et al., 2002).

Studies of occupational demands are fundamental for the design of test batteries that are used for initial screenings and incumbent soldiers (Jetté et al., 1989; Scofield & Kardouni, 2015; Warr et al., 2017). The APFT was never formally validated against occupational demands (East et al., 2019), due to being created as an indicator of general health and fitness, rather than a true job-simulation test (J. J. Knapik & East, 2014). Thus, APFT scores are not strong predictors of soldier's task performance (Deakin et al., 2000). In 2013, the Army made a concerted effort to develop fitness tests that are as close to job-simulation tests as possible, while also being easy to administer and grade for large units at a time across multiple locations (Warr et al., 2017). 113 Warrior Tasks and Battle Drills (WTBD) and Common Soldier Tasks (CST) were identified as representing the occupational physical demands of the soldier (East et al., 2019). The Baseline Soldier Physical Readiness Requirements Study (BSPRRS) was conducted in three phases from 2013-2019 as mandated by the Headquarters of the Department of the Army, with the explicit intent of creating a new Army fitness test that is strongly predictive of occupational performance as represented by WTBD/CST (East et al., 2019).

In phase I of the BSPRRS, 113 WTBD/CSTs were reduced to 11 that were physically demanding, common, and crucial to mission success. These were further broken down into five common core tasks: "move over long distances under heavy loads, build a hasty fighting position, move over-under-around-through obstacles on uneven-urban terrain, employ progressive levels of force (close quarters combat), and extract and transport a casualty" (East et al., 2019). The Warrior Task and Battle Drills- Simulation Test (WTBD-ST) was then constructed ad hoc to measure these five common core tasks for the validity test in Phase II. In Phase II, male (n = 278) and female (n = 46) soldiers performed the WTBD-ST and 23 physical fitness tests to predict WTBD-ST performance with multiple regression. The list of 23 events was generated by physiologists and Army physical fitness experts and included all three APFT events. The regression yielded a highly predictive (R^2 = .74) model with 8 events included: sled-drag, power throw, two-mile run, deadlift, sled push, leg tuck, push-up, kettlebell squat. This initial battery was modified into a new 8-event model (R^2 = .73) after considerations regarding evaluation of all physical and skill components, and injury risk: sled drag, two-mile run, deadlift, sled push, push-ups, power throw, leg tuck, 300 yd shuttle run. In phase III, a new group of male (n = 136) and female (n = 16) soldiers conducted the WTBD-ST and the eight fitness tests selected from the Phase II model. Four of the eight events had a very strong correlation to WTBD-ST scores (R^2 = .832): sled drag, power throw, two-mile run, one-repetition maximum (1RM) deadlift. Adding in the remaining four events slightly increased predictive capability (R^2 = .835): leg tuck, sled push, 300 yd shuttle run, push-ups. After senior Army leaders raised concerns regarding admin time, cost, and total event number, modified versions of the sled drag, sled push, and 300 yd shuttle run were combined into a single event. This new 6-event test battery was highly correlated (R^2 = .80) to the WTBD-ST, and became the ACFT after slight modifications.

The ACFT thus improves upon the APFT by keeping the health and fitness components, but adding motor skills and functional tests featuring a combination of capabilities (East et al., 2019). In Phase II of the BSPRRS, analysis revealed that the APFT was a moderate predictor of WTBD-ST performance ($R^2 = .43$). The ACFT almost doubles the predictive capability of the APFT for occupational demands. As part of H2F doctrine, the ACFT measures all five fitness domains required for soldier preparedness as measured by the WTBD/CST: muscular strength, muscular endurance, aerobic endurance, anaerobic power, and anaerobic endurance (Department of the Army, 2020b). The ACFT consists of six tests: 3-repetition maximum deadlift (MDL), standing power throw (SPT), hand-release push-up (HRP), sprint/ drag/carry (SDC), leg tuck (LTK), and two-mile run (2MR) (Department of the Army, 2019a). With this test battery, the ACFT introduces several new components of fitness, including total-body strength and power, anaerobic capacity, speed, and agility. Indeed, Roberts et al. (2021) found only a moderate correlation ($r^2 = .18$) between APFT and ACFT scores, likely due to one event being similar (HRP) and one being identical (2MR). Given the nature of these six events, ACFT performance is likely dependent on power production. As the product of force and velocity, power represents both strength and speed capabilities and their interaction (Cormie et al., 2011). Power production is a key factor for athlete and soldier performance (J. B. Cronin & Hansen, 2005; J. Cronin & Sleivert, 2005; Scofield et al., 2017), and measuring both strength and speed provide many insights into performance capability (Baker, 2001; Haff & Stone, 2015; James et al., 2016).

Velocity testing and monitoring has increased in popularity in the last decade due to early studies revealing near-perfect correlations between load and velocity that remained stable over time (González-Badillo & Sánchez-Medina, 2010). Another key finding was that velocity could be used as a surrogate for metabolic or neuromuscular fatigue (Sanchez-Medina & González-Badillo, 2011). Velocity has become accepted as an alternative method of measuring intensity, along with load which is more common historically for strength and conditioning (Weakley et al., 2020). Velocity has many uses, from monitoring daily training, to periodic testing, up to basing all training variables on velocity (Weakley et al., 2021). Velocity testing allows practitioners to account for normal and abnormal daily physiological fluctuations due to stressors and typical biological fluctuations (Jovanović & Flanagan, 2014; Mann, 2016).Velocity research expanded with the introduction of new, easy-to-use technologies that enable valid and reliable monitoring during resistance training (RT) (Dorrell et al., 2019; Garnacho-Castaño et al., 2015; Stock et al., 2011). Linear position transducers (LPT) have emerged as the most valid method that can be used in laboratory and field settings, relative to the gold standard of video capture and force plates (Banyard et al., 2017; Mitter et al., 2019; Perez-Castilla et al., 2019). The ACFT introduces several events highly reliant on strength, power and velocity (East et al., 2019). There has yet to be any research into the relationship between ACFT performance and velocity production. Understanding this connection would provide insight into the optimal testing and training methods for ACFT and occupational performance of military personnel.

Load-velocity profiles (LVP) are incrementally loaded tests of a RT movement, calculated using either absolute load or load relative to bodyweight (Jovanović & Flanagan, 2014; Weakley et al., 2021). LVPs are typically performed for non-ballistic resistance training exercises, but have also been investigated with ballistic exercises (García-Ramos et al., 2018). Initial LVP studies often used Smith machines and pauses between eccentric to concentric phases, which may have limited ecological validity for real-world performance (Conceição et al., 2016; González-Badillo & Sánchez-Medina, 2010; Pallarés et al., 2014). Banyard and colleagues (2018) found that a free-weight back squat LVP was reliable (Banyard et al., 2018). LVPs for the squat and bench press were sensitive enough to detect strength or power emphasis in training 2 days/week for 4 weeks with 30 trained men (Pérez-Castilla & García-Ramos, 2020). LVPs are exercise -specific (Conceição et al., 2016; Fahs et al., 2019; Garcia-Ramos & Jaric, 2018; Weakley et al., 2021), possibly due to muscle architecture, biomechanics of pushing vs pulling, fiber lengths and fiber arrangements and pennation angle (Sanchez-Medina et al., 2014). Several studies have examined LVPs of the conventional straight barbell deadlift (Fahs et al., 2019; Jukic et al., 2020; Ruf et al., 2018), but hex bar deadlift LVPs have not been investigated. The hex bar deadlift demonstrated different muscle activation patterns (Andersen et al., 2018) and kinematics than the straight barbell deadlift, with the hex bar deadlift potentially producing greater velocity and power compared to the straight bar (Lake et al., 2017; Swinton et al., 2011). The MDL event of the ACFT uses the hex bar deadlift, thus tactical strength and conditioning coaches and the Army would benefit from understanding the properties of the hex bar deadlift LVP with a military population. The relationship between ACFT performance and LVPs may provide a more complete and meaningful soldier performance profile.

Force-velocity profiles (FVP) are similar to LVPs, with the key difference being that FVPs require the measurement of force, either from a force plate, calculation from acceleration data (Levernier et al., 2020), or other inputs (Samozino et al., 2008). The force-velocity relationship for a single human skeletal muscle is hyperbolic, which was demonstrated as early as 1950 (Wilkie, 1950). It was later discovered that unlike single-muscle, single-joint movements, force and velocity have an inverse linear relationship during multi-joint movements such as the leg press (Bosco et al., 1995) and cycling (Vandewalle, Peres, et al., 1987). A classic study found that the FVP of the elbow flexors shifted directionally based on maximal velocity or maximal force training (Kaneko et al., 1983).

In 2008, Samozino and colleagues created a modern FVP method for the squat jump (Samozino et al., 2008). Later studies validated this method with other ballistic exercise such as bench throws (Rahmani et al., 2018) and countermovement jumps (Jiménez-Reyes, Samozino, Pareja-Blanco, et al., 2017). These FVPs require maximal intent attempts of a movement at several different loads. Force, velocity, power and slope parameters are then calculated based on the inverse linear relationship between force and velocity (Morin & Samozino, 2016). This FVP method also includes a validated process of determining optimal slope of FVP for optimal height, based on maximal power (Samozino et al., 2014, 2012). The difference between measured slope and optimal slope may differentiate athletes from sports with different force production requirements (Giroux et al., 2016). FVPs can differentiate athletes from different sports (Giroux et al., 2016), and performance level within a given sport (Colyer et al., 2018). Colyer and colleagues (2018) found that maximum force and maximum velocity change based on training emphasis over an 18-month period, independent of maximal power, similar to the foundational study by Kaneko et al. (1983). FVP parameters have not been investigated with a military population, and the relationship between FVPs and ACFT performance may provide rich information given the apparent strength and power-dependent nature of the events.

In addition to the Army’s focus on occupational-relevant testing and the inclusion of strength and power events into the ACFT, the issue of sex differences in physical fitness test scores has re-emerged as a concern. With the Army’s opening of seven Combat Arms Military Occupational Specialties (MOS) to female soldiers in 2016, sex differences in physical test performance have received considerable attention (Foulis, Sharp, et al., 2017). Physical fitness test scores factor into all aspects of a soldier's career profile, from initial entry options to good standing status and promotions. Women were integrated into the Army in 1975, several years before the APFT was introduced in 1980 (East, 2013). At this time, each sex had its own mandatory physical fitness test: men: inverted crawl, run/dodge/jump, horizontal ladder, sit-up and two-mile run; women: 80m shuttle run, push-up, sit-up, run/dodge/jump, one-mile run (East, 2013; East et al., 2019). When the APFT became official in 1980 (and in the 40 years since), raw scores are normalized by age and sex tables, maintaining the consideration of physiological sex difference.

The initial version of the ACFT in 2019, the ACFT 1.0, discarded the age- and sex-normalized standards of the APFT. The ACFT 1.0 scoring system, like the OPAT, was based on occupational requirements, and included rankings corresponding to the physical demands of MOS's: Moderate, Significant, and Heavy. (Department of the Army, 2019a). This is significant because normalized total APFT scores showed no sex differences (Draicchio et al., 2020; Roberts et al., 2021). The ACFT began pilot testing in 2019 to determine standards, injury risks, and other factors, including pass and failure rates between sexes (U.S. Army Center for Initial Military Training, 2018). Army reports surfaced in 2020 of sex differences in performance, with a 35% passing rate for females compared to 90% for men, and average women's total ACFT score 100 points lower (Allen, 2021; Gillibrand & Blumenthal, 2020). The first published study from a non-Army source reported a similar disparity, with a 9% passing rate for women vs. 82% for men (Roberts et al., 2021). In 2020, U.S. Senators government officials raised concerns, based on an independent review of the BSPRRS, that there was an unequal representation of women in the validation samples used in the BSPRRS during Phase II (14.3% female) and Phase

III (10.5% female) (East et al., 2019; Gillibrand & Blumenthal, 2020; Malek et al., 2020). The BSPRRS comprised 800 complete data records for final analyses: 691 men (86%) and 109 women (14%) (East et al., 2019). Based on early data during the implementation period, the ACFT 2.0 was introduced, allowing a soldier to substitute the Plank event (2:00 passing standard) for the LTK. Sex differences in total ACFT performance and high failure rate on the LTK led to Congress halting the test in January of 2021 as it was currently being scored (Allen, 2021).

In April 2021, the ACFT 3.0 was announced. The ACFT 3.0 proposes five performance categories corresponding to sex-specific percentiles: platinum (top 1%), gold (10%), silver (25%), bronze (50%) and green (360 points up to 50%) (Army, 2021, p. 3). These will be updated yearly based on the prior year's performance, with the minimum standard remaining sex-neutral (60 on each event for minimum total score of 360) (Army, 2021, p. 3). In addition, the Plank was instated as a permanent alternative for the LTK, rather than a temporary option as with the ACFT 2.0, and will be scored on the same 100 scale. The ACFT 3.0 is a response to the sex differences in total and LTK scores, and may address the fact that the LTK was added to the battery not due to mathematical reasons but on the conceptual basis that the ACFT should measure all components of fitness for injury considerations (East et al., 2019; Gillibrand & Blumenthal, 2020; Ryan, 2020).

The proposed changes included in the ACFT 3.0 are significant because the other primary Army physical fitness test included in H2F doctrine is the sex-neutral Occupational Physical Assessment Test (OPAT). OPAT scores function to place soldiers into Military Occupational Specialties (MOS) that they are qualified for, such that the highest performance category designates soldier to a combat arms MOS (Department of the Army, 2020b). Therefore, OPAT scores are not sex or age-normalized, ensuring that occupational capability supersedes sex differences. This leads to less women qualifying for combat arms specialties (Draicchio et al., 2020). The ACFT 1.0 was in line with this approach, but the ACFT 3.0 marks a noteworthy departure from this mindset. A survey of 4,384 male and 363 female soldiers found that higher injury rates for women were nullified by controlling for sex differences in BF% and physical capabilities as measured by APFT performance (Anderson et al., 2017). In the effort for a fair test in terms of career opportunities, and the optimal test for predictability and carryover to soldier tasks, a think tank is conducting an independent review of ACFT scores throughout 2021 (Brown, 2021). The report may lead to further changes before official ACFT implementation in March of 2022.

Sex differences in strength and power are crucial for understanding potential differences in ACFT performance. Women are approximately 2/3rd as strong as men in terms of lower body and absolute maximal strength (Laubach, 1976). Greater differences may exist in the upper body, with women closer to ∼ 50% of men's strength (Laubach, 1976). A classic study found that women's elbow flexor strength was 52% that of men (Miller et al., 1993), and more recent research found that women's elbow extensors were 58% as strong as those of men (Merrigan et al., 2018). However, these studies found no sex differences in strength relative to muscle cross-sectional area (Merrigan et al., 2018; Miller et al., 1993). The general consensus is that strength relative to body mass is similar (Lloyd & Faigenbaum, 2016; Merrigan et al., 2019; Miller et al., 1993). A recent meta-analysis of strength adaptations to resistance training found no sex differences in lower body strength adaptations to training, but women may gain more relative strength than men from upper body training (Roberts et al., 2020). In terms of power training, the slope of the load velocity profile may differ more between sexes than between strength levels, such that women are slower at low relative loads but faster at high relative loads (Torrejón et al., 2019). LVPs and FVPs are a way of examining whether or not differences in ACFT performance are driven by strength or velocity.

Sex differences in body composition may also be a major factor for disparities in ACFT performance. Compared to men, women tend to have lower body mass (BM), lower fat-free mass (FFM) and higher body-fat percentage (BF%) (Kraemer et al., 2001). A longitudinal analysis of active military member data from 1995 to 2008 reported that either overweight or obesity (BMI ≥ 25) increased from 51% to 61%, approaching the national civilian average of 68% (Flegal et al., 2010; Reyes-Guzman et al., 2015). Women had a greater increase than men in that timespan, from 21 to 35% vs. 49 to 50% (Reyes-Guzman et al., 2015). The only investigation to date into the relationship between BMI and ACFT performance revealed no relationship (Roberts et al., 2021), in contrast to the negative relationship with BMI and APFT performance (J. Knapik, 1989; Pierce et al., 2017). The shift from endurance-based events (APFT) to a more comprehensive test featuring strength and power events (ACFT), may require more sophisticated measurements of body composition than BMI to detect relationships and direct nutritional and training foci. Due to the relative lack of obese military members (12.7%) (Reyes-Guzman et al., 2015), BMI may have little predictive power for differentiating between fat mass (FM) and FFM (Shah & Braverman, 2012).

Fat-free mass index (FFMI) and fat mass index (FMI) are indices that account for FFM and FM, respectively, by dividing those by height (VanItallie et al., 1990). FFMI can differentiate levels of competitive play and positions between college athletes (Trexler et al., 2017), and different military specialties (Royer et al., 2018). Conversely to BMI, FFM and FFMI were both correlated with ACFT but not APFT performance (Roberts et al., 2021). Thus, the ACFT may represent a shift in optimal body composition from the APFT, in which maximizing muscle mass will lead to better performance, potentially leading to heavier soldiers and rendering BMI further obsolete with respect to occupational demands in the military. During conventional deadlifts, women had higher mean and peak velocities across 30,60, and 90% 1RM when normalized to fat-free mass (FFM) (Jones et al., 2016). BF%, the ratio of FM to total BM (FM + FFM), was correlated to push-up and two-mile raw scores in ROTC cadets (Steed et al., 2016). However, when normalized to sex and age tables, these correlations were erased. The sex and age normative data table therefore accounted for sex differences in BF%. In a similar study with ROTC cadets, there were sex differences in pushup and two-mile performance on the APFT but total APFT scores were not different (Draicchio et al., 2020). Sex differences in FMI, FFMI, and BF% may play a key role in influencing ACFT performance, which includes a similar pushup event and identical two-mile run as the APFT. Further investigation is required to improve our understanding of the relationship between ACFT scores and body composition before solid conclusions can be drawn.

The United States Army Reserve Officer's Training Corps (ROTC) enrolls ~ 20,000 cadets at >1,000 universities and colleges (Army ROTC, 2021). The ROTC has produced Army officers since 1916, accounting for more than half of all commissioned officers (Army ROTC, 2021; Neiberg, 2009). Women were integrated into the ROTC in the mid-1970s and currently make up ~ 20% of the ROTC countrywide. ROTC cadets participate in Physical Readiness

Training (PRT), mandated structured physical training workouts with their battalions. PRT is the Army's doctrine of physical training methodology and was updated in 2012 before a redesign in 2020 as part of the H2F system (Department of the Army, 2012, 2020a). PRT from 2012 emphasized aerobic training/running, calisthenics, and bodyweight resistance training for Army fitness and APFT performance, with the H2F model incorporating resistance training as preparation for the ACFT (Department of the Army, 2012, 2020a). Since Thomas and colleagues (2004) first provided descriptives of ROTC cadet fitness, strength and body composition, there have been numerous studies of the relationship of these variables to APFT performance with the ROTC population (Draicchio et al., 2020; Oliver et al., 2017; Steed et al., 2016). The first non-military issued study of the ACFT was recently published, and involved comparison of body composition and ACFT scores of ROTC cadets (Roberts et al., 2021). Laboratory measurements enhance our understanding of physical tests if they are valid and reliable (Liguori & Medicine, 2021), and the relationship between LVP, FVP, body composition and ACFT performance has not been established. In addition, the effect of PRT and the influence of sex on these measures could provide valuable scientific and practical insight into optimal training methods.

Purpose of the Study

The primary purpose of this study was to determine the relationship between body composition and ACFT performance. The secondary purpose was to investigate the relationship between ACFT performance and metrics derived from a load-velocity profile of the hex bar deadlift and a force-velocity profile of the squat jump. The tertiary purpose was to examine sex differences in ACFT performance, body composition and velocity profiles, and to determine if sex differences in body composition influence ACFT performance. These findings will reveal the utility of these laboratory measurements for ACFT-specific testing, training, and monitoring efforts, and direct new recruits and incumbent Army members to the physiological aspects of training on which to focus.

Research Questions

1. What is the relationship between ACFT performance and body composition measures?
2. What is the relationship between ACFT performance and a) hex bar deadlift load-velocity profile metrics and b) squat jump force-velocity profiles metrics?
3. Are there sex differences in ACFT performance, and are they explained by differences in body composition and velocity profiles?

Hypotheses

1. Body composition measures will demonstrate a strong relationship with ACFT scores.
2. Load-velocity profile and force-velocity profile metrics will demonstrate a moderate relationship with ACFT scores.
3. Sex differences will exist in ACFT performance, body composition and velocity profiles. Sex differences in ACFT performance will be partially explained by differences in body composition.

CHAPTER TWO: REVIEW OF LITERATURE

The Army Combat Fitness Test

East, DeGroot, Muraca-Grabowski, 2019

Baseline Soldier Physical Readiness Requirements Study

This technical report from the CIMT was mandated by the Headquarters of the Department of the Army and presents a joint effort with many Army organizations including TRADOC, USA Medical Command, USARIEM, US Army Public Health Center. The purpose was to analyze Army physical doctrine in terms of the physical requirements of WTBD and CST, and investigate a substitute test for the APFT that was more highly correlated to WTBC/CST. There were three phases: I) Systematic literature review and soldier interviews, focus groups, and surveys to analyze and categorize WTBD/CSTs and create a new ad hoc test, WTBD-ST to be used in Phase II, II) Male (n = 278) and female (n = 46) soldiers performed the new WTBD-ST, the APFT, and 23 physical fitness tests selected by physiologists and Army physical fitness experts, to predict WTBD-ST performance with multiple regression, III) Male (n = 136) and female (n = 16) soldiers conducted the WTBD-ST and the eight fitness tests with the highest predictive validity from Phase II.

In Phase I, 113 WTBD/CSTs were reduced to 11 that were simultaneously physically demanding, common, but also crucial to mission success. These were further broken down into 5 common core tasks: “move over long distances under heavy loads, build a hasty fighting position, move over-under-around-through obstacles on uneven-urban terrain, employ progressive levels of force (close quarters combat), and extract and transport a casualty”. In Phase II, data analysis revealed that the APFT was a moderate predictor of WTBD-ST performance ($R^2 = .43$). Multiple regression of the 23 physical fitness tests on WTBD-ST performance yielded a highly predictive ($R^2 = .74$) model with 8 events: sled drag, power throw, two-mile run, 1RM deadlift, sled push, leg tuck, push-up, kettlebell squat. This initial battery was modified into a different 8-event model ($R^2 = .73$) after considerations regarding evaluation of all physical and skill components so that the test would be more comprehensive: sled drag, two-mile run, 1RM deadlift, sled push, push-ups, power throw, leg tuck, 300 yd shuttle run.

Phase III, with a new soldier sample, revealed that a combination of four of the eight events had a very strong correlation to WTBD-ST scores ($R^2 = .832$): sled drag, power throw, two-mile run, 1RM deadlift. Adding in the remaining four events slightly increased predictive capability ($R^2 = .835$): leg tuck, sled push, 300 yd shuttle run, push-ups. Reliability analysis was conducted on test-retest scores of these eight events three days apart. All eight events were reliable with Cronbach's $\alpha >.70$, with the lowest being sled push ($\alpha = .84$) and highest being power throw ($\alpha = .99$). After presentation of these results, senior Army leaders raised concerns about administrative time, cost, and total event number for the new test. Modified versions of the sled drag, sled push, and 300 yd shuttle run were combined into a single event: SDC. The new 6-event test battery was a strong predictor ($R^2 = .80$) of WTBD/CST performance, and after slight modifications to individual events became the ACFT 1.0.

Roberts, Rushing, Plaisance, 2021

Sex Differences in Body Composition and Fitness Scores in Military Reserve Officers' Training Corps Cadets

This is the first published ACFT study not commissioned by the Army. The investigators sought to determine the influence of body composition measures and indices on ACFT and APFT scores, and to examine sex differences in these variables. Male (n = 42) and female (n = 26) Army ROTC cadets were recruited. Anthropometrics were taken and body composition was measured with BIA to calculate FFM and FFMI. Participants performed an APFT and an ACFT on separate days. The ACFT at the time of testing was the ACFT 1.0, in which the LTK was a mandatory event and the Plank was not an option.

Results revealed a sex difference in total ACFT score and all individual events, but not APFT scores. 19/23 (82%) men and 1/11 (9%) of women passed the ACFT. There were significant sex differences for HT, BM, FFM, FFMI, and BF%, but no differences for BMI. FFM and FFMI were significantly correlated with ACFT (r = .63, r= .74, respectively) but not APFT. BMI was not correlated with either test, suggesting that direct measurement of FFM may be more important than simply body mass. A limitation was its cross-sectional design, with no intervention or follow-up. The authors concluded that BMI was not a valuable predictor of ACFT performance, and that FFMI may have potential use in this population as a monitoring tool for nutrition and training changes. The authors encourage the Army to use nutrition counseling and utilize strength training programs to increase muscle mass of male and female soldiers.

Army Fitness Testing, Laboratory Testing, and Sex

Thomas, Lumpp, Schreiber, Keith, 2004

Physical Fitness Profile of Army ROTC Cadets

This study provides descriptives of the general fitness and body composition of Army ROTC cadets. Laboratory tests and an APFT were conducted to compare ROTC cadet fitness status to sex and age norms. Male (n=30) and female (n = 13) cadets completed three tests over a 2-week period. In the laboratory, cadets were assessed for aerobic capacity via VO_2 max , body composition via hydrostatic weighing, and strength via bench press 1RM. These tests were chosen due to their ubiquity in research and practice, their relationship to general health, and the presence of norms for comparison. The APFT was chosen to represent the Army PT norms, as this was the test of record at the time. The bench press 1RM was performed with free weights and 1RM was estimated based on repetitions performed at a submaximal load. The Bruce treadmill protocol was used for assessing VO_2 max.

No statistical analysis was performed, as this study was purely descriptive in nature. The following laboratory results were obtained for men and women, respectively: VO_2 max 49.6 ± 6.1 mL/kg/min vs. 40.8 ± 3.9 mL/kg/min, BF% 14.8 ± 4.2% vs. 23.9 ± 3.8%, and 1RM bench press 86.5 ± 24.9 kg vs. 35.3 ± 8.2 kg. On the individual events of the APFT the following raw scores were recorded for men and women, respectively: push-ups 60.2 ± 13.2 repetitions vs. 33.3 ± 11.20 repetitions, sit-ups 70.5 ± 12.8 repetitions vs. 65.0 ±12.9 repetitions, and two-mile run 13.97 ± 1.4 minutes vs. 17.0 ± 1.6 minutes. Compared to APFT norms published in 2002, mean APFT raw scores for these ROTC cadets were ≥ 83rd percentile. Compared to norms published by ACSM in 2000, cadets in this study were in the average group for BF% and above average for VO_2 max. For bench press 1RM, men were above average (55th percentile) and women were below average (30th percentile).

Steed, Krull, Morgan, Tucker, Ludy, 2016

Relationship Between Body Fat and Physical Fitness in Army ROTC Cadets

The primary purpose of this study was to compare BF% calculated from three different methods. The secondary purpose was to investigate the relationships between BF% determined with these methods, BMI, and APFT total and individual event scores. The three methods were: 1) BF% calculated from HT and circumference (based on Army Body Composition Program methods and equations for men and women), 2) Air-displacement plethysmography (Bod Pod using Siri equation), 3) BIA (InBody 230). Male (n = 11) and female (n = 2) Army ROTC cadets were recruited for the study. All four methods were performed on the same day for a given participant. For the circumference calculation method, men were measured for neck (base of neck) and waist (navel level) circumference, and women were measured for neck, waist, and hip (level of maximal lateral width) circumference.

Men had greater HT, BM, and circumference measurements, but statistical tests for sex differences were not run due to low sample size. Men also had higher APFT total and event scores, and lower BF% as assessed by all three methods. BF% was similar among the three methods, and none were correlated to BMI. Total APFT score was not correlated with BMI or BF% as assessed by the three body composition methods. Individual APFT events were not correlated with BMI. Push-up performance (raw score) was highly negatively correlated with BF% from all three methods (all r = -.80). Sit-up performance was not correlated with BF%. Two-mile run (raw score) had a significant correlation with BF% via air-displacement plethysmography and BIA (both r = .80) and a significant although lesser correlation with BF% as calculated via the circumference method (r = .60). The research team concluded that BMI was not a predictor of APFT performance. Although BF% influences push-up and two-mile run raw scores, it did not influence total score, possibly due to its lack of correlation with sit-up. Importantly, it should be noted that correlations between pushup, two-mile run and BF% disappeared when using sex and age-standardized scores/100.

Draicchio, Martin, Fyock-Martin, Merrigan, 2020

Retrospective Cohort Analysis of the Army Physical Fitness Test and the Occupational Physical Assessment Test in Reserve Officer Training Corps Cadets: A Brief Report

The purpose of this study was to investigate sex differences in APFT and OPAT performance, and examine the relationship between APFT and OPAT scores. Female (n = 18) and male (n = 72) Army ROTC cadets volunteered for the study. The APFT and OPAT were administered four days apart according to standard procedures. APFT events were tested in order and OPAT events were tested in random order with interval aerobic run always performed as the final event. The inter-event rest period on each test was 10 minutes for the APFT and 5 minutes for the OPAT.

Men had higher raw scores than women on two APFT events: pushups (d = 1.64) and two-mile run (d = -1.05). There was no sex difference on sit-ups, pass rates for the APFT (64% vs. 65%), or BMI. On the OPAT, men had higher total scores and higher individual event scores on all events: power throw (d = 2.28), strength deadlift (d = 1.74), standing long jump (d = 1.24), and interval aerobic run (d = .86). The strongest inter-test correlations between APFT and OPAT were as follows: push-ups and power throw (r = .64), sit-ups and long jump (r = .41), two-mile run and interval aerobic run (r = -.57). Within the OPAT, the interval aerobic run had the weakest relationship with the other three events, standing long jump, seated power throw, strength deadlift.

Oliver, Stone, Holt, Jenke, Jagim, Jones 2017

The Effect of Physical Readiness Training on Reserve Officers' Training Corps Freshmen Cadets

The primary purpose of this study was to observe the effect of 9 months of PRT on laboratory measures of fitness and APFT performance of freshman ROTC cadets. All male (n = 13) and female (n = 6) cadets had no prior military physical training experience, although 9 had prior experience with aerobic exercise through recreation or sport. Participants performed the test battery before the Fall semester (pre), between the Fall and Spring (mid) and at the end of the Spring (post). The 9 months of PRT were based on FM7-22, published in 2012, and included 2 days of primarily bodyweight circuits, sprints, and medium distance runs (2-3 miles), and 1 day of army-specific activities including ruck marches. Testing occurred over three days: 1) Body composition and aerobic capacity, 2) Upper and lower body strength, lower body power, 3) The APFT. Body composition was assessed via DEXA. Aerobic capacity was measured using the Bruce protocol on a treadmill, with oxygen consumption measured by a Parvo gas analyzer. Cadets performed between 3-5 maximal effort CMJs with a Vertec to measure jump height. The Lewis formula was then applied to estimate lower body power. Strength was assessed with 1RM bench press and back squat testing on the Smith Machine.

BM and BF% were similar from pre to post. Men had greater BM, height, and lower BF% than women. VO_2 max was similar pre-post, with men having greater VO_2 max than women at both timepoints (52.7, 48.1 mL/kg/min vs. 39.8, 37.4 mL/kg/min, respectively). Bench press 1RM improved from pre to mid, but not mid to post. Women improved squat 1RM at both timepoints, while men saw no improvement in squat 1RM. Lower body power, as calculated from CMJ height, was unchanged after the 9-month training period. Interestingly, there was a greater improvement, although not statistically significant, in jump height for women (11 ± 17%) compared to men (1 ± 5%). There were no significant changes to APFT pass rate for men or women. Men and women increased push-up and sit-up raw scores to the same extent, while only women decreased 2MR times.

Knapik, Wright, Kowal, Vogel 1980

The Influence of U.S. Army Basic Initial Entry Training on the Muscular Strength of Men and Women

This study was a response to the integration of women into the Army and Basic Initial Entry Training (Basic training; BT) specifically. The researchers examined sex differences in isometric strength and responses to BT. 948 males and 496 female soldiers were recruited upon entering basic training, but samples sizes varied for each analysis. Soldiers were assessed during week 1 of BT and again at week 6 or 7. BT consisted of 1-hour sessions of strength training and calisthenics 5-6 days/week, running, rucking, and various required occupational activities. All physical training was periodized in a linear fashion. Four-site skinfold measurements were taken from biceps, triceps, suprailiac, and subscapular sites. BF% and subsequently FFM were calculated using the Durnin and Wormersley equation. Maximal voluntary isometric contractions (MVIC) of the upper torso (seated with 90° elbow angle), leg extensors (seated with 90° knee angle), and trunk extensors (standing with strap around acromion process) were assessed using a proprietary device previously validated by USARIEM. Force was transmitted to a cable attached to a tensiometer for the measurement of peak force. Each MVIC was performed for three trials of 3-5 seconds each, with 30 seconds rest between trials. A reliability analysis was also conducted on 8 men and 8 women from the sample.

After 6-7 weeks of BT, FFM and BM increased, and BF% decreased in men (n=769) and women (n=393), with larger percentage differences for women in BM and FFM, but similar change in BF%. ICCs for the reliability subsample were .97, .92, .83 for the upper torso, leg endurance, and trunk extensors, respectively. Men had higher MVICs than women at both timepoints. Both men and women produced greater MVIC’s for all three muscle groups tested, with similar improvements in leg extension (9.7% vs. 12.4%), and greater increases for women than men for upper torso (4.2 vs. 9.3%) and trunk extension (8.1% vs. 15.9%). When expressed relative to BM, sex differences in MVIC peak force were reduced, and were further reduced when accounting for FFM. Force ratio of women to men increased from 57,65, and 66% pre-training to 60, 67, and 72% at post for the upper torso, legs, and trunk extensors, respectively.

Kraemer, Mazzetti, Nindl, Gotshalk, Volek, Bush, Marx, Dohi, Gomez, Miles, Fleck, Newton, Häkkinen, 2001

Effect of Resistance Training on Women’s Strength/Power and Occupational Performances

This was a 6-month longitudinal study comparing different physical training programs for women. A control group of active but not resistance-trained men (n=100) performed the test battery at one timepoint to enable sex and change comparisons. 93 female participants were designated to one of six groups, matched for size and strength (n = 11-18 in each group): total body strength/power RT, total body strength/hypertrophy RT, upper body strength/power RT, upper body strength/hypertrophy RT, field-based plyometric and partner-resisted training, aerobic training (running 35-40 min 2 days/week, other cardio 1day/week; all aerobic training performed at 60-85% estimated maximal heart rate). All RT groups also performed ~ 30 min running post-training, and the aerobic group added light band resistance. All programs required training 3 days/week and were periodized into two 12-week mesocycles.

At baseline, 3 months, and 6 months after training, participants underwent a comprehensive test battery: body composition, 1-RM strength testing (squat, bench press, high pull), power testing (squat jump, bench press throw with 30% 1RM), squat endurance test (45 kg, standardized 36 cm range-of-motion, 37.5 repetitions-per-minute tempo), 1RM box lift, box lift endurance (20.45 kg, as many reps as possible in 10 minutes), loaded carry (two miles with 34.1 kg ruck), and an APFT. Body composition was measured using the seven-site caliper skinfolds method, Jackson and Pollock equations and Siri equations. All 1RM and power testing was performed on a Smith machine.

After 6 months of training, total body training increased BM more than upper body and aerobic groups. Compared to the control group of men, all groups had lower BM, lower FFM and higher BF% at all timepoints. Total body power training increased squat 1RM more than all other groups, all RT groups increased bench press 1RM more than aerobic, and total body power training increased bench press 1RM more than field training. All 1-RMs were higher for the men at all timepoints. The total body power group increased squat jump power more than aerobic training group, and both total- and upper body power training increased bench press throw power more than aerobic training. Total body hypertrophy training increased squat endurance more than upper body power training, field and solely aerobic training. Sex differences in squat endurance at baseline were non-existent at 6 months for total body power and total body hypertrophy groups. Total body power training increased 1RM box lift more than aerobic training. For the endurance box lift, loaded carry and APFT push-up, all RT groups improved more than the aerobic group, and there were no sex differences in these tests for all RT groups at 6 months. All RT groups increased APFT sit-up performance more than the aerobic group. Total body hypertrophy, upper body hypertrophy, and field and aerobic groups matched men's performance in the sit-up at 6 months, while total body and upper body power groups outperformed men on sit-ups at 6 months. Total body hypertrophy, upper body hypertrophy, and upper body power training produced greater improvements in two-mile run time than field training, and upper body hypertrophy and upper body power groups matched men's performance (control group) at 6 months. Overall, women were able to bridge the gap in sex performance better on endurance-based events rather than strength events or measures of body composition.

Velocity Profiles

Banyard, Nosaka, Vernon, Haff, 2018

The Reliability of Individualized Load-Velocity Profiles

This study was a response to the bulk of previous LVP research using mean propulsive velocity (MPV), which is not available on many velocity measurement devices, and Smith machines, which may lack ecological validity in applied strength and conditioning settings. The primary purpose of this study was to determine and compare the reliability of peak velocity (PV), mean velocity (MV), and MPV during LVPs of the free weight barbell squat. The secondary purpose was to determine whether a second-order polynomial equation was a better descriptor of the L-V relationship than a linear relationship. The participants were 18 men (≥ 6 months RT experience, back squat 1RM 142.3 ± 28.3 kg, back squat 1RM relative to bodyweight 1.74 ± 0.21). All squats were performed without straps or belts.

On day 1, participants performed a baseline 1RM squat test to determine relative loads for future testing. On days 2-4, three LVPs were constructed based on MV, PV, and MPV measured at 20%, 40%, 60% 80% and 90% 1RM. Three repetitions each were performed at 20,40, and 60% 1RM, 1 repetition each was performed at 80 and 90% 1RM, and this was followed by ≤ five 1RM attempts. MV, PV, and MPV were measured during each repetition by 4 LPTs (Celesco) and analyzed in LabVIEW. The repetition with the highest MV of the three at 20-60% was used for analysis. Depth was monitored by visual displacement data and compared to pre-established depth measured with a goniometer at the knee during Day 1 testing. The eccentric phase was self-controlled and the concentric phase was as fast as possible. Fisher's r to z-transformations were used to determine differences between all correlations.

The relationship between load and velocity was linear for PV at all loads, while the relationships for MV and MPV was linear from 20-90% 1RM. Reliability was high for MV, MPV and PV at 20-90% 1RM, but low at 100% 1RM for MV (ICC = .55, CV = 19.4%) and

MPV (ICC = .66, CV = 18.0%). The smallest detectable difference across all loads (20-100% 1RM) was highest for PV (.11 to .19), followed by MPV (.08 to .11) and MV (.06 to .11). LVPs were created from PV (20-100%1RM), MV (20-90% 1RM) and MPV (20-90% 1RM), showing almost perfect correlations between load and velocity. In terms of the strength of the correlation between load and velocity, there was no difference between linear regression and polynomial regression for all three velocity variables. Importantly, this study validates the use of the MV metric for light loads. Although previous LVP research hinted that MPV might be more accurate than MV at light loads due to deceleration at end range of motion, MV was valid in this study at loads as light as 20% 1RM. The authors suggest that the poor reliability of MV and MPV at 100% 1RM may be due to the contributions of horizontal movement of the bar path and SSC. The authors also recommend that individual LVPs rather than group LVPs be used for acute variable prescription, due to the wide range of individual velocities at a given relative intensity.

Samozino, Morin, Hintzy, Belli, 2008

A Simple Method for Measuring Force, Velocity and Power Output During Squat Jump

The researchers sought to use the laws of mechanics to mathematically develop and validate a novel field-based methodology for estimating power output of jumps. The participants were 11 active men who were not involved in jumping sports and did not have extensive plyometric experience. Two to three days after a familiarization session, participants performed two squat jumps (no countermovement), with arms crossed, on a force plate. They squatted to a knee angle of 90°, verified by a ruler at a pre-set individualized height, and held this position for ~ 2 seconds before jumping as high as they could. The participants were instructed to land in the same plantar flexed position as their take-off position. The novel computational method and force plate were used to calculate the following variables during the push-off/concentric phase: mean force, mean velocity, and mean power. Three inputs were needed for the computational method: body mass, vertical push-off distance, and jump height (calculated from flight time derived from force plate in this study).

Average force, velocity and power were similar between the force plate and computational methods. Mean bias and % mean bias comparing computational method to force plate were -11.5 N ± 25.4N (-.88 % ± 1.96%) for mean force, .017 m/s ± .033 m/s (1.60% ± 3.01%) for mean velocity, and -1.66 W ± 39.8 W (-.12% ± 2.82%) for mean power. CV for the computational method was 2.56%, 3.84%, and 6.35%, similar to the 2.52%, 6.23%, and 7.24% for force plate measurements of mean force, velocity, and power. The novel method proved to be valid in comparison to the gold standard force plate measurement. Accounting for push-off height was an important takeaway from this study as it has a direct effect on work being done and therefore power.

Cormie, McGuigan, Newton, 2010

Adaptations in Athletic Performance After Ballistic Power Versus Strength Training

The purpose of this study was to compare the effects of 10 weeks of power training with ballistic movements versus strength training with high intensities. Twenty-four moderately trained men (relative squat strength 1.30 ± .15) were randomized into 3 groups for 10 weeks of training 3 days/week (n = 8 each): strength training, power training, and control group. Depending on the day, the power training group performed CMJ with bodyweight or 30% 1RM and the strength training group performed three sets of squats at 75-90% 1RM. The groups undergoing training were tested at baseline, five weeks, and 10 weeks, and control was tested at baseline and 10 weeks. Seven days after week 10 testing, the strength training group performed jump squat testing again, but using %1RM from baseline numbers. This was done to assess absolute changes in FV profile. The testing battery for day 1 was dominant-leg vastus lateralis ultrasound to measure muscle thickness and pennation angle, squat 1RM, body composition with DEXA, 3-second isometric squat test at 140° knee angle on a force plate, CMJ power tests from 0-80% 1RM at 20% increments in randomized order, and bodyweight SJ test on force plate with LPT measuring velocity. EMG data was collected from the vastus lateralis and biceps femoris of the dominant leg during the isometric squat and jump power tests. The day 2 testing battery was a 40m sprint with a staggered-stance start and timing gates at 5,10, 20, 30 and 40m.

There was a significant improvement in squat 1RM in the strength training group only at five weeks and 10 weeks. Peak power and displacement increased above baseline similarly for both training groups across all loads, but the power training group did not increase their bodyweight SJ performance. The power training group had improvements over baseline for 20, 30, and 40m sprint and flying 15 (measured from 5-20m), while the strength training group had improvements for 40m only. There were no between-group differences for sprint performance at any timepoint. There was a similar upward shift of the FV profile for the training groups compared to baseline, for three loads for the strength training group for velocity and force, and two loads for the power training group for velocity. There were no training effects for FV or force-power relationship, or joint angles during 1RM and bodyweight jump squat compared to control group. Strength training increased leg muscle mass, muscle thickness and pennation angle compared to baseline, with the changes in leg muscle mass and muscle thickness being greater than the changes achieved by the power training group. EMG detected that strength training also increased MVIC at post-test more than power training, but there were no between-group differences for average muscle activation during the unloaded jump squat. As a whole, strength training and power training produced similar improvements in jump squat performance, with strength training being superior for leg muscle mass and absolute strength, and power training being potentially practically but not statistically better for sprint performance under 40m. This study provides further evidence for the importance of maximal strength as a driver of all force/velocity/power components, at least with this moderately strong population.

CHAPTER THREE: METHODS

Experimental Design

This study was performed using a repeated measures and cross-sectional design. In November of 2020, ROTC cadets performed body composition (BC) testing, a squat jump (SJ) FVP, a hex bar deadlift (DL) LVP, and an Army Combat Fitness Test (ACFT). In March, participants completed identical testing measures as a follow-up after conducting physical training (PT) with their battalion during January and February for ~ 8 weeks. All testing and training took place at the same time of day for each participant. The PT in January and February was running and strength training on Monday and Wednesday, and ruck marches on Friday. PT was based on exercises and recommendations included in the H2F PRT manual (Department of the Army, 2020a).

Participants

The Army Reserve Officer Training Corps (ROTC) program is a training program for future Army officers offered at postsecondary institutions. All cadets must pass the current PT test of record in order to move forward in the program and commission upon graduation. Seventy-seven Army ROTC cadets volunteered to take part in the study. Three participants were excluded from data analysis due to not completing an ACFT at either time point, and two were excluded due to dropping out of ROTC during the course of the study. Data was analyzed from male (n = 55, age 21.3 ± 2.0 yr., height 174.2 ± 5.9 cm, body mass 74.4 ± 10.9 kg, body fat percentage 19.8 ± 5.3%) and female (n = 17, age 20.6 ± 1.8 yr., height 163.7 ± 6.9 cm, body mass 63.3 ± 6.5 kg, body fat percentage 26.2 ± 4.3%) cadets. Sample sizes were different for each analysis due to participant availability and mandatory COVID protocol including 2-week quarantine for any cadet with possible exposure to virus. Tables 1 and 2 display the sample sizes for each test and comparison, and sample sizes are noted in all analyses. Power analysis using freely available, open-source software (G*Power 3.1.9.4, HHU, Dusseldorf, Germany) revealed that for a normal model of a bivariate correlation between ACFT total score and BF%, to achieve minimum power of 0.80, α-value of 0.05, and a correlation of $r = .47$ derived from a similar correlational study (Roberts et al., 2021), the minimum sample size is 14.

All participants had currently been doing PT with the ROTC battalion for ≥ 2 months prior to first round of testing. The ROTC training regimen between testing timepoints was ~ 8 weeks of PT, including concurrent resistance training and aerobic training 3 days per week in ~ 1-hour sessions. Monday and Wednesday consisted of circuits of calisthenics, sprints, various resistance training or anerobic capacity exercises, and short runs (1-3 miles). Fridays were ruck marches of progressively increasing distance (Department of the Army, 2012). All participants were required to have no injuries within the previous 6 months. Before participating in the study, all study procedures, risks, and benefits were explained, and all questions were answered. Each volunteer then provided their written informed consent to participate in the study and filled out a Physical Activity Readiness Questionnaire (PAR-Q+) and a medical history and activity questionnaire (MHAQ) to assess their physical ability to participate in the study. This study was approved by the University's Institutional Review Board.

Table 1. Dates, times and sample sizes for each test

	Fall 2020			Spring 2021			Both Timepoints
Test	**n**	**Dates**	**Times**	**n**	**Dates**	**Times**	**n**
ACFT	65	11/17 - 11/19	0600	59	3/9 - 3/11	0600	52
FVP/LVP	57	11/9, 11/23	0600, 0645	47	3/20 - 3/21	0600, 0645	39
BC	57	11/21 – 11/22	0600 - 1100	64	3/1, 3/3	0500 - 0830	51

Table 2. Sample sizes for comparisons between laboratory measurements and Army Combat Fitness Test performance

Test	Fall 2020	Spring 2021	Both Timepoints
ACFT, FVP/LVP	52	44	34
ACFT, BC	52	58	42
ACFT, FVP/LVP, BC	44	43	30

Army Combat Fitness Test

The ACFTs were administered and overseen by certified instructors from the University's Department of Military Science, according to the published Army guidelines for the test (Department of the Army, 2020b). The ACFT has been updated since its inception in 2019, and the current version at the time of data collection was the ACFT 2.0. The ACFT 2.0 consists of 6 events, listed here in order with brief descriptions. Complete descriptions and testing procedures are specified in the H2F testing manual (Department of the Army, 2020b).

- 3-repetition maximum deadlift (MDL): The cadet performs three repetitions of the hex bar deadlift at the heaviest load possible (lbs.) with proper technique. The cadet must not excessively flex spine or bring the knees together. After a successful first attempt, the cadet can make a second attempt to achieve a heavier weight for a higher score.
- Standing power throw (SPT): The cadet starts facing away from throwing lane without touching the line with their heels. The cadet then throws a 10-pound medicine ball overhead and backwards for maximal horizontal distance (meters) without the feet touching the line. The cadet has two attempts to maximize their score.
- Hand-release push-up (HRP): The cadet has two minutes to complete as many push-ups as possible with proper technique. The index fingers must be inside the outer edge of the cadet's shoulders during all push-ups. When the body reaches the ground after each repetition, the cadet must maximally extend the elbow and horizontally abduct the arm so that the upper arms form a "T" position. Then the

cadet returns their hands to the starting position underneath the shoulders for the next repetition. Cadets can rest in the front leaning rest position (elbows extended) as long as this position is strictly maintained.

- Sprint/drag/carry (SDC): The cadet completes the following 5 events in the shortest time possible: Sprint, 90 lb. Sled Drag, Lateral Shuffle, 40 lb. Double Kettlebell Farmer's Carry, and Sprint. Each event is 50m with a 180° turn at the 25 m line. The cadet must touch the 25 m line with a hand and foot during the two Sprints and the Lateral Shuffle.
- Leg tuck (LTK): The cadet begins the test in a straight-arm hang with hands in an alternated grip on a straight pull-up bar. A complete repetition requires flexing the elbows, knees, and hips so that both knees or thighs touch the elbows or upper arm. The downward motion must be performed under control back to the straight-arm hang position before attempting another repetition.
    - PLANK: During the time of testing, the ACFT 2.0 offered the PLANK as an alternative to the LTK. The cadet must maintain a proper plank position (elbows and feet on ground, back straight) for two minutes for a passing score.
- Two-Mile Run (2MR): The cadet completes a self-paced outdoor two-mile run in the shortest duration possible.

Each event has a raw score and a score out of 100 that is calculated based on a spreadsheet from the Army (Department of the Army, 2019b). Cadets must achieve a minimum of 60 points on each event to pass the ACFT. If a cadet was not able to perform ≥ one repetition of the LTK, they performed the PLANK as a substitute. If they held a two-minute plank they were awarded 60/100 possible points for the LTK event; otherwise, they received a 0 and failed that event and the ACFT. As of April 2021, the Army is performing diagnostics on the ACFT 3.0, which includes a plank scored from 58 to 100 points (United States Army, 2021, p. 3). As this standard was not in place during the time of data collection and therefore participants opting for the PLANK terminated the test at two minutes for a passing score, LTK raw scores were used for statistical analysis in the current study. The ACFT also has a cumulative score (all standardized scores summed together out of a possible 600 points). Instructors recorded individual event scores and calculated the total score using the scorecard provided by the Army. As an element of the BSPRRS, a reliability analysis was conducted on the eight-event test that became the ACFT. Test-retest scores of these eight events three days apart revealed high reliability, with all Cronbach's $\alpha >.70$, the lowest at $\alpha = .84$ and the highest at $\alpha = .99$ (East et al., 2019). Cadets were instructed to adhere to a similar nutrition plan the day before and the day of the ACFTs. Raw scores were used for all analyses other than the event-to-event comparison, which used the scores/100 to standardize scores of events with raw scores in different units of measure. All cadets wore their standard Army Physical Fitness Uniforms for all ACFTs.

Body Composition and Anthropometrics

Participants were asked to be sufficiently hydrated and to have abstained from food consumption for a minimum of two hours before arriving for body composition (BC) testing. All BC testing took place at the same time of day for each cadet (0600 - 0900). Upon arrival to the laboratory, height (HT) and weight (bodymass; BM) were measured using a stadiometer and scale (Health-o- meter Professional Scale, Model 500

KL, Pelstar, Alsip, IL, USA). BC was measured by a noninvasive bioelectrical impedance spectroscopy (BIS) device (SOZO, Impedimed, Brisbane, Australia). Participants stood on the device platform while contacting the electrodes for approximately 20 seconds. All procedures followed the manufacturer's guidelines. Variables collected were fat-free mass (FFM), skeletal muscle mass (SMM), fat mass (FM), and body fat percentage (BF%). Fat-free mass index (FFMI) was calculated as FFM (kg) / HT $(m)^2$, and fat mass index (FMI) was calculated as FM (kg) / HT $(m)^2$ (VanItallie et al., 1990).

Force-Velocity Profile

Before conducting the squat jump force-velocity profile (SJ FVP), cadets performed the Preparation Drill (Standard version) consisting of ten each of the following: Bend and reach, rear lunge, high jumper, rower, squat bender, bent-leg body twist, forward lunge, prone row, windmill, and push-up (Department of the Army, 2020c). After the warmup, cadets were weighed and assigned to a light or heavy version of the FVP based on their BM. Participants <155 lbs. (70.3 kg) performed the light version of the test in the Fall and Spring (n = 24, 19, respectively) with loads of 0 kg (PVC pipe), 16 kg, and 25 kg, in order. Participants >155 lbs. (70.3 kg) performed the heavy version of the test in the Fall and Spring (n = 33, 28, respectively) with loads of 0 kg (PVC pipe), 20 kg, and 43 kg, in order. Participants were assigned to these groups to ensure that each participant could successfully jump with proper technique for all loads tested. Lower limb length and initial squat height were measured with a 1/4" non-stretch fiberglass tape measure (Dukal FTM1) meeting Army specifications. These were measured following the validated protocol in order to calculate height of push-off as the lower limb length at standing minus initial height at bottom of range of motion (Samozino et al., 2008).

The squat jump was performed by having the cadet place the dowel or barbell in a high-bar position with feet in the width each cadet determined to be most comfortable for reaching maximum jump height. Cadets squatted down to a 90° knee angle as verified by a Certified Strength and Conditioning Specialist (NSCA – CSCS,*D) or Tactical Strength and Conditioning Facilitator (TSAC - F). After holding the 90° knee angle position for ∼ 2 seconds, cadets were instructed to jump as high as possible and maintain full leg extension in the air before landing with minimal knee flexion. Excessively flexing the knees in the air or upon landing lowers the center of mass at landing, thus artificially inflating flight time and overestimating jump height (Yamashita et al., 2020). The rest periods between each load were ∼3-5 minutes to allow for full recovery. Two repetitions were performed at each load, and the repetition with the highest jump height at each load was used for analysis (Samozino et al., 2008).

A jump mat (Just Jump System, Power Systems, Knoxville, TN) was used during the squat jumps to calculate jump height based on flight time. The jump mat was shown to be a reliable method of analyzing jump height (ICC=.96), with coefficient of variation (CV) of 3.7% during countermovement jumps (McMahon et al., 2016). The following variables were calculated for each FVP: P_{max} (Maximal power; W), F_0 (theoretical maximum force; N), V_0 (theoretical maximum velocity; m/s) using a validated method (Samozino et al., 2008). Briefly, force was plotted against mean velocity (MV) at each load to derive a correlation and regression equation, with F_0 calculated as the y-intercept, V_0 as the x-intercept, and the slope of each FVP ($Slope_{fv}$) was calculated as $– F_0/V_0$.

Force and velocity were highly correlated in the Fall (*r* = -.956 ± .046, range = -.837 to -.999) and Spring (*r* = -.952 ± .055, range = -.783 to -.999).

Relative values for power, force, and slope were calculated by dividing the absolute values by BM (kg). A more negative slope may represent greater velocity capabilities and a less negative slope may represent greater force capabilities (Morin & Samozino, 2016). Optimal slope ($\mathrm{Slope}_{\mathrm{FV\ opt}}$), the slope of the FV profile that maximizes jump height for a given P_{max} and height of push-off, was calculated according to the validated method (Samozino et al., 2012). FV imbalance was calculated as $\mathrm{Slope}_{\mathrm{fv\ imb}} = (S_{FV}/S_{FV\ op}) \times 100$, with the interpretation that $\mathrm{Slope}_{\mathrm{fv\ imb}}$>100% means velocity deficit and $\mathrm{Slope}_{\mathrm{fv\ imb}}$ < 100% means force deficit (Samozino et al., 2014). P_{max} was calculated as $P_{max} = F_0V_0/4$, determined to be the same as P_{max} derived from the second-order polynomial equation for power and velocity (Jaric, 2015; Vandewalle, Pérès, et al., 1987). Intra-class correlation coefficients (ICC) were calculated to determine the relative reliability of FVP parameters (Weir, 2005) during pilot testing (n=5). Two-way random ICC's ($ICC_{2,1}$) were interpreted as follows: 0–0.1, 0.1–0.3, 0.3–0.5, 0.5–0.7, 0.7–0.9, and 0.9–1.0: trivial, small, moderate, large, very large, and nearly perfect, respectively (Hopkins et al., 2009). For assessing absolute reliability, coefficient of variation (CV) was calculated as: (standard deviation/mean)*100. ICCs for all FVP metrics of force, velocity and power were very large or nearly perfect ($ICC_{2,1}$ range .871 to .966; CV 3.85% to 9.62%). ICCs for slopes and FV_{imb} were very large ($ICC_{2,1}$ range = .874 to .897; CV 15.49% to 16.46%).

Load-Velocity Profile

Participants began the hex bar deadlift load-velocity profile (DL LVP) ~ 5 minutes after the SJ. As with the FVP, participants were assigned to a light or heavy version of the LVP. Participants <155 lbs. (70.3 kg) performed the LVP with loads of 27 kg (empty bar), 36 kg, 50 kg, 59 kg, and 68 kg, in order. Participants >155 lbs. (70.3 kg) performed the LVP with loads of 27 kg (empty bar), 50 kg, 68 kg, 77 kg, and 91 kg, in order. The loads were chosen to ensure that none would be supramaximal, while still employing a wide range to maximize validity. The load-velocity relationship for the conventional barbell deadlift was shown to be highly reliable from loads of 20-90% 1RM (Ruf et al., 2018). For the repetitions with the empty bar, weight plates were set up underneath the sleeves of the barbell to match the height of the loaded bar conditions.

The rest periods between each load were ~3-5 minutes for full recovery. Participants were instructed to start each repetition in a fully upright position before lowering themselves under control to the start position. On command, they stood up as explosively as possible while keeping both feet firmly on the floor, followed by a slight pause at the top of the movement to ensure full hip and knee extension. Starting the hex bar deadlift from a static position eliminates any measurement error of the common prescription of self-selected eccentric speeds for lower body movements (Banyard et al., 2018).

For every repetition, the participants were instructed to “explode out of the bottom” and maintain foot contact with the floor (Behm & Sale, 1993; Newton et al., 1996). Repetitions were stopped if the knees began moving closer together or there was substantial spinal flexion. Two repetitions were performed at each load, and the repetition with the highest mean velocity (MV) was used for analysis (Sanchez-Medina et al., 2010). A Certified Strength and Conditioning Specialist (NSCA – CSCS,*D) and Tactical Strength and Conditioning Facilitator (TSAC-F) was present during all testing sessions.

A linear position transducer (Tendo Power Analyzer V-316, Tendo Sports Machines London, UK) was used to collect kinematic data during the DL LVP. It consists of a sensor unit Velcro-strapped to the end of the barbell and connected to a Kevlar cord, enabling measurement and calculation of MV based on time and displacement, with a sample taken every 10mm of displacement. The Tendo linear position transducer (LPT) was found to be highly reliable for MV (ICC = .982) (Garnacho-Castaño et al., 2015). MV was chosen due to the high reliability and validity of the MV linear model (Banyard et al., 2018; García-Ramos et al., 2019), and the recommendation that MV be used as the velocity metric for LVPs of non-ballistic RT exercises (Jidovtseff et al., 2011). Load and MV were highly correlated in the Fall (r = -.978 ± .016, range = -.923 to -.999) and Spring (r = -.980 ± .019, range = -.916 to -.999).

The following variables were calculated for each LVP, similar to the calculations used for the FVP: P_{max} (Maximal power; W), DL $Load_{max}$ (theoretical maximum load; kg), and DL V_{max} (theoretical maximum velocity; m/s). MV was plotted against load to derive a correlation and regression equation, with, DL V_{max} as the y-intercept, DL $Load_{max}$ as the x-intercept and the slope of each LVP (S_{fv}) as - DL V_{max} / DL $Load_{max}$. DL P_{max} was calculated as DL P_{max} = DL $Load_{max}$ (converted to N) x DL V_{max}= /4. DL $Load_{max\ rel}$ and DL $P_{max\ rel}$ was calculated by dividing the respective absolute values by BM (kg). Reliability analyses of pilot data (n=5) were calculated according to the same methods described in the FVP section above. ICCs for LVP metrics of force, velocity and power were nearly perfect ($ICC_{2,1}$ range = .905 to .991; CV range = 2.29% to 6.35%). $ICC_{2,1}$ for DL $Slope_{LV}$ was moderate ($ICC_{2,1}$ = .329, CV = 10.50%).

Statistical Analysis

Data are presented as mean ± SD. Prior to statistical procedures, data was assessed for normality with the Shapiro-Wilk test and visual analysis of histograms. Raw scores were used for all analyses other than total ACFT scores and the ACFT event-to-event correlations, for which the standardized individual events scores/100 were used. All total ACFT scores analyzed were the score that included either A) the LTK if participants completed at least one repetition, or B) the PLANK if participants could not complete one repetition of the LTK. To compare which single event had the strongest relationship to the other five, Pearson's product-moment correlation coefficients were calculated between each event and the aggregate of the 5 other events (using scores out of 100 for standardization). For this analysis, the LTK or plank score/100 was used, to best reflect the current ACFT 3.0. For the velocity profile analyses, one participant's force-velocity profile data was excluded due to technique errors and lack of acceptable correlation between force and velocity ($r < .5$).

Simple bivariate correlations were used to calculate Pearson's product-moment correlation coefficients, to determine the relationship between total ACFT score and BC measures, FVP metrics and LVP metrics in the Fall. Pearson's product moment correlation coefficients (r) were interpreted as follows: trivial (<0.1), small (0.1–0.3), moderate (0.3–0.5), high (0.5–0.7), very high (0.7–0.9), or practically perfect (>0.9) (Hopkins et al., 2009). Stepwise linear multiple regression was run to calculate the ability of sex, BC measures, SJ FVP metrics, and DL LVP metrics to explain ACFT total score and individual event performance in the Fall. Multicollinearity was assessed by examining variance inflation factor (VIF), tolerance, and correlations between independent variables. Any models which had VIF >10 or average VIF>1 (Bowerman & O'Connell, 1990), tolerance <.2 (Menard, 1995), or correlations between independent variables $r \geq .80$ (Field, 2014) were re-run with the newest variable causing the multicollinearity removed. This was repeated until the model met the criteria above for the assumption of non-multicollinearity.

A two-way (sex * time) mixed factorial ANOVA was run for the dependent variables of ACFT total and individual event performance, BC measures, LVP metrics, and FVP metrics. Main effects were run for time (Fall vs. Spring) and sex (men vs. women). Cohen's *d* was calculated for all comparisons, with the magnitude of the effect size interpreted as follows: trivial (<0.2), small (0.2–0.6), moderate (0.6–1.2), large (1.2–2.0), and very large (>2.0) (Hopkins et al., 2009). Significance for all statistical tests was defined as an alpha level of $p \leq 0.05$. Statistical analysis was performed using SPSS (v.28.0.0, IBM, Armonk, New York).

CHAPTER FOUR: RESULTS

Army Combat Fitness Test

ACFT total and individual raw scores and standardized scores/100 in the Fall and Spring are displayed in Table 3 for descriptive purposes. All correlations between individual event scores/100 and aggregates of the other 5 were significant (*p*<.01) in both Fall (n=65) and Spring (n=59): The highest correlation was SDC (*r* = .78, .74), followed by SPT (*r* = .76, .73), MDL (*r* = .74,.68), LTK/PLANK (*r* = .74, .59) and HRP (*r* = .68, .61), and the lowest being 2MR (*r* = .65, .59).

Table 3. Army Combat Fitness Test total score and individual event raw and standardized scores/100 in the Fall and Spring (Mean ± SD)

Fall (n = 65)

Test	Raw (units)	Score
Total (/600)		455.97 ± 59.01
MDL (kg)	100.14 ± 27.99	74.65 ± 12.23
SPT (m)	7.67 ± 1.87	70.03 ± 10.13
HRP (repetitions)	37.08 ± 10.13	77.65 ± 9.16
SDC (s)	124.6 ± 19.51	79.06 ± 12.07
LTK (repetitions)	6.71 ± 6.44	72.08 ± 15.86
2MR (s)	959.83 ± 113.97	83.32 ± 11.03

Spring (n = 59)

Test	Raw (units)	Score
Total (/600)		468.90 ± 53.62
MDL (kg)	108.86 ± 28.93	78.25 ± 12.91
SPT (m)	7.65 ± 1.94	70.39 ± 10.06
HRP (repetitions)	41.39 ± 9.21	81.32 ± 8.24
SDC (s)	113.53 ± 16.09	86.54 ± 11.51
LTK (repetitions)	6.70 ± 6.37	72.05 ± 15.78
2MR (s)	985.27 ± 101.51	80.34 ± 10.88

The score/100 column for LTK includes PLANK scores for cadets who took PLANK in lieu of LTK.

Average ACFT total and individual standardized scores (/100) for men and women in the Fall are displayed in Figure 1. In the Fall, 65 cadets took the ACFT 2.0 with the PLANK option and three failed (95.38% pass rate). The three failures were due to the inability to score the minimum points (60) on the following: 1) SPT (one woman), 2) SPT and PLANK (one woman), and 3) SDC (one male). With the LTK as a mandatory test, the pass rate would be 73.85% (48/65) due to 16 failing the LTK (75.38% pass rate on LTK: 11 women and 5 men). In the Spring, 59 cadets took the ACFT 2.0 with the PLANK option and four failed (93.22% pass rate). Three failures were due to the inability to score the minimum points (60) for the SPT (two women, one man), and one for the PLANK (one man). With the LTK as a mandatory test, the pass rate would be 72.88% (43/59) due to 15 failing the LTK (74.58% pass rate on LTK: 10 women, 5 men). With total ACFT scores summed from both timepoints, substituting the PLANK for the LTK increased the pass rate from 73.90% to 95.16%. See Table 4 for breakdown of ACFT pass rate by sex and test version.

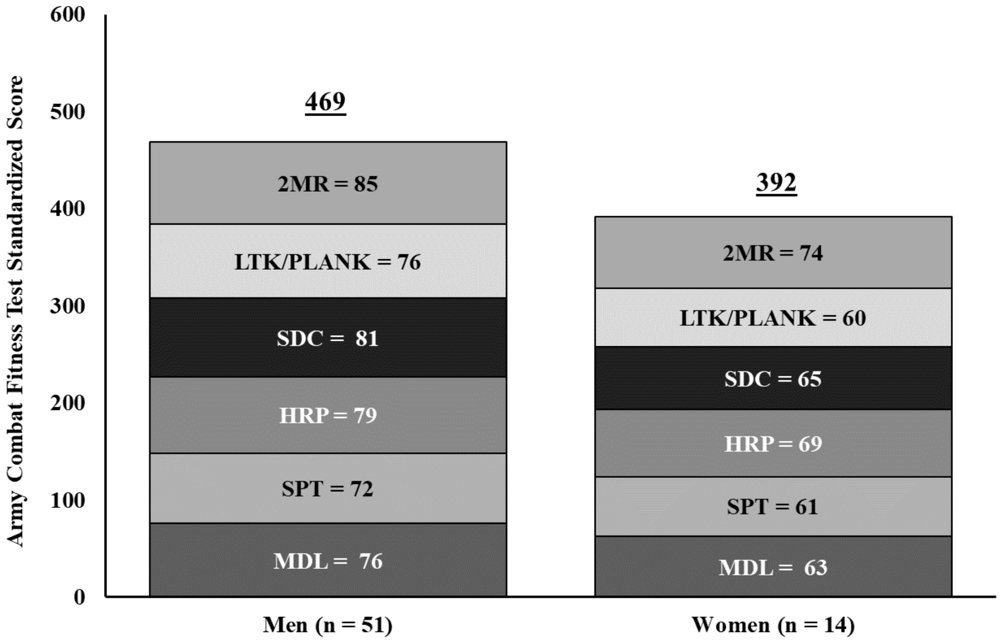


Figure 1. Average Army Combat Fitness Test total and individual standardized scores (/100) for men and women

Table 4. Army Combat Fitness Test pass rate by sex and test version.

Fall

Version of ACFT	**Men (n = 51)**	**Women (n = 14)**
With LTK	88.24% (45/51)	21.43% (3/14)
With PLANK	98.04% (50/51)	85.71% (12/14)

Spring

Version of ACFT	**Men (n = 44)**	**Women (n = 15)**
With LTK	86.36% (38/44)	33.33% (5/15)
With PLANK	95.45% (42/44)	86.67% (13/15)

There were no interaction effects for sex * time for total ACFT score (F = .79, p =.38, η^2_p = .02) or any of the individual events: MDL (F = 2.71, p = .11, η^2_p = .05), SPT (F = .20, p = .65, η^2_p < .01), HRP (F = .13, p = .73, η^2_p < .01), SDC (F = 1.46, p = .23, η^2_p = .03), LTK (F = .19, p = .67, η^2_p < .01), and 2MR (F = .02, p = .88 , η^2_p <.01). There were significant main effects for sex for total ACFT (F = 41.01, p < .01, η^2_p = .45) and time for total ACFT (F = 49.78, p < .01, η^2_p = .50). See Table 5 and 6 for complete main effects for total score and individual events for sex and time, respectively.

Table 5. Marginal means for men and women collapsed across time for Army Combat Fitness Test performance

Test	**Men**	**Women**	**Mean Difference ± SE**	***p***	**Cohen's *d***
TOTAL(/600)	507.55 (490.00, 525.09)	421.99 (404.45, 439.54)	-85.55 ± 13.36	<.01*	-0.89
MDL (kg)	125.27 (116.04, 134.51)	86.43 (77.20, 95.67)	-38.84 ± 7.03	<.01*	-0.77
SPT (m)	9.26 (8.72, 9.80)	6.14 (5.60, 6.68)	-3.12 ± 0.41	<.01*	-1.06
HRP (repetitions)	44.23 (40.70, 47.76)	34.46 (30.93, 37.99)	-9.77 ± 2.69	<.01*	-0.50
SDC (s)	104.97 (100.06, 109.87)	131.09 (126.19, 135.99)	26.13 ± 3.73	<.01*	0.97
LTK (repetitions)	10.24 (7.87, 12.61)	3.22 (0.85, 5.59)	-7.02 ± 1.81	<.01*	-0.54
2MR (s)	913.06 (873.26, 952.85)	1018.19 (978.40, 1057.99)	105.14 ± 30.3	<.01*	0.48

Means are presented as mean (lower limit, upper limit 95% confidence level); *=Significant difference between men (n=40) and women (n=12)

Table 6. Marginal means for Army Combat Fitness Test performance during Fall and Spring (n = 52)

Test	**Fall**	**Spring**	**Mean Difference ± SE**	***p***	**Cohen's *d***
TOTAL(/600)	454.23 (442.56, 465.89)	475.31 (463.65, 486.98)	21.09 ± 2.99	<.01*	0.98
MDL (kg)	101.72 (95.53, 107.92)	109.98 (103.79, 116.18)	8.26 ± 1.80	<.01	0.64
SPT (m)	7.57 (7.20, 7.95)	7.83 (7.45, 8.20)	0.25 ± 0.14	.08	0.25
HRP (repetitions)	37.15 (34.62, 39.70)	41.55 (39.02, 44.07)	4.40 ± 1.13	<.01*	0.54
SDC (s)	124.76 (121.35, 128.17)	111.30 (107.89, 114.71)	-13.47 ± 1.34	<.01*	-1.40
LTK (repetitions)	6.55 (4.97, 8.14)	6.91 (5.32, 8.50)	0.36 ± 0.44	.42	0.11
2MR (s)	956.90 (929.96, 983.85)	974.35 (947.40, 1001.29)	17.45 ± 8.63	.05*	0.28

Means are presented as mean (lower limit, upper limit 95% confidence level); *=Significant difference between Fall and Spring scores

Body Composition

Simple correlations between BC measures and total ACFT scores are shown in Table 7, and the relationship between SMM and ACFT total score is shown in Figure 2.

Table 7. Correlations between Army Combat Fitness Test total score and body composition measures in the Fall (n = 52)

Measure	***r***	***p***
BM (kg)	.35	.01
HT (cm)	.33	<.01
BMI (kg/m^2)	.16	.26
FFM (kg)	.62	<.01
SMM (kg)	.67	<.01
FM (kg)	-.25	<.01
BF%	-.53	<.01
FFMI (kg/m^2)	.50	<.01
FMI (kg/m^2)	-.35	.01

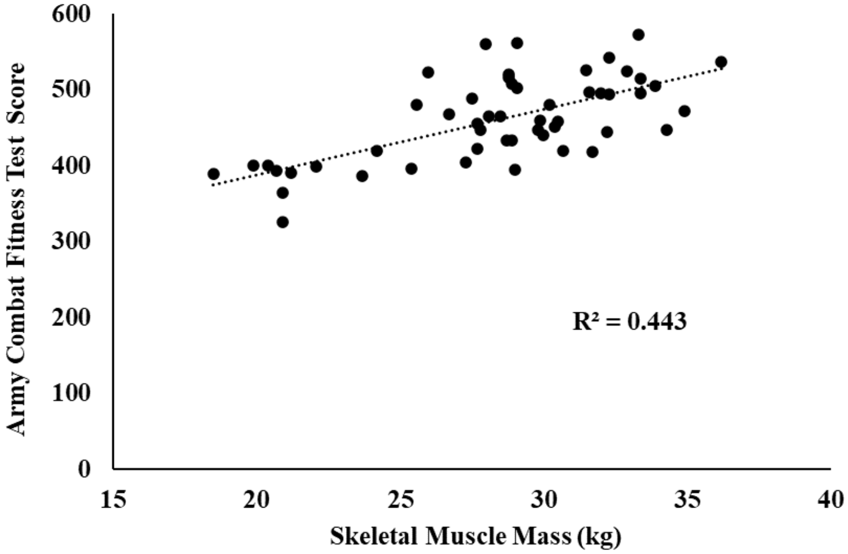


Figure 2. Correlation between skeletal muscle mass and Army Combat Fitness Test total score in the Fall (n = 52)

The results of the stepwise multiple regression analysis for ACFT total score and all events are displayed in Table 8. SMM explained the greatest variance for Total, SPT and SDC. Adding BF% to the model for Total increased R^2 by .068. FFM explained the greatest variance for MDL and HRP. Adding Sex to the model for MDL increased R^2 by .047, and adding FM to the model for HRP increased R^2 by .090. BF% explained the greatest variance for LTK, and adding Sex increased R^2 by .052. Sex explained the greatest variance for 2MR, and adding FM increased R^2 by .065.

Table 8. Stepwise multiple regression results for body composition measures and Army Combat Fitness Test total and individual events in the Fall (n = 52)

Test	**R^2 adj**	**SEE**	**Measure**	**R^2**	**β**	***p***
TOTAL(/600)	.490	39.950	SMM	.443	0.537	<.01
			BF%	.510	-0.290	.01
MDL (kg)	.443	20.710	FFM	.418	0.485	<.01
			SEX	.465	0.270	.04
SPT (m)	.552	1.193	SMM	.561	0.749	<.01
HRP (repetitions)	.280	8.518	FFM	.220	0.535	<.01
			FM	.310	-0.308	.02
SDC (s)	.404	14.860	SMM	.416	-0.645	<.01
LTK (repetitions)	.468	4.609	BF%	.436	-0.534	<.01
			SEX	.489	0.261	.03
2MR (s)	.308	96.366	SEX	.271	-0.479	<.01
			FM	.335	0.258	.03

Note: Adjusted R^2 and standard error of the estimate (SEE) are reported for the full model. Independent variables are listed in order of inclusion. Standardized coefficient (β) and significance (*p*) are reported for each independent variable, and R^2 is reported as a cumulative value.

There were no interaction effects for sex * time for BC measures: BM (F = 3.14, $p = .08$, $\eta^2_p < .01$), BMI (F = 3.20, $p = .08$, $\eta^2_p < .01$), FFM (F = 2.68, $p = .11$, $\eta^2_p = .05$), SMM (F = 2.02, $p = .16$, $\eta^2_p = .04$), FM (F = .33, $p = .57$, $\eta^2_p = .01$), BF% (F = .04, $p = .85$, $\eta^2_p < .01$), FFMI (F = 2.45, $p = .12$, $\eta^2_p = .05$) and FMI (F = .40, $p = .53$, $\eta^2_p = .01$). There were significant main effects for sex (see Table 9) but no significant main effects for time (see Table 10). Men (n=53; 174.18 ± 5.85 cm) were taller than women (n=17; 163.74 ± 6.91 cm): $p < .01$, $d = -1.71$.

Table 9. Marginal means for men and women collapsed across time for body composition measures

Measure	**Men**	**Women**	**Mean Difference ± SE**	***p***	**Cohen's *d***
BM (kg)	78.20 (73.64, 82.75)	66.27 (61.72, 70.82)	-11.92 ± 3.50	<.01*	-0.48
BMI (kg/m^2)	25.21 (23.77, 26.65)	24.02 (22.58, 25.46)	-1.19 ± 1.11	.29	-0.15
FFM (kg)	63.37 (60.41, 66.34)	50.19 (47.22, 53.16)	-13.18 ± 2.28	<.01*	-0.81
SMM (kg)	32.97 (31.97, 33.98)	23.74 (22.73, 24.74)	-9.24 ± 0.77	<.01*	-1.68
FM (kg)	14.82 (12.56, 17.09)	16.08 (13.82, 18.35)	1.26 ± 1.74	.47	0.10
BF%	18.18 (16.16, 20.20)	24.24 (22.22, 26.26)	6.07 ± 1.55	<.01*	0.55
FFMI (kg/m^2)	20.51 (19.57, 21.44)	18.15 (17.22, 19.09)	-2.35 ± 0.72	<.01*	-0.46
FMI (kg/m^2)	4.71 (3.97, 5.44)	5.87 (5.13, 6.61)	1.16 ± 0.57	.05*	0.29

Means are presented as mean (lower limit, upper limit 95% confidence level); *=Significant difference between men (n=40) and women (n=11)

Table 10. Marginal means for body composition measures during Fall and Spring (n = 51)

Measure	**Fall**	**Spring**	**Mean Difference ± SE**	***p***	**Cohen's *d***
BM (kg)	72.01 (69.09, 74.93)	72.46 (69.54, 75.37)	-0.45 ± 0.41	.28	0.15
BMI (kg/m^2)	24.54 (23.62, 25.46)	24.69 (23.77, 25.61)	-0.15 ± 0.14	.28	0.15
FFM (kg)	56.53 (54.62, 58.44)	57.03 (55.12, 58.94)	-0.50 ± 0.33	.14	0.21
SMM (kg)	28.21 (27.49, 28.93)	28.5 (27.78, 29.22)	-0.30 ± 0.35	.40	0.12
FM (kg)	15.48 (14.01, 16.95)	15.43 (13.96, 16.90)	0.05 ± 0.31	.87	-0.02
BF%	21.30 (19.97, 22.62)	21.12 (19.80, 22.45)	0.18 ± 0.35	.61	-0.07
FFMI (kg/m^2)	19.25 (18.64, 19.85)	19.41 (18.81, 20.02)	-0.17 ± 0.11	.14	0.21
FMI (kg/m^2)	5.30 (4.82, 5.78)	5.28 (4.80, 5.76)	0.02 ± 0.10	.86	-0.03

Means are presented as mean (lower limit, upper limit 95% confidence level)

Squat Jump Force-Velocity Profile

Simple correlations between FVP metrics and total ACFT score are shown in Table 11, and the relationship between SJ $\text{Height}_{\text{unloaded}}$ and ACFT total score is shown in Figure 3.

Table 11. Correlations between total Army Combat Fitness Test score and squat jump force-velocity profile metrics in the Fall (n = 51)

Metric	***r***	***p***
SJ $\text{Height}_{\text{unloaded}}$ (m)	.65	<.01
SJ V_0 (m/s)	-.05	.75
SJ F_o (N)	.60	<.01
SJ $F_{o\ rel}$ (N/kg)	.46	<.01
SJ P_{max} (W)	.40	<.01
SJ $P_{max\ rel}$ (W/kg)	.41	<.01
SJ Slope_{FV} (ns/m)	-.39	<.01
SJ $\text{Slope}_{FV\ rel}$ (ns·m/kg)	-.32	.02
SJ FV_{imb} (%)	.34	.02

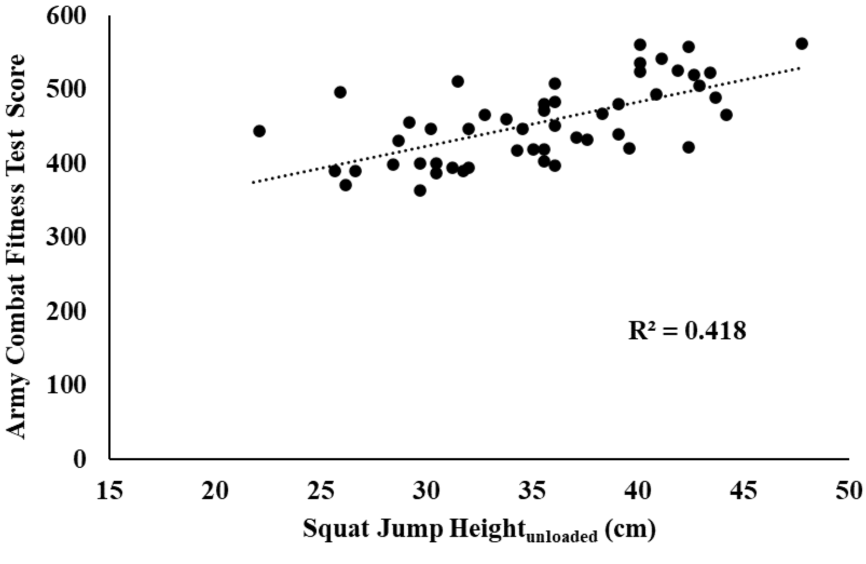


Figure 3. Correlation between SJ $\text{Height}_{\text{unloaded}}$ and Army Combat Fitness Test total score (n = 51)

The results of the stepwise multiple regression analysis for ACFT total score and all events are shown in table 12 below. SJ $\text{Height}_{\text{unloaded}}$ explained the greatest variance for Total, SPT, HRP, LTK and 2MR. Adding SJ F_o to the models for Total, SPT, and HRP increased R^2 by .238, .145, and .083, respectively. Adding SJ Slope_{FV} to the model for LTK increased R^2 by .171 and adding SJ FV_{imb} to the model for 2MR increased R^2 by .192. SJ F_0 explained the greatest variance for MDL. Sex explained the greatest variance for SDC, and adding SJ F_0 to the model increased R^2 by .156.

Table 12. Stepwise multiple regression results for squat jump force-velocity profile metrics and Army Combat Fitness Test total and individual events in the Fall (n = 51)

Test	**R^2 adj**	**SEE**	**Measure**	**R^2**	**B**	***p***
TOTAL(/600)	.641	32.286	SJ $\text{Height}_{\text{unloaded}}$	.418	0.550	<.01
			SJ F_o	.656	0.497	<.01
MDL (kg)	.548	18.663	SJ F_o	.257	1.542	<.01
SPT (m)	.415	1.405	SJ $\text{Height}_{\text{unloaded}}$	.293	0.466	<.01
			SJ F_o	.438	0.388	<.01
HRP (repetitions)	.263	8.655	SJ $\text{Height}_{\text{unloaded}}$	.209	0.400	<.01
			SJ F_o	.292	0.294	.02
SDC (s)	..444	14.601	SEX	.310	-0.448	<.01
			SJ F_o	.466	-0.410	<.01
LTK (repetitions)	.555	4.004	SJ $\text{Height}_{\text{unloaded}}$	.401	0.673	<.01
			SJ Slope_{FV}	.573	-0.416	<.01
2MR (s)	.468	86.610	SJ $\text{Height}_{\text{unloaded}}$	.297	-0.582	<.01
			SJ FV_{imb}	.489	-0.440	<.01

Note: Adjusted R^2 and standard error of the estimate (SEE) are reported for the full model. Independent variables are listed in order of inclusion. Standardized coefficient (β) and significance (*p*) are reported for each independent variable, and R^2 is reported as a cumulative value.

There were no interaction effects for sex * time for FVP metrics: SJ $\text{Height}_{\text{unloaded}}$ (F = .04, p = .84, $\eta^2_p < .01$), SJ V_0 (F = .83, p = .37, η^2_p =.02), SJ F_o (F = .14, p = .71, $\eta^2_p < .01$), SJ $F_{o\ rel}$ (F = .30, p = .59, η^2_p = .01), SJ P_{max} (F = .68, p = .42, η^2_p = .02), SJ $P_{max\ rel}$ (F = .50, p = .49, η^2_p =.01), SJ Slope_{FV} (F = .13, p = .72, $\eta^2_p < .01$), SJ $\text{Slope}_{FV\ rel}$ (F = .20, p = .65, η^2_p = .01), and SJ FV_{imb} (F = .19, p = .66, η^2_p = .01). There were significant main effects for sex (see Table 13) but no significant main effects for time (see Table 14).

Table 13. Marginal means for men and women collapsed across time for squat jump force-velocity profile metrics

Metric	**Men**	**Women**	**Mean Difference ± SE**	***p***	**Cohen's *d***
SJ Height unloaded (m)	0.39 (0.37, 0.42)	0.31 (0.29, 0.34)	-0.08 ± 0.02	<.01*	-0.60
SJ V_0 (m/s)	3.84 (2.79, 4.90)	3.01 (1.96, 4.06)	-0.83 ± 0.84	.33	-0.16
SJ F_o (N)	3400.39 (2995.34, 3805.45)	2633.25 (2228.20, 3038.31)	-767.14 ± 322.73	.02*	-0.39
SJ $F_{o\ rel}$ (N/kg)	44.66 (37.99, 51.33)	37.73 (31.05, 44.40)	-6.93 ± 5.32	.20	-0.21
SJ P_{max} (W)	2765.71 (2376.24, 3155.17)	1891.02 (1501.55, 2280.48)	-874.69 ± 310.31	.01*	-0.46
SJ $P_{max\ rel}$ (W/kg)	35.64 (31.75, 39.53)	26.68 (22.79, 30.57)	-8.96 ± 3.10	.01*	-0.47
SJ $Slope_{FV}$ (ns/m)	-1251.30 (-1536.92, -956.63)	-996.49 (-1282.14, -710.85)	254.78 ± 227.60	.27	0.18
SJ $Slope_{FV\ rel}$ (ns·m/kg)	-16.60 (-20.93, -12.26)	-14.38 (-18.72, -10.05)	2.22 ± 3.45	.53	0.10
SJ FV_{imb} (%)	105.34 (79.53, 131.16)	89.52 (63.70, 115.33)	-15.83 ± 20.57	.45	-0.13

Means are presented as mean (lower limit, upper limit 95% confidence level); *=Significant difference between men (n=32) and women (n=6)

Table 14. Marginal means for squat jump force-velocity profile metrics during Fall and Spring (n = 38)

Metric	**Fall**	**Spring**	**Mean Difference ± SE**	***p***	**Cohen's *d***
SJ Height unloaded (m)	0.35 (0.34, 0.37)	0.35 (0.33, 0.37)	0.00 ± 0.01	.73	-0.06
SJ V_0 (m/s)	3.42 (2.66, 4.18)	3.44 (2.68, 4.20)	-0.02 ± 0.45	.97	0.01
SJ F_o (N)	2974.71 (2681.86, 3267.55)	3058.94 (2766.09, 3351.79)	-84.23 ± 175.17	.63	0.08
SJ $F_{o\ rel}$ (N/kg)	40.76 (36.15, 45.36)	41.63 (37.03, 46.24)	-0.88 ± 2.49	.73	0.06
SJ P_{max} (W)	2312.99 (2040.10, 2585.88)	2343.74 (2070.84, 2616.63)	-30.75 ± 152.94	.84	0.03
SJ $P_{max\ rel}$ (W/kg)	31.03 (28.01, 34.04)	31.29 (28.28, 34.31)	-0.27 ± 2.01	.90	0.02
SJ $Slope_{FV}$ (ns/m)	-1089.20 (-1313.45, -864.87)	-1158.60 (-1382.90, -934.32)	69.45 ± 151.90	.65	-0.07
SJ $Slope_{FV\ rel}$ (ns·m/kg)	-15.10 (-18.38, -11.82)	-15.87 (-19.15, -12.60)	0.77 ± 2.11	.72	-0.06
SJ FV_{imb} (%)	94.57 (74.24, 114.90)	100.29 (79.96, 120.62)	-5.73 ± 13.82	.68	0.07

Means are presented as mean (lower limit, upper limit 95% confidence level);

Deadlift Load-Velocity Profile

Simple correlations between LVP metrics and total ACFT score are shown in Table 15, and the relationship between DL P_{max} and ACFT total score is shown in Figure 4.

Table 15. Correlations between Army Combat Fitness Test total score and hex bar deadlift load-velocity profile metrics in the Fall (n = 52)

Metric	***r***	***p***
DL V_{max} (m/s)	.36	<.01
DL $Load_{max}$ (kg)	.61	<.01
DL $Load_{max\ rel}$ (kg/kg)	.55	<.01
DL P_{max} (W)	.78	<.01
DL $P_{max\ rel}$ (W/kg)	.77	<.01
DL $Slope_{LV}$ (kg·m/s)	.43	<.01

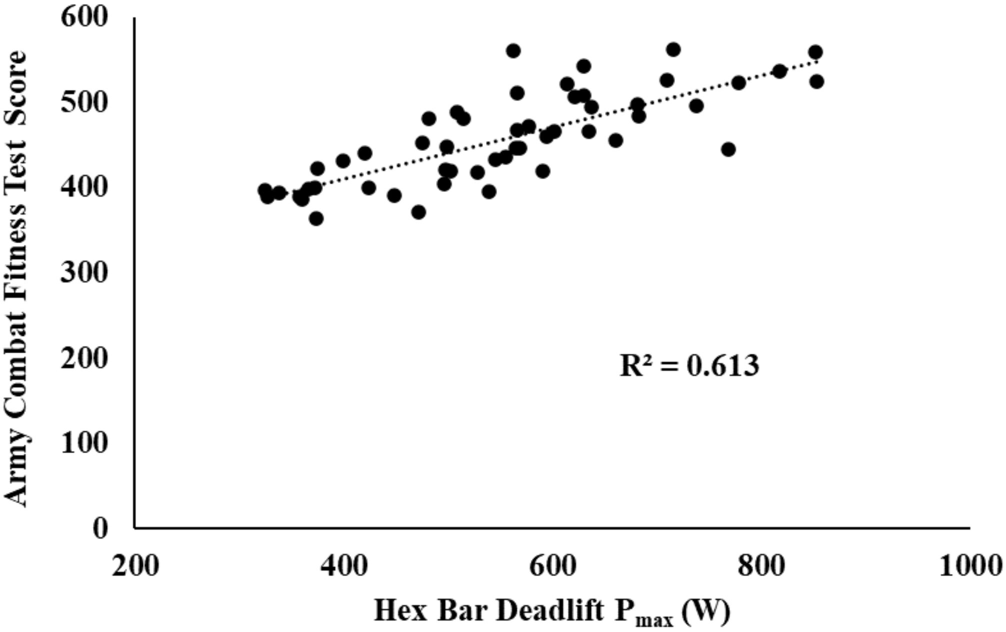


Figure 4. Correlation between hex bar DL P_{max} and Army Combat Fitness Test total score (n = 52)

The results of the stepwise multiple regression analysis for ACFT total score and all events are in table 16 below. DL P_{max} explained the greatest variance for Total, MDL, SPT, HRP, and SDC. Adding sex to the models for SPT and SDC increased R^2 by .052 and .053, respectively. Adding DL V_{max} to the model for Total increased R^2 by .069. Adding DL $Load_{max\ rel}$ to the model for MDL increased R^2 by .031. DL $P_{max\ rel}$ explained the greatest variance for LTK and 2MR.

Table 16. Stepwise multiple regression results for load-velocity profile metrics and Army Combat Fitness Test total and individual events in the Fall (n = 52)

Test	**R^2 adj**	**SEE**	**Measure**	**R^2**	**β**	***p***
TOTAL(/600)	.670	30.850	DL P_{max}	.613	0.749	<.01
			DL V_{max}	.683	0.265	<.01
MDL (kg)	.664	16.068	DL P_{max}	.646	1.012	<.01
			DL $Load_{max\ rel}$	.677	-0.274	.03
SPT (m)	.665	1.061	DL P_{max}	.627	0.650	<.01
			SEX	.679	0.268	.01
HRP (repetitions)	.303	8.356	DL P_{max}	.317	0.563	<.01
SDC (s)	.509	13.710	DL P_{max}	.475	-0.546	<.01
			SEX	.528	-0.271	.02
LTK (repetitions)	.429	4.503	DL $P_{max\ rel}$	.440	0.663	<.01
2MR (s)	.318	97.339	DL $P_{max\ rel}$	.331	-1.130	<.01

Note: Adjusted R^2 and standard error of the estimate (SEE) are reported for the full model. Independent variables are listed in order of inclusion. Standardized coefficient (β) and significance (*p*) are reported for each independent variable, and R^2 is reported as a cumulative value.

There were no interaction effects for sex * time for LVP metrics: DL V_{max} (F = .38, p = .54, η^2_p = .01), DL $Load_{max}$ (F = .06, p = .81, η^2_p < .01), DL $Load_{max\ rel}$ (F = .11, p = .74, η^2_p < .01), DL P_{max} (F = .10, p = .76, η^2_p < .01), DL $P_{max\ rel}$ (F < .01, p > .99 , η^2_p <.01), and DL $Slope_{LV}$ (F = .25, p = .62, η^2_p = .01). There were significant main effects for sex (see Table 17) but no significant main effects for time (see Table 18).

Table 17. Marginal means for men and women collapsed across time for hex bar deadlift load-velocity profile metrics

Metric	**Men**	**Women**	**Mean Difference ± SE**	***p***	**Cohen's *d***
DL V_{max} (m/s)	1.56 (1.48, 1.64)	1.42 (1.34, 1.49)	-0.14 ± 0.06	.03*	-0.37
DL $Load_{max}$ (kg)	184.65 (169.87, 199.42)	138.25 (123.48, 153.02)	-46.4 ± 11.83	<.01*	-0.63
DL $Load_{max\ rel}$ (kg/kg)	2.38 (2.17, 2.60)	1.97 (1.75, 2.18)	-0.42 ± 0.17	.02*	-0.39
DL P_{max} (W)	693.02 (633.46, 752.58)	481.34 (421.78, 540.89)	-211.68 ± 47.67	<.01*	-0.71
DL $P_{max\ rel}$ (W/kg)	8.96 (8.14, 9.79)	6.82 (5.99, 7.65)	-2.14 ± 0.66	<.01*	-0.52
DL $Slope_{LV}$ (kg·m/s)	-0.009 (-0.010, -0.008)	-0.011 (-0.012, -0.010)	-0.002 ± 0.009	.02*	-0.38

Means are presented as mean (lower limit, upper limit 95% confidence level); *=Significant difference between men (n=33) and women (n=6)

Table 18. Hex bar deadlift load-velocity profile metrics during Fall and Spring (n = 39)

Metric	**Fall**	**Spring**	**Mean Difference ± SE**	***p***	**Cohen's *d***
DL V_{max} (m/s)	1.48 (1.42, 1.54)	1.49 (1.43, 1.55)	-0.01 ± 0.04	.81	0.04
DL $Load_{max}$ (kg)	160.22 (149.17, 171.28)	162.68 (151.62, 173.73)	-2.46 ± 7.08	.73	0.06
DL $Load_{max\ rel}$ (kg/kg)	2.16 (2.00, 2.32)	2.19 (2.03, 2.34)	-0.03 ± 0.10	.80	0.04
DL P_{max} (W)	578.86 (541.03, 616.69)	595.5 (557.67, 633.33)	-16.64 ± 15.41	.29	0.17
DL $P_{max\ rel}$ (W/kg)	7.80 (7.27, 8.33)	7.98 (7.46, 8.51)	-0.18 ± 0.22	.41	0.13
DL $Slope_{LV}$ (kg·m/s)	-0.01 (-0.011, -0.009)	-0.01 (-0.010, -0.009)	-0.002 ± 0.006	.63	0.08

Means are presented as mean (lower limit, upper limit 95% confidence level)

CHAPTER FIVE: DISCUSSION

The main findings from this study are: 1) Body composition and lower body force and power production during ballistic and strength movements had a strong influence on ACFT total and event scores, 2) Among individual events, the MDL, SPT, HRP and SDC favor cadets with more FFM and SMM 3) From the SJ FVP, SJ $\text{Height}_{\text{unloaded}}$ had the greatest predictive capability for total ACFT and all events other than MDL and SDC, 4) From the hex bar DL LVP, DL P_{max} exerted the biggest influence on all events other than the LTK and 2MR, which were best explained by DL $P_{\text{max rel}}$, 5) Significant sex differences exist on ACFT performance, accounting for a significant portion of the variance in MDL, LTK and 2MR.

Army Combat Fitness Test

Cadets improved their performance from Fall to Spring on the ACFT overall and on MDL, HRP, and SDC specifically. The lack of changes on the SPT and LTK are noteworthy. From an observational perspective, this may be due to lack of training in these specific movements, as medicine balls and pull-up bars were used only occasionally with some cadets never using them. The LTK is a hybrid strength/strength-endurance event, such that for someone performing less than ~ five repetitions, particularly those struggling to get one, it is a pure strength test and not in the realm of local muscular endurance. The true muscular endurance test, the HRP, saw significant improvements, as all cadets were fairly proficient to begin with and simply increased their endurance. The decrease in 2MR performance ($\Delta = 17$ seconds; ~ 2%) may be due to environmental factors and differences in the route utilized during testing. Averaged across the three testing days, solar radiation and relative humidity at the time when the

2MR event began were greater in the Spring compared to the Fall (15.3 W/m^2 vs. 9.3 W/m^2; 92.0% vs. 81.6%, respectively) (*WeatherSTEM*, 2021).

All correlations between ACFT events were significant, with SDC demonstrating a very high correlation and 2MR exhibiting a high correlation to the aggregate scores of the other events combined. This may point to the importance of training anaerobic rather than aerobic capacity for the ACFT, and the overall strong inter-relatedness of the events. This finding suggests that the ACFT is similar to the OPAT in this regard. The lone test of aerobic endurance within the OPAT, the interval aerobic run, demonstrated the weakest relationship to the other events (standing long jump, seated power throw, strength deadlift), which were highly correlated to each other (Draicchio et al., 2020). Furthermore, the ACFT contrasts with the APFT, in which all three events were similarly related (Draicchio et al., 2020). The current findings provide quantitative evidence for the ACFT as an improvement over the APFT in terms of ability to measure a wider range of physical attributes, supporting the findings from the BSPRRS (East et al., 2019).

Body Composition

All body composition variables except for BMI showed significant correlations with ACFT performance. This is further evidence of BMI's lack of relevance in predicting ACFT performance (Roberts et al., 2021). Cadet BMI values in the current study (~ 23-25 kg/m^2) were very similar to BMI values (~24-25 kg/m^2) previously recorded for ROTC cadets (Draicchio et al., 2020; Roberts et al., 2021; Steed et al., 2016). For this population, BMI was previously shown to have no relationship with BF% (Steed et al., 2016) or FFMI (Roberts et al., 2021). The authors of the current study agree with Robert and colleagues (2021) that while these BMI values would place the average cadet on the borderline between the normal (18.5 - 24.9) and overweight (25.0 - 29.9) BMI range (Pi-Sunyer, 2000), this measure can be discarded in terms of predicting ACFT performance. This recommendation is further supported if more comprehensive body composition measurements are available, especially considering the relative ease of use and portability of BIA/BIS devices.

Total amount of muscle mass (SMM) had the greatest influence on overall ACFT performance in the current investigation, and either SMM or FFM had the greatest influence on all individual events other than LTK and 2MR. In a previous study, FFM had no relationship with APFT performance, while demonstrating a significant correlation with ACFT performance ($r^2 = .40$), similar to the relationship observed in the current study ($r^2 = .38$) (Roberts et al., 2021). BF% was the primary BC variable included in the LTK regression model, but with the PLANK as an alternative to the LTK in the ACFT 3.0, future research can determine the extent to which BF% influences PLANK performance. Interestingly, BF% was able to explain an additional 6.8% of the variance in total ACFT score after accounting for SMM. As a whole, SMM and BF% accounted for ~ 49% of the variance in ACFT score, revealing the importance of body composition for ACFT performance. FM was a secondary variable in the model for HRP and 2MR. Therefore, optimizing body composition for ACFT performance may require prioritizing muscle mass accretion, while also limiting excess FM accumulation, especially if HRP and/or 2MR performance is a concern.

Velocity Profiles

SJ $\text{Height}_{\text{unloaded}}$ and SJ F_0 demonstrated high correlations with total ACFT score, while FVP metrics of slope and power had moderate correlations. The multiple regression analysis revealed that SJ $\text{Height}_{\text{unloaded}}$ combined with maximal force (SJ F_0) accounted for the greatest variance in ACFT performance overall. In addition, SJ $\text{Height}_{\text{unloaded}}$ was the primary variable included in the model for all events other than MDL and SDC. MDL was most influenced by SJ F_o, which is also indicative of absolute maximal strength. Interestingly, sex demonstrated greater predictive capability than any FVP metric in the SDC model. The SDC also had the second largest sex differences ($d = .97$) out of the six events. Our results indicate that a jump test alone may be as useful or more useful than the FVP method for assessing the influence of lower body power production on ACFT performance in this population. Because the optimal load for power production for the squat jump is typically ~ 0% 1RM, i.e., bodyweight, and jump testing requires minimal equipment, this would be fairly easy to implement (Cormie et al., 2007, 2008, 2010). Recent studies suggest that the FVP may not be a reliable tool for prescribing and monitoring training (Kotani et al., 2021; Valenzuela et al., 2020). More discussion of FVP reliability is provided in the Limitation section below.

The hex bar deadlift LVP parameters offer another glance into monitoring and/or testing velocity in relationship to ACFT performance. DL P_{max} and DL $P_{\text{max rel}}$ had very high correlations with overall ACFT performance, while the individual components of power, DL V_{max} and DL Load_{max} had moderate and high correlations, respectively. The regression model analyses revealed that DL P_{max} accounted for the greatest variance in total score, MDL, SPT, HRP and SDC, while DL $P_{\text{max rel}}$ accounted for the greatest portion of the variance in LTK and 2MR performance. These results mirror the observed relationships between body composition and ACFT performance, as more muscular cadets excelled in the MDL, SPT, HRP, and SDC. For the LTK and 2MR, relative power production may be more important than absolute, and this may be related to the finding that BF% demonstrated the greatest predictive capability for LTK and FM was a secondary variable included in the 2MR model. The hex bar DL LVP may be a useful tool for contextualizing ACFT performance, and additional investigations can assess the utility of LVPs of other resistance training movements in this context.

Sex-Related Differences

Males outperformed females on total ACFT score by 87 and 81 points, on average, in the Fall and Spring, respectively. These results are similar to an early report during the ACFT trial period that, on average, women scored ~ 100 points lower than men (Allen, 2021). Our findings are also similar to data from Phase II of the BSPRRS (East et al., 2019). Male (n=278) and female (n=46) soldiers took the WTBD-ST along with 23 fitness tests to create a new test battery with the highest possible predictive validity for the WTBD-ST. The greatest percentage difference between men and women's individual event performance was on the LTK in the current study (10.24 repetitions vs. 3.22 repetitions, respectively) and on the leg tuck in the BSPRRS (7.99 repetitions vs. 1.33 repetitions, respectively). Adding in the LTK during Phase II of the BSPRRS did not add significant predictive capability to the test battery. Rather, the LTK was added in the stated effort for a balanced and comprehensive test battery (East et al., 2019). An independent review was conducted and provided cause for concern after analysis of the BSPRSS and data from the implementation period from 2019-2020, with the conclusion that including the LTK may produce skewed results (Gillibrand & Blumenthal, 2020; Malek et al., 2020). This is supported by our findings that the LTK was failed disproportionately more often by women compared to men, and that sex demonstrated significant predictive capability in the regression model for LTK. The LTK is in stark contrast to a similar event from the APFT, the sit-up. It has been reported that women have similar sit-up raw scores (Draicchio et al., 2020; East et al., 2019; Thomas et al., 2004; Varley-Campbell et al., 2018) or lesser scores (Dada et al., 2017; Epstein et al., 2015) compared to men, but sex-normalized scores rendered any differences null for the APFT. The LTK, however, seems to be largely affected by sex.

The cadet pass rates we observed with the LTK version of the ACFT (28% for women and 87% for men, averaged across timepoints) were slightly higher than those reported by Roberts et al. (2021) for Army ROTC cadets (9% and 82%, respectively), and similar to early figures reported by the Army (35% and 90%, respectively) (Allen, 2021; Gillibrand & Blumenthal, 2020). When substituting PLANK for LTK, there was a more pronounced increase in pass rate for women (28% to 86%) compared to men (87% to 98%). Our findings support the Army's rationale to implement the plank as a permanent alternative to the LTK, and the proposed sex-normalized tier system (Army, 2021). With the announcement of the ACFT 3.0, which installs the PLANK as a permanent alternative to the LTK, additional investigations can now determine the existence of sex-related differences on the PLANK.

In agreement with a previous study of Army ROTC cadets (Roberts et al., 2021), there were no sex differences in BMI, and BMI was not a predictor of total ACFT performance in the current investigation. The BF% of our current sample of men and women (18% and 24%) is similar to other ROTC studies:, 15 and 26% (Roberts et al., 2021), 20% and 30% (Oliver et al.,

2017) and 15% and 24% (Thomas et al., 2004). Also in line with previous findings of ROTC cadets, men had greater overall body size (HT and BM), SMM, FFM, FFMI, and lower BF% and FMI than women (Oliver et al., 2017; Roberts et al., 2021). These BC measures all had significant correlations with ACFT total score. This is markedly different than the APFT, which was previously found to have no correlation with FFM, FMI, or BF% with ROTC cadets (Roberts et al., 2021; Steed et al., 2016). However, in a prior study, raw scores for pushup and two-mile run, two events which are similar to the HRP and 2MR in the ACFT, were correlated with BF% (Steed et al., 2016). The conversion of raw scores to sex-normalized scores on the APFT was a method to account for sex differences in BF%. The results of the current study support the sex-normalized percentile system of the ACFT 3.0, in the effort to account for sex differences in BC.

The results of the current study suggest that the SPT may be the biggest contributor to women failing the ACFT now that the LTK is voluntary. Of the 7 event failures across both timepoints, five were due to SPT (four women and one man). The SPT demonstrated moderate sex-based differences (*d* = -1.06), the largest of any of the six events. On an investigation of the OPAT (standing long jump, deadlift, seated power throw, and interval aerobic run), the seated power throw exhibited the greatest sex difference by effect size (*d* = 2.28) (Draicchio et al., 2020). The SPT is intended to measure total body power and the seated power throw is a measure of upper body power. Our findings reveal that sex-based differences for the Army population may be greatest on single-effort ballistic tests. Other than the LTK, the SPT also represents the greatest sex differences as reported in the BSPRRS (East et al., 2019). In the regression model in the current study, SMM was the sole BC predictor of SPT performance, accounting for ~ 55% shared variance. Although sex was not included in the model, it is worth nothing that SMM had the greatest sex differences of the BC measures (28% difference, *d* = -1.68). In addition, sex accounted for a significant portion of the variance in SPT in the DL LVP model. Similar to the LTK, cadets did not improve upon their SPT performance from Fall to Spring. There exists a clear need for direct SPT training to remedy this situation to increase the ACFT pass rate for this population.

Training for the Army Combat Fitness Test

The lack of significant changes in velocity profiles and BC measures after two months of training in the current study is in line with a previous study examining changes over nine months of PRT in ROTC freshmen (Oliver et al., 2017). After nine months, there were no changes in freshman ROTC cadets' BM, BF%, VO_2 max, or lower body power assessed with a countermovement jump. Interestingly, there was a greater improvement, although not statistically significant, in jump height for women (11% ± 17%) compared to men (1% ± 5%) (Oliver et al., 2017). While not statistically significant, this may be due to low sample size and these differences may be important for practical applications. The increase in jump height for women could be reflective of increased lower body strength (squat 1RM), which was not increased for men. Two months of training in the current study was insufficient to see differences in the laboratory-based performance variables under consideration, or to determine if there are sex-specific training effects on ACFT performance. In the study by Oliver and colleagues (2017), PRT was conducted similar to PRT in the current study, and included two days of mainly bodyweight circuits, sprints and medium distance runs (2-3 miles), and one day of army-specific activities including ruck marches (Department of the Army, 2012; Oliver et al., 2017). However, there was no controlling for cadets' nutrition or physical activity, including self-directed aerobic training or RT outside of PRT, in the previous or current study. In both cases, PRT was conducted with minimal RT equipment and almost all loading was bodyweight-based, other than ruck marches. However, our results reveal that ACFT score is highly influenced by SMM and maximal lower body force and power production, with absolute values often contributing more than relative values. As progressive increases in intensity are a central tenet of RT program design for strength and power gains (Kraemer & Ratamess, 2004), we agree with previous authors (Kraemer & Szivak, 2012; Oliver et al., 2017; Thomas et al., 2004) that RT should be prioritized during PRT.

With the ACFT 3.0 making the LTK optional, and the strong relationship between SMM and the most commonly failed ACFT event in the current study, the SPT, it may be more important for women to focus on increasing SMM rather than lowering BF% for passing the ACFT. Several of our other key findings highlight the importance of muscle mass and power to the ACFT. The 2MR had the weakest relationship to the other 5 events on the ACFT, SMM and FFM accounted for the greatest variance on all ACFT events other than 2MR, and SJ $\text{Height}_{\text{unloaded}}$ and DL P_{max} had the strongest influence on ACFT score from the velocity profiles.. Based on these findings, the authors recommend that a significant portion of precious PRT time be allocated to strength and power training.

In a landmark study of training methods for women's occupational physical performance in the Army, Kraemer and colleagues assessed the effects of a 6 month periodized program of total body or upper body RT, calisthenics training, and solely aerobic training (Kraemer et al., 2001). When women performed total body or solely upper body RT for six months, they were able to match scores of a control group of men on several endurance-based events: endurance box lift, loaded carry, and push-ups, and score higher than men on sit-ups (Kraemer et al., 2001). In addition, after 6 months of upper body hypertrophy and power training, women matched men's two mile-run times, and both the total body power and total body hypertrophy groups matched men's performance on a barbell squat endurance test. Women performing upper body training improved on a loaded carry test to a greater degree than women performing exclusively aerobic training (Kraemer et al., 1987, 2001). Another study found that as load carried during ruck marches increased, muscle mass rather than aerobic capacity was the biggest influence on relative workload (Lyons et al., 2005). This connection between RT, muscle mass and loaded carries is crucial because a loaded carry is essentially a direct measurement of one of the five constructs of WTBD performance (East et al., 2019). A recent meta-analysis confirmed this finding, showing that men and women had similar hypertrophic and lower body strength responses to the same resistance training program, but women displayed greater upper body strength responses than men (Roberts et al., 2020).

Previous research has shown that sex differences in strength and body composition can be reduced with RT. Although men entering BT had higher MVICs than women at pre and 6-7 weeks post training, both sexes increased MVIC's of all three muscle groups tested, with similar improvements in leg extension (9.7% vs. 12.4%), and greater increases for women for upper torso (4.2 vs. 9.3%) and trunk extension (8.1% vs. 15.9%) (J. J. Knapik et al., 1980). Female: male isometric strength ratios increased from 57, 65, and 66% at pre-training to 60, 67, and 72% at post-training for the upper torso, legs, and trunk extensors (J. J. Knapik et al., 1980). Although

6 months of total body power and hypertrophy training for women could not erase sex differences in maximal absolute strength with a control group of men, training led to a similar 1RM squat relative to FFM as men (Kraemer et al., 2001). When women performed 3 days/week of RT and 2 days/week of running for 14 weeks, they increased box lift 1RM 16-19%, box lift endurance test by 17%, and increased upper and lower body maximal strength (J. J. Knapik, 1997). BM was unchanged but FM was reduced by 9% (18.8 kg to 17.2 kg), FFM increased 6% (48.2 kg to 51 kg), and BF% decreased from 27.6% to 24.9% (J. J. Knapik, 1997). In a direct comparison of men and women, after 6-7 weeks of BT, women (n = 393) had greater percentage increases than men (n = 769) for BM (3.72% vs. 1.13%) and FFM (5.90% vs. 3.04%), and a similar decrease in BF% (1.5% vs. 1.8%) (J. J. Knapik et al., 1980). Six months of total body training for women increased BM more than upper body training and aerobic training groups (Kraemer et al., 2001). Eight weeks of PRT in the current study did not lead to any significant changes in BC measures, with the largest change being a small effect for FFM (d = .21). However, previous research suggests that RT performed for at least 6 weeks can cause significant improvements in the strength and body composition of female soldiers. The effects of different training programs on ACFT performance have yet to be studied.

In the only study to date comparing the ACFT to its predecessor, ACFT performance was significantly correlated (r=.42) with APFT performance for ROTC cadets (Roberts et al., 2021), potentially due to the similar events (pushups and two-mile run). However, a fundamental difference between the approach to training for the ACFT vs. the APFT will be the drive to increase muscle mass, which explains the greatest portion of the variance in ACFT performance, over the desire to reduce BF%. In addition, the regression analyses would indicate that absolute power and force production may be more related to ACFT performance than relative measures. For 30 years military physiologists have suggested that greater absolute strength and power are more important than measures relative to BM for occupational performance, (E. Harman & Frykman, 1992). This phenomenon is supported by an occupational demands study in the British Army, which found that FFM and absolute measures of strength and power were more related to occupational demands than relative strength (Rayson et al., 2000). It has been suggested that muscle mass may be a better predictor of occupational performance than the events of the APFT itself (E. Harman & Frykman, 1992), and that bodyweight-based testing batteries such as the APFT are biased against heavier individuals (Vanderburgh, 2008). The two-mile run event of the APFT was shown to exhibit bias against heavier Army cadets, regardless of the proportion of FFM (Vanderburgh & Mahar, 1995), and negative correlations have been reported for BM and APFT events (E. A. Harman, Gutekunst, Frykman, Sharp, et al., 2008; Vanderburgh & Crowder, 2006). The results of the current study point to a reversal of this bias, and a training emphasis on absolute strength and power, and muscle mass accretion.

Limitations

There are several limitations of this study. One limitation is that raw score for individual PLANK times were not analyzed. In April 2021, the ACFT 3.0 was introduced, with passing times and scores for the PLANK delineated from 2:09 (60 points) to 4:20 (100 points) (United States Army, 2021). However, the ACFT 2.0 was the official test at the time of data collection for this study (November 2020 and March 2021). In the ACFT 2.0, the tester was instructed to stop the cadet performing the PLANK at two minutes for a passing score (60 points). Therefore, we were not able to analyze differences in PLANK performance, as cadets were stopped after hitting the established requirement (two minutes), and then given a passing score of 60. Although ACFT PLANK performance data has not been published to date, a study of the fitness tests used by the Canadian Armed Forces reported that plank performance differentiated top and bottom quintiles for both female and male soldiers (Tingelstad et al., 2016). Future ACFT studies will be able to assess the properties of the PLANK in the context of the ACFT. Another potential limitation is the validity of the timing mat compared to criterion measures. Timing mats demonstrate a strong correlation to the criterion method (force plate), but may overestimate true jump height (McMahon et al., 2016; Whitmer et al., 2015). However, jumps performed on the timing mat produced the same heights as a field-based criterion method (Whitmer et al., 2015), which is the most common field measurement of vertical jump and may be more applicable to the field-based testing and training that the Army performs.

Another important limitation is the absence of accounting for the training and nutrition regimen of the cadets for the period of time (~ 15 weeks) between Fall and Spring testing. After Fall testing in November, cadets left campus and did not perform PT with the battalion for ~ 7 weeks due to Army ROTC and University-wide COVID-19 mandates. Therefore, cadets arrived for Spring PT in January with varying and unknown levels of fitness and BC changes during this break. During the 8 weeks of Spring PT before Spring testing in March, the researchers did not have any PRT compliance records. Thus, these findings are limited to two cross-sectional analyses rather than a true longitudinal study and this may be one of the primary reasons for the overall lack of differences in velocity profiles or BC from Fall to Spring. Participants were not told their individual BC, LVP or FVP results from Fall testing, so it can be assumed that if they did change their personal training or nutrition in the 15 weeks between testing periods, it was not based on this study's results.

The velocity profile analyses require some important caveats. The cadets performed squats (mostly unloaded) and squat jumps (unloaded) throughout the 8-week PT programs before Fall and Spring testing, but anecdotally they had relatively little experience with loaded squat jumps. Due to COVID-19 and consequent time constraints, there was no familiarization testing with the loaded squat jump. Reliability data from our laboratory reported very large or nearly perfect ICCs for FVP metrics, with high CVs (~ 15-16%) for the slope metrics and FV_{imb}, which is calculated partly based on slope. Hex bar DL LVP reliability data from our laboratory revealed near-perfect ICCs and low CVs for all metrics except for DL $Slope_{LV}$ ($ICC_{2,1}$ = .33, CV = 10.50%). Slope seems to be the least reliable velocity metric (Janicijevic et al., 2020, p. 202) , which may be due to the fact that it is sensitive to fluctuations in maximal velocity, maximal force/load, or both simultaneously. Recent reliability studies have reported low ICC's and high CV's for free weight squat jump FVP metrics (Kotani et al., 2021; Valenzuela et al., 2020). The authors suggested that participant strength level in relationship to loads being tested, the use of absolute, relative or BM-based loads, and fatigue may explain the divergent findings in SJ FVP reliability investigations (Kotani et al., 2021). Although basing training on FV_{imb} has reported success (Jiménez-Reyes, Samozino, Brughelli, et al., 2017; Simpson et al., 2020), further research is needed into the reliability of FVPs before basing training prescriptions on them with this population, and for the purpose of ACFT performance.

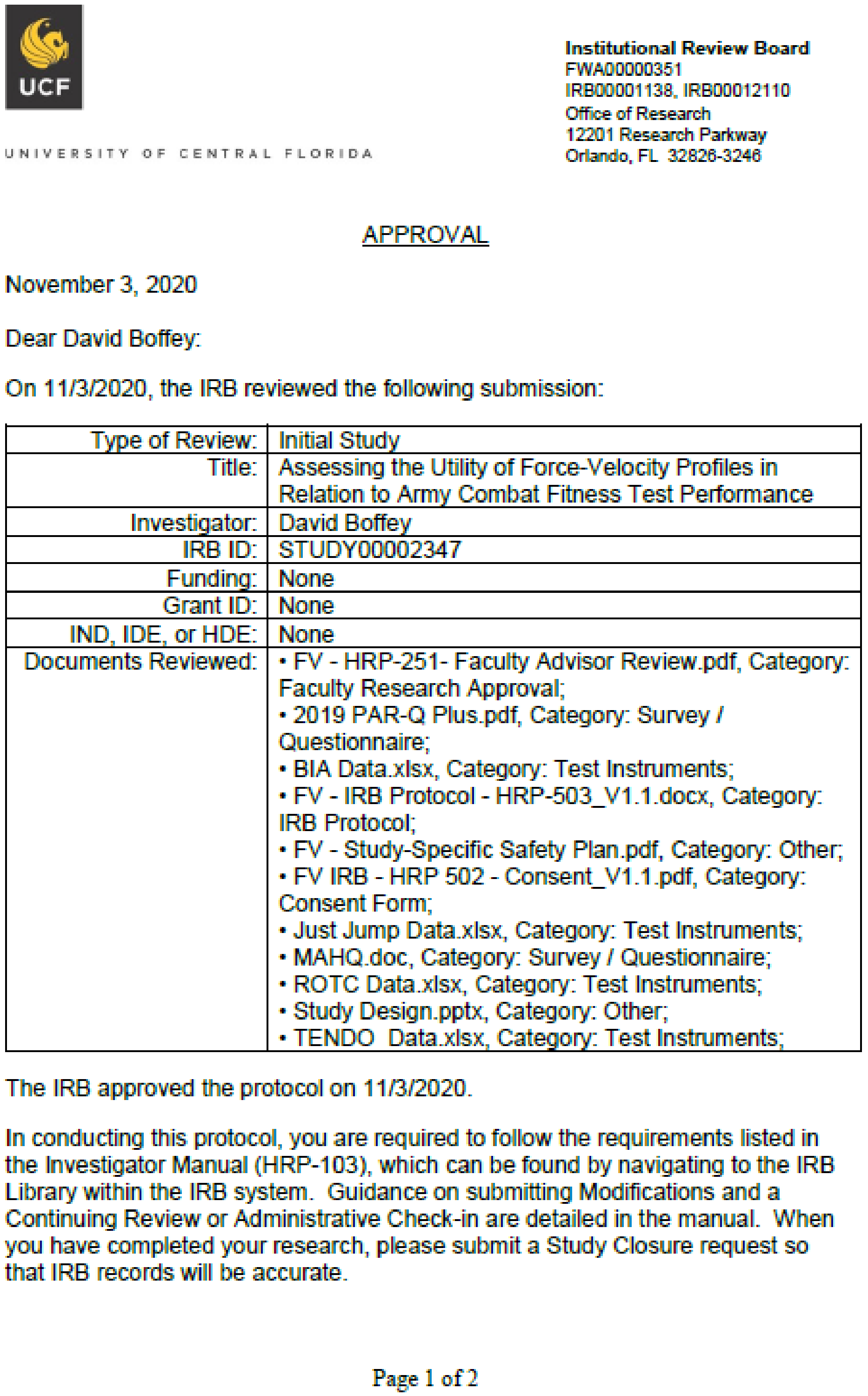
Lastly, the results of this study should be delimited to Army ROTC cadets, who represent the majority of future Army Officers, but do not represent the majority of the Army population.

In addition, for many of the cadets these results represent their first attempts at the ACFT and a learning curve would be expected as the ACFT becomes the mandatory physical fitness test for the Army in 2022. A final limitation is the sample size discrepancy between men and women, but this is ubiquitous in research with the Army population (Dada et al., 2017; Draicchio et al., 2020; East et al., 2019; Foulis, Redmond, et al., 2017; Steed et al., 2016).

Conclusion

Body composition and power production during lower body strength training and ballistic movements may have a strong influence on ACFT total and individual event scores. SJ $\text{Height}_{\text{unloaded}}$ and DL P_{max} displayed the greatest shared variance with total ACFT score and for most of the individual events. In terms of BC, the MDL, SPT, HRP and SDC favor cadets with more muscle mass. The LTK is primarily influenced by BF% and the 2MR is affected by FM. Sex was included in several of the regression models for individual events but not ACFT total score. Sex had greater predictive capability for the 2MR than any BC measure, and for the SDC than any SJ metric. Men outperformed women on all individual events, with notable differences on the SPT and SDC, and had a higher total ACFT score. With the introduction of the ACFT 3.0 in April 2021, the PLANK was established as a substitution for the LTK. If this option remains when the ACFT is implemented in March of 2022, BF% will not exert a primary influence on any of the ACFT events as recorded in the results of this study. In this regard and in consideration of the influence of absolute strength and power production of the lower body, the ACFT represents a major shift in the Army's PT emphases and standards. In addition, the two-mile run on the APFT had more stringent standards than the 2MR, and this could lead to less emphasis on running, which has traditionally stood as a primary component of the Army's physical culture (Kraemer & Szivak, 2012). It is recommended that all Army members taking the ACFT maximize power production and increase SMM through total body resistance training programs.

APPENDIX:
IRB APPROVAL LETTER



UCF
UNIVERSITY OF CENTRAL FLORIDA

Institutional Review Board
FWA00000351
IRB00001138, IRB00012110
Office of Research
12201 Research Parkway
Orlando, FL 32826-3246

APPROVAL

November 3, 2020

Dear David Boffey:

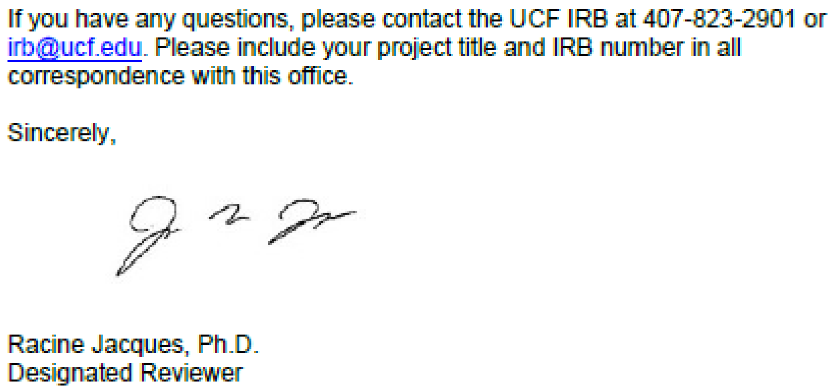
On 11/3/2020, the IRB reviewed the following submission:

Type of Review:	Initial Study
Title:	Assessing the Utility of Force-Velocity Profiles in Relation to Army Combat Fitness Test Performance
Investigator:	David Boffey
IRB ID:	STUDY00002347
Funding:	None
Grant ID:	None
IND, IDE, or HDE:	None
Documents Reviewed:	• FV - HRP-251- Faculty Advisor Review.pdf, Category: Faculty Research Approval; • 2019 PAR-Q Plus.pdf, Category: Survey / Questionnaire; • BIA Data.xlsx, Category: Test Instruments; • FV - IRB Protocol - HRP-503_V1.1.docx, Category: IRB Protocol; • FV - Study-Specific Safety Plan.pdf, Category: Other; • FV IRB - HRP 502 - Consent_V1.1.pdf, Category: Consent Form; • Just Jump Data.xlsx, Category: Test Instruments; • MAHQ.doc, Category: Survey / Questionnaire; • ROTC Data.xlsx, Category: Test Instruments; • Study Design.pptx, Category: Other; • TENDO Data.xlsx, Category: Test Instruments;

The IRB approved the protocol on 11/3/2020.

In conducting this protocol, you are required to follow the requirements listed in the Investigator Manual (HRP-103), which can be found by navigating to the IRB Library within the IRB system. Guidance on submitting Modifications and a Continuing Review or Administrative Check-in are detailed in the manual. When you have completed your research, please submit a Study Closure request so that IRB records will be accurate.

Page 1 of 2



If you have any questions, please contact the UCF IRB at 407-823-2901 or irb@ucf.edu. Please include your project title and IRB number in all correspondence with this office.

Sincerely,

Racine Jacques, Ph.D.
Designated Reviewer

Page 2 of 2

REFERENCES

Allen, N. (2021, March 13). US army halts gender neutral fitness test as women struggle. *NZ Herald*. https://www.nzherald.co.nz/world/us-army-halts-gender-neutral-fitness-test-as-women-struggle/CHFHJA5EYGHHQR4W73QZEHIHXY/

Andersen, V., Fimland, M. S., Mo, D.-A., Iversen, V. M., Vederhus, T., Hellebø, L. R. R., Nordaune, K. I., & Saeterbakken, A. H. (2018). Electromyographic comparison of barbell deadlift, hex bar deadlift, and hip thrust exercises: A cross-over study. *The Journal of Strength & Conditioning Research*, *32*(3), 587–593.

Anderson, M. K., Grier, T., Dada, E. O., Canham-Chervak, M., & Jones, B. H. (2017). The role of gender and physical performance on injuries: An Army study. *American Journal of Preventive Medicine*, *52*(5), e131–e138.

Army. (2021). *ACFT 3.0: Recognizing Performance Excellence*.

Army ROTC. (2021). *Army ROTC*. https://www.goarmy.com/rotc/legacy-and-value.html

Baker, D. (2001). A series of studies on the training of high-intensity muscle power in rugby league football players. *Journal of Strength and Conditioning Research*, *15*(2), 198–209.

Banyard, H. G., Nosaka, K., Sato, K., & Haff, G. G. (2017). Validity of various methods for determining velocity, force, and power in the back squat. *International Journal of Sports Physiology and Performance*, *12*(9), 1170–1176. https://doi.org/10.1123/ijspp.2016-0627

Banyard, H. G., Nosaka, K., Vernon, A. D., & Haff, G. G. (2018). The reliability of individualized load–velocity profiles. *International Journal of Sports Physiology and Performance*, *13*(6), 763–769. https://doi.org/10.1123/ijspp.2017-0610

Behm, D. G., & Sale, D. G. (1993). Intended rather than actual movement velocity determines velocity-specific training response. *Journal of Applied Physiology*, *74*(1), 359–368. https://doi.org/10.1152/jappl.1993.74.1.359

Bosco, C., Belli, A., Astrua, M., Tihanyi, J., Pozzo, R., Kellis, S., Tsarpela, O., Foti, C., Manno, R., & Tranquilli, C. (1995). A dynamometer for evaluation of dynamic muscle work. *European Journal of Applied Physiology and Occupational Physiology*, *70*(5), 379–386.

Bowerman, B. L., & O'Connell, R. T. (1990). *Linear Statistical Models: An Applied Approach* (2nd ed.). Duxbury.

Brown, D. (2021, March 30). Army Combat Fitness Disaster: Units refusing to take test, medics bailing. *Clearance Jobs*. https://news.clearancejobs.com/2021/03/31/army-combat-fitness-disaster-units-refusing-to-take-test-medics-bailing/

Colyer, S. L., Stokes, K. A., Bilzon, J. L. J., Holdcroft, D., & Salo, A. I. T. (2018). Training-related changes in force–power profiles: Implications for the skeleton start. *International Journal of Sports Physiology and Performance*, *13*(4), 412–419. https://doi.org/10.1123/ijspp.2017-0110

Conceição, F., Fernandes, J., Lewis, M., Gonzaléz-Badillo, J. J., & Jimenéz-Reyes, P. (2016). Movement velocity as a measure of exercise intensity in three lower limb exercises. *Journal of Sports Sciences*, *34*(12), 1099–1106.

Cormie, P., McBride, J. M., & McCaulley, G. O. (2008). Power-time, force-time, and velocity-time curve analysis during the jump squat: Impact of load. *Journal of Applied Biomechanics*, *24*(2), 112–120. https://doi.org/10.1123/jab.24.2.112

Cormie, P., Mccaulley, G. O., Triplett, N. T., & Mcbride, J. M. (2007). Optimal loading for maximal power output during lower-body resistance exercises. *Medicine & Science in Sports & Exercise, 39*(2), 340–349. https://doi.org/10.1249/01.mss.0000246993.71599.bf

Cormie, P., Mcguigan, M. R., & Newton, R. U. (2010). Adaptations in athletic performance after ballistic power versus strength training. *Medicine & Science in Sports & Exercise, 42*(8), 1582–1598. https://doi.org/10.1249/MSS.0b013e3181d2013a

Cormie, P., McGuigan, M. R., & Newton, R. U. (2011). Developing maximal neuromuscular power. *Sports Medicine*, *41*(1), 17–38. https://doi.org/10.2165/11537690-000000000-00000

Cronin, J. B., & Hansen, K. T. (2005). Strength and power predictors of sports speed. *Journal of Strength & Conditioning Research*, *19*(2), 349–357.

Cronin, J., & Sleivert, G. (2005). Challenges in understanding the influence of maximal power training on improving athletic performance. *Sports Medicine*, *35*(3), 213–234. https://doi.org/10.2165/00007256-200535030-00003

Dada, E. O., Anderson, M. K., Grier, T., Alemany, J. A., & Jones, B. H. (2017). Sex and age differences in physical performance: A comparison of Army basic training and operational populations. *Journal of Science and Medicine in Sport*, *20*, S68–S73.

Deakin, J. M., Pelot, R., Smith, J. T., & Weber, C. L. (2000). *Development and Validation of Canadian Forces Minimum Physical Fitness Standard (MPFS 2000).*

Department of the Army. (2012). *Army physical readiness training field manual FM 7-22*.

Department of the Army. (2019a). *ACFT IOC - Oct 19-Sep 20*. https://www.army.mil/acft/

Department of the Army. (2019b). *Army ACFT FY 20 Standards*. https://www.army.mil/acft/

Department of the Army. (2020a). *FM 7-22. Holistic Health and Fitness*. https://www.army.mil/acft/

Department of the Army. (2020b). *ATP 7-22.01. Holistic health and fitness testing*. https://www.army.mil/acft/

Department of the Army. (2020c). *ATP 7-22.02. Holistic health and fitness drills and exercises*. https://www.army.mil/acft/

Dorrell, H. F., Moore, J. M., Smith, M. F., & Gee, T. I. (2019). Validity and reliability of a linear positional transducer across commonly practised resistance training exercises. *Journal of Sports Sciences*, *37*(1), 67–73. https://doi.org/10.1080/02640414.2018.1482588

Draicchio, C., Martin, J. R., Fyock-Martin, M. B., & Merrigan, J. J. (2020). Retrospective cohort analysis of the army physical fitness test and the occupational physical assessment test in reserve officer training corps cadets: A brief report. *Military Medicine*, *185*(7/8:e937). https://doi.org/10.1093/milmed/usz489

East, W. B. (2013). *A historical review and analysis of army physical readiness training and assessment:* Defense Technical Information Center. https://doi.org/10.21236/ADA622014

East, W. B., DeGroot, D., & Muraca-Grabowski, S. (2019). *Technical Report: T19.041-13.1. Baseline Soldier Physical Readiness Requirements Study.* Research and Analysis Division, U.S. Army Center for Initial Entry Training, FT Eustis, VA.

Epstein, Y., Fleischmann, C., Yanovich, R., & Heled, Y. (2015). Physiological and medical aspects that put women soldiers at increased risk for overuse injuries. *Journal of Strength* *and Conditioning Research*, *29*(Supplement 11), S107–S110. https://doi.org/10.1519/JSC.0000000000001079

Fahs, C. A., Blumkaitis, J. C., & Rossow, L. M. (2019). Factors related to average concentric velocity of four barbell exercises at various loads. *Journal of Strength and Conditioning Research*, *33*(3), 597–605. https://doi.org/10.1519/JSC.0000000000003043

Field, A. (2014). Regression. In *Discovering Statistics Using IBM SPPS Statistics* (4th ed., p. 325). Sage.

Flegal, K. M., Carroll, M. D., Ogden, C. L., & Curtin, L. R. (2010). Prevalence and trends in obesity among US adults, 1999-2008. *Journal of the American Medial Association*, *303*(3), 235–241.

Foulis, S. A., Redmond, J. E., Frykman, P. N., Warr, B. J., Zambraski, E. J., & Sharp, M. A. (2017). US Army physical demands study: Reliability of simulations of physically demanding tasks performed by Combat Arms soldiers. *The Journal of Strength & Conditioning Research*, *31*(12), 3245–3252.

Foulis, S. A., Sharp, M. A., Redmond, J. E., Frykman, P. N., Warr, B. J., Gebhardt, D. L., Baker, T. A., Canino, M. C., & Zambraski, E. J. (2017). US Army physical demands study: Development of the occupational physical assessment test for combat arms soldiers. *Journal of Science and Medicine in Sport*, *20*, S74–S78.

Garcia-Ramos, A., & Jaric, S. (2018). Two-point method: A quick and fatigue-free procedure for assessment of muscle mechanical capacities and the 1 repetition maximum. *Strength and Conditioning Journal*, *40*(2), 54–66. https://doi.org/10.1519/SSC.0000000000000359

García-Ramos, A., Pestaña-Melero, F. L., Pérez-Castilla, A., Rojas, F. J., & Haff, G. G. (2018). Differences in the load–velocity profile between 4 bench-press variants. *International Journal of Sports Physiology and Performance*, *13*(3), 326–331. https://doi.org/10.1123/ijspp.2017-0158

García-Ramos, A., Ulloa-Díaz, D., Barboza-González, P., Rodríguez-Perea, Á., Martínez-García, D., Quidel-Catrilelbún, M., Guede-Rojas, F., Cuevas-Aburto, J., Janicijevic, D., & Weakley, J. (2019). Assessment of the load-velocity profile in the free-weight prone bench pull exercise through different velocity variables and regression models. *PLOS ONE*, *14*(2), e0212085. https://doi.org/10.1371/journal.pone.0212085

Garnacho-Castaño, M. V., López-Lastra, S., & Maté-Muñoz, J. L. (2015). Reliability and validity assessment of a linear position transducer. *Journal of Sports Science & Medicine*, *14*(1), 128–136.

Gillibrand, K., & Blumenthal, R. (2020). *Letter to US Senate*. https://s3.amazonaws.com/static.militarytimes.com/assets/pdfs/1603297227.pdf

Giroux, C., Rabita, G., Chollet, D., & Guilhem, G. (2016). Optimal balance between force and velocity differs among world-class athletes. *Journal of Applied Biomechanics*, *32*(1), 59–68. https://doi.org/10.1123/jab.2015-0070

González-Badillo, J. J., & Sánchez-Medina, L. (2010). Movement velocity as a measure of loading intensity in resistance training. *International Journal of Sports Medicine*, *31*(05), 347–352. https://doi.org/10.1055/s-0030-1248333

Haff, G. G., & Stone, M. H. (2015). Methods of developing power with special reference to football players. *Strength and Conditioning Journal*, *37*(6), 2–16. https://doi.org/10.1519/SSC.0000000000000153

Harman, E. A., Gutekunst, D. J., Frykman, P. N., Nindl, B. C., Alemany, J. A., Mello, R. P., & Sharp, M. A. (2008). Effects of two different eight-week training programs on military physical performance. *Journal of Strength and Conditioning Research*, *22*(2), 524–534. https://doi.org/10.1519/JSC.0b013e31816347b6

Harman, E. A., Gutekunst, D. J., Frykman, P. N., Sharp, M. A., Nindl, B. C., Alemany, J. A., & Mello, R. P. (2008). Prediction of simulated battlefield physical performance from field-expedient tests. *Military Medicine*, *173*(1), 36–41. https://doi.org/10.7205/milmed.173.1.36

Harman, E., & Frykman, P. (1992). The Relationship of Body Size and Composition to the Performance of Physically Demanding Military Tasks. In *Body composition and physical performance: Applications for the military services* (pp. 105–118). National Academy Press.

Hopkins, W. G., Marshall, S. W., Batterham, A. M., & Hanin, J. (2009). Progressive statistics for studies in sports medicine and exercise science. *Medicine & Science in Sports & Exercise*, *41*(1), 3–13. https://doi.org/10.1249/MSS.0b013e31818cb278

James, L. P., Haff, G. G., Kelly, V. G., & Beckman, E. M. (2016). Towards a determination of the physiological characteristics distinguishing successful mixed martial arts athletes: A systematic review of combat sport literature. *Sports Medicine*, *46*(10), 1525–1551. https://doi.org/10.1007/s40279-016-0493-1

Janicijevic, D., Knezevic, O. M., Mirkov, D. M., Pérez-Castilla, A., Petrovic, M., Samozino, P., & Garcia-Ramos, A. (2020). Assessment of the force-velocity relationship during vertical jumps: Influence of the starting position, analysis procedures and number of loads. *European Journal of Sport Science*, *20*(5), 614–623.

Jaric, S. (2015). Force-velocity relationship of muscles performing multi-joint maximum performance tasks. *International Journal of Sports Medicine*, *36*(09), 699–704. https://doi.org/10.1055/s-0035-1547283

Jetté, M., Kimick, A., & Sidney, K. (1989). Evaluating the occupational physical fitness of Canadian forces infantry personnel. *Military Medicine*, *154*(6), 318–322.

Jidovtseff, B., Harris, N. K., Crielaard, J.-M., & Cronin, J. B. (2011). Using the load-velocity relationship for 1RM prediction. *The Journal of Strength & Conditioning Research*, *25*(1), 267–270. https://doi.org/10.1519/JSC.0b013e3181b62c5f

Jiménez-Reyes, P., Samozino, P., Brughelli, M., & Morin, J.-B. (2017). Effectiveness of an individualized training based on force-velocity profiling during jumping. *Frontiers in Physiology*, *7*. https://doi.org/10.3389/fphys.2016.00677

Jiménez-Reyes, P., Samozino, P., Pareja-Blanco, F., Conceição, F., Cuadrado-Peñafiel, V., González-Badillo, J. J., & Morin, J.-B. (2017). Validity of a simple method for measuring force-velocity-power profile in countermovement jump. *International Journal of Sports Physiology and Performance*, *12*(1), 36–43. https://doi.org/10.1123/IJSPP.2015-0484

Jones, M., Jagim, A., Haff, G., Carr, P., Martin, J., & Oliver, J. (2016). Greater strength drives difference in power between sexes in the conventional deadlift exercise. *Sports*, *4*(3), 43. https://doi.org/10.3390/sports4030043

Jovanović, M., & Flanagan, D. E. P. (2014). Researched applications of velocity-based strength training. *Journal of Australian Strength and Conditioning*, *21*(1), 58–69.

Jukic, I., Garcia-Ramos, A., Malecek, J., Omcirk, D., & Tufano, J. J. (2020). Validity of load-velocity relationship to predict 1 repetition maximum during deadlifts performed with and without lifting straps: The accuracy of six prediction models. *Journal of Strength and Conditioning Research*. https://doi.org/10.1519/JSC.0000000000003596

Kaneko, M., Fuchimoto, T., Toji, H., & Suei, K. (1983). Training effect of different loads on thd force-velocity relationship and mechanical power output in human muscle. *Scandinavian Journal of Sports Science*, *5*(2), 50–55.

Knapik, J. (1989). The Army Physical Fitness Test (APFT): A review of the literature. *Military Medicine*, *154*(6), 326–329.

Knapik, J. J. (1997). The influence of physical fitness training on the manual material handling capability of women. *Applied Ergonomics*, *28*(5–6), 339–345. https://doi.org/10.1016/s0003-6870(97)00004-5

Knapik, J. J., & East, W. B. (2014). History of United States Army physical fitness and physical readiness training. *United States Army Medical Department Journal*, *Apr-Jun*, 5–19.

Knapik, J. J., Wright, J. E., Kowal, D. M., & Vogel, J. A. (1980). The influence of U.S. Army Basic Initial Entry Training on the muscular strength of men and women. *Aviation, Space, and Environmental Medicine*, *51*(10), 1086–1090.

Knapik, J., Reynolds, K., Santee, W. R., & Friedl, K. E. (2012). Load Carriage in Military Operations: A Review of Historical, Physiological, Biomechanical and Medical Aspects.

In *Military Quantitative Physiology: Problems and Concepts in Military Operational Medicine* (pp. 303–337). Office of the Surgeon General and the Borden Institute.

Kotani, Y., Lake, J., Guppy, S. N., Poon, W., Nosaka, K., Hori, N., & Haff, G. G. (2021). Reliability of the squat jump force-velocity and load-velocity profiles. *Journal of Strength and Conditioning Research*, *Publish Ahead of Print*. https://doi.org/10.1519/JSC.0000000000004057

Kraemer, W. J., Mazzetti, S. A., Nindl, B. C., Gotshalk, L. A., Volek, J. S., Bush, J. A., Marx, J. O., Dohi, K., Gomez, A. L., & Miles, M. (2001). Effect of resistance training on women's strength/power and occupational performances. *Medicine & Science in Sports & Exercise*, *33*(6), 1011–1025.

Kraemer, W. J., & Ratamess, N. A. (2004). Fundamentals of Resistance Training: Progression and Exercise Prescription. *Medicine & Science in Sports & Exercise*, *36*(4), 674–688. https://doi.org/10.1249/01.MSS.0000121945.36635.61

Kraemer, W. J., & Szivak, T. K. (2012). Strength training for the warfighter. *The Journal of Strength & Conditioning Research*, *26*(7), S107–S118.

Kraemer, W. J., Vogel, J. A., Patton, J. F., Dziados, J. E., & Reynolds, K. L. (1987). *The effects of various physical training programs on short duration, high intensity load bearing performance and the Army physical fitness test*. Army Research Institute of Environmental Medicine.

Lake, J., Duncan, F., Jackson, M., & Naworynsky, D. (2017). Effect of a hexagonal barbell on the mechanical demand of deadlift performance. *Sports*, *5*(4), 82.

Laubach, L. L. (1976). Comparative muscular strength of men and women: A review of the literature. *Aviation, Space, and Environmental Medicine*, *47*(5), 534–542.

Levernier, G., Samozino, P., & Laffaye, G. (2020). Force–velocity–power profile in high elite boulder, lead, speed climber competitors. *International Journal of Sports Physiology and Performance*.

Liguori, G., & Medicine, A. C. of S. (2021). *ACSM's guidelines for exercise testing and prescription* (11th ed.). Lippincott Williams & Wilkins.

Lloyd, R. S., & Faigenbaum, A. D. (2016). Age- and Sex- Related Differences and Their Implications for Resistance Exercise. In *Essentials of Strength Training and Conditioning* (4th ed., pp. 135–154). Human Kinetics.

Lyons, J., Allsopp, A., & Bilzon, J. (2005). Influences of body composition upon the relative metabolic and cardiovascular demands of load-carriage. *Occupational Medicine*, *55*(5), 380–384. https://doi.org/10.1093/occmed/kqi087

Malek, K. A., Kregel, K. C., Frey-Law, L. A., Evans, L., & Bhatt, R. (2020). *Review Report: Baseline Soldier Physical Readiness Requirements Study*. University of Iowa Virtual Soldier Research Program. https://iti.uiowa.edu/sites/iti.uiowa.edu/files/2021-03/Univ%20of%20Iowa%20Review%20Report%20W911S0-19-C-0005%20Baseline%20Soldier%20Performance%20Readiness%20Requirement%20Study%20(BSPRR)%20Peer%20Review%20Report%201-Apr2020%20v2.pdf

Mann, B. (2016). *Developing Explosive Athletes: Use of Velocity Based Training in Athletes*. Ultimate Athlete Concepts.

McMahon, J. J., Jones, P. A., & Comfort, P. (2016). A correction equation for jump height measured using the just jump system. *International Journal of Sports Physiology and Performance*, *11*(4), 555–557.

Menard, S. (1995). *Applied Logistic Regression Analysis. Sage University Paper Series on Quantitative Applications in the Social Sciences*. Sage.

Merrigan, J. J., Tufano, J. J., Oliver, J. M., White, J. B., Fields, J. B., & Jones, M. T. (2019). Reducing the loss of velocity and power in women athletes via rest redistribution. *International Journal of Sports Physiology and Performance*, *15*(2), 255–261. https://doi.org/10.1123/ijspp.2019-0264

Merrigan, J. J., White, J. B., Hu, Y. E., Stone, J. D., Oliver, J. M., & Jones, M. T. (2018). Differences in elbow extensor muscle characteristics between resistance-trained men and women. *European Journal of Applied Physiology*, *118*(11), 2359–2366. https://doi.org/10.1007/s00421-018-3962-4

Miller, A. E. J., MacDougall, J. D., Tarnopolsky, M. A., & Sale, D. G. (1993). Gender differences in strength and muscle fiber characteristics. *European Journal of Applied Physiology and Occupational Physiology*, *66*(3), 254–262.

Mitter, B., Hölbling, D., Bauer, P., Stöckl, M., Baca, A., & Tschan, H. (2019). Concurrent validity of field-based diagnostic technology monitoring movement velocity in powerlifting exercises. *Journal of Strength and Conditioning Research, Publish Ahead of Print*. https://doi.org/10.1519/JSC.0000000000003143

Morin, J.-B., & Samozino, P. (2016). Interpreting power-force-velocity profiles for individualized and specific training. *International Journal of Sports Physiology and Performance, 11*(2), 267–272. https://doi.org/10.1123/ijspp.2015-0638

Myers, M. (2018). *A new Army PT test is on its way. This is not a drill.* https://www.armytimes.com/news/your-army/2018/07/09/a-new-army-pt-test-is-on-its-way-this-is-not-a-drill/

Neiberg, M. S. (2009). *Making citizen-soldiers: ROTC and the ideology of American military service*. Harvard University Press.

Newton, R. U., Kraemer, W. J., Häkkinen, K., Humphries, B. J., & Murphy, A. J. (1996). Kinematics, kinetics, and muscle activation during explosive upper body movements. *Journal of Applied Biomechanics*, *12*(1), 31–43.

Nindl, B. C., Leone, C. D., Tharion, W. J., Johnson, R. F., Castellani, J. W., Patton, J. F., & Montain, S. J. (2002). Physical performance responses during 72 h of military operational stress. *Medicine & Science in Sports & Exercise*, *34*(11), 1814–1822.

Oliver, J. M., Stone, J. D., Holt, C., Jenke, S. C., Jagim, A. R., & Jones, M. T. (2017). The effect of physical readiness training on Reserve Officers' Training Corps freshmen cadets. *Military Medicine*, *182*(11), e1981–e1986. https://doi.org/10.7205/MILMED-D-17-00079

Pallarés, J. G., Sánchez-Medina, L., Pérez, C. E., De La Cruz-Sánchez, E., & Mora-Rodriguez, R. (2014). Imposing a pause between the eccentric and concentric phases increases the reliability of isoinertial strength assessments. *Journal of Sports Sciences*, *32*(12), 1165–1175. https://doi.org/10.1080/02640414.2014.889844

Pérez-Castilla, A., & García-Ramos, A. (2020). Changes in the load–velocity profile following power- and strength-oriented resistance-training programs. *International Journal of Sports Physiology and Performance, 15*(10), 1460–1466. https://doi.org/10.1123/ijspp.2019-0840

Perez-Castilla, A., Piepoli, A., Delgado-García, G., Garrido-Blanca, G., & García-Ramos, A. (2019). Reliability and concurrent validity of seven commercially available devices for the assessment of movement velocity at different intensities during the bench press: *Journal of Strength and Conditioning Research*, *33*(5), 1258–1265. https://doi.org/10.1519/JSC.0000000000003118

Pierce, J. R., DeGroot, D. W., Grier, T. L., Hauret, K. G., Nindl, B. C., East, W. B., McGurk, M. S., & Jones, B. H. (2017). Body mass index predicts selected physical fitness attributes but is not associated with performance on military relevant tasks in U.S. Army Soldiers. *Journal of Science and Medicine in Sport, 20,* S79–S84. https://doi.org/10.1016/j.jsams.2017.08.021

Pi-Sunyer, F. X. (2000). *The practical guide: Identification, evaluation, and treatment of overweight and obesity in adults*. National Institutes of Health, National Heart, Lung, and Blood Institutes. http://www.nhlbi.nih.gov/ files/docs/guidelines/prctgd_c.pdf

Rahmani, A., Samozino, P., Morin, J.-B., & Morel, B. (2018). A simple method for assessing upper-limb force–velocity profile in bench press. *International Journal of Sports Physiology and Performance*, *13*(2), 200–207. https://doi.org/10.1123/ijspp.2016-0814

Rayson, M., Holliman, D., & Belyavin, A. (2000). Development of physical selection procedures for the British Army. Phase 2: Relationship between physical performance tests and criterion tasks. *Ergonomics*, *43*(1), 73–105.

Reyes-Guzman, C. M., Bray, R. M., Forman-Hoffman, V. L., & Williams, J. (2015). Overweight and obesity trends among active duty military personnel: A 13-year perspective. *American Journal of Preventive Medicine*, *48*(2), 145–153.

Roberts, B. M., Nuckols, G., & Krieger, J. W. (2020). Sex differences in resistance training: A systematic review and meta-analysis. *Journal of Strength and Conditioning Research*, *34*(5), 1448–1460. https://doi.org/10.1519/JSC.0000000000003521

Roberts, B. M., Rushing, K. A., & Plaisance, E. P. (2021). Sex differences in body composition and fitness scores in military reserve officers' training corps cadets. *Military Medicine*, *Published Ahead of Print*, 1–5. https://doi.org/10.1093/milmed/usaa496

Royer, S. D., Thomas, D. T., Winters, J. D., Abt, J. P., Best, S., Poploski, K. M., Zalaiskalns, A., & Lephart, S. M. (2018). Physical, physiological, and dietary comparisons between marine corps forces special operations command critical skills operators and enablers. *Military Medicine*, *183*(11–12), e341–e347.

Ruf, L., Chéry, C., & Taylor, K.-L. (2018). Validity and reliability of the load-velocity relationship to predict the one-repetition maximum in deadlift. *The Journal of Strength & Conditioning Research*, *32*(3), 681–689. https://doi.org/10.1519/JSC.0000000000002369

Ryan, M. (2020, October 20). Senators urge Pentagon to suspend implementation of Army's new fitness test. *The Washington Post*. https://www.washingtonpost.com/nationalsecurity/army-new-fitness-test/2020/10/20/d46660bc-12da-11eb-82af-864652063d61_story.html

Samozino, Edouard, P., Sangnier, S., Brughelli, M., Gimenez, P., & Morin, J.-B. (2014). Force-velocity profile: Imbalance determination and effect on lower limb ballistic performance. *International Journal of Sports Medicine*, *35*(06), 505–510. https://doi.org/10.1055/s-0033-1354382

Samozino, P., Morin, J.-B., Hintzy, F., & Belli, A. (2008). A simple method for measuring force, velocity and power output during squat jump. *Journal of Biomechanics*, *41*(14), 2940–2945. https://doi.org/10.1016/j.jbiomech.2008.07.028

Samozino, P., Rejc, E., Di Prampero, P. E., Belli, A., & Morin, J.-B. (2012). Optimal force–velocity profile in ballistic movement-altius: Citius or fortius. *Medicine & Science in Sports & Exercise*, *44*(2), 313–322. https://doi.org/10.1249/MSS.0b013e31822d757a

Sanchez-Medina, L., & González-Badillo, J. J. (2011). Velocity loss as an indicator of neuromuscular fatigue during resistance training. *Medicine & Science in Sports & Exercise*, *43*(9), 1725–1734. https://doi.org/10.1249/MSS.0b013e318213f880

Sanchez-Medina, L., González-Badillo, J., Pérez, C., & Pallarés, J. (2014). Velocity- and power-load relationships of the bench pull vs. Bench press exercises. *International Journal of Sports Medicine*, *35*(03), 209–216. https://doi.org/10.1055/s-0033-1351252

Sanchez-Medina, L., Perez, C. E., & Gonzalez-Badillo, J. J. (2010). Importance of the propulsive phase in strength assessment. *International Journal of Sports Medicine*, *31*(02), 123–129. https://doi.org/10.1055/s-0029-1242815

Scofield, D. E., & Kardouni, J. R. (2015). The tactical athlete: A product of 21st century strength and conditioning. *Strength & Conditioning Journal*, *37*(4), 2–7. https://doi.org/10.1519/SSC.0000000000000149

Scofield, D. E., Sauers, S. E., Spiering, B. A., Sharp, M. A., & Nindl, B. C. (2017). Evidence-based approach to strength and power training to improve performance in tactical populations. In *NSCA's Essentials of Tactical Strength and Conditioning* (pp. 417–432). Human Kinetics.

Shah, N. R., & Braverman, E. R. (2012). Measuring adiposity in patients: The utility of body mass index (BMI), percent body fat, and leptin. *PloS One*, *7*(4), e33308.

Simpson, A., Waldron, M., Cushion, E., & Tallent, J. (2020). Optimised force-velocity training during pre-season enhances physical performance in professional rugby league players. *Journal of Sports Sciences*, 1–10. https://doi.org/10.1080/02640414.2020.1805850

Steed, C. L., Krull, B. R., Morgan, A. L., Tucker, R. M., & Ludy, M.-J. (2016). Relationship between body fat and physical fitness in Army ROTC cadets. *Military Medicine*, *181*(9), 1007–1012. https://doi.org/10.7205/MILMED-D-15-00425

Stock, M. S., Beck, T. W., DeFreitas, J. M., & Dillon, M. A. (2011). Test–retest reliability of barbell velocity during the free-weight bench-press exercise. *The Journal of Strength & Conditioning Research*, *25*(1), 171. https://doi.org/10.1519/JSC.0b013e318201bdf9

Swinton, P. A., Stewart, A., Agouris, I., Keogh, J. W., & Lloyd, R. (2011). A biomechanical analysis of straight and hexagonal barbell deadlifts using submaximal loads. *The Journal of Strength & Conditioning Research*, *25*(7), 2000–2009. https://doi.org/10.1519/JSC.0b013e3181e73f87

Thomas, D. Q., Lumpp, S. A., Schreiber, J. A., & Keith, J. A. (2004). Physical fitness profile of Army ROTC cadets. *Journal of Strength and Conditioning Research*, *18*(4), 904–907.

Tingelstad, H. C., Theoret, D., Spicovck, M., & Haman, F. (2016). Explaining performance on military tasks in the canadian armed forces: The importance of morphological and physical fitness characteristics. *Military Medicine*, *181*(11), e1623–e1629. https://doi.org/10.7205/MILMED-D-15-00458

Torrejón, A., Balsalobre-Fernández, C., Haff, G. G., & García-Ramos, A. (2019). The load-velocity profile differs more between men and women than between individuals with different strength levels. *Sports Biomechanics*, *18*(3), 245–255. https://doi.org/10.1080/14763141.2018.1433872

Trexler, E. T., Smith-Ryan, A. E., Blue, M. N., Schumacher, R. M., Mayhew, J. L., Mann, J. B., Ivey, P. A., Hirsch, K. R., & Mock, M. G. (2017). Fat-free mass index in NCAA Division I and II collegiate American football players. *Journal of Strength and Conditioning Research*, *31*(10), 2719–2727. https://doi.org/10.1519/JSC.0000000000001737

United States Army. (2021). *ACFT Scoring Standards 3.0*. https://www.army.mil/acft/

U.S. Army Center for Initial Military Training. (2018). *US Army ACFT Field Testing Manual V 1.4*. https://www.army.mil/acft/

Valenzuela, P. L., Sánchez-Martínez, G., Torrontegi, E., Vázquez-Carrión, J., Montalvo, Z., & Haff, G. G. (2020). Should we base training prescription on the force–velocity profile? Exploratory study of its between-day reliability and differences between methods. *International Journal of Sports Physiology and Performance*, *Publish Ahead of Print*, 1–7. https://doi.org/10.1123/ijspp.2020-0308

Vanderburgh, P. M. (2008). Occupational relevance and body mass bias in military physical fitness tests. *Medicine & Science in Sports & Exercise*, *40*(8), 1538–1545. https://doi.org/10.1249/MSS.0b013e31817323ee

Vanderburgh, P. M., & Crowder, T. A. (2006). Body mass penalties in the physical fitness tests of the Army, Air Force, and Navy. *Military Medicine*, *171*(8), 753–756.

Vanderburgh, P. M., & Mahar, M. T. (1995). Scaling of 2-mile run times by body weight and fat-free weight in college-age men. *The Journal of Strength & Conditioning Research*, *9*(2), 67–70.

Vandewalle, H., Peres, G., Heller, J., Panel, J., & Monod, H. (1987). Force-velocity relationship and maximal power on a cycle ergometer. *European Journal of Applied Physiology and Occupational Physiology*, *56*(6), 650–656.

Vandewalle, H., Pérès, G., & Monod, H. (1987). Standard anaerobic exercise tests. *Sports Medicine*, *4*(4), 268–289. https://doi.org/10.2165/00007256-198704040-00004

VanItallie, T. B., Yang, M. U., Heymsfield, S. B., Funk, R. C., & Boileau, R. A. (1990). Height-normalized indices of the body's fat-free mass and fat mass: Potentially useful indicators of nutritional status. *The American Journal of Clinical Nutrition*, *52*(6), 953–959. https://doi.org/10.1093/ajcn/52.6.953

Varley-Campbell, J., Cooper, C., Wilkerson, D., Wardle, S., Greeves, J., & Lorenc, T. (2018). Sex-specific changes in physical performance following military training: A systematic review. *Sports Medicine*, *48*(11), 2623–2640. https://doi.org/10.1007/s40279-018-0983-4

War Department. (1941). *FM 21-20 1941 (OBSOLETE): Basic Field Manual, Physical Training*. US Government Printing Office.

Warr, B. J., Gagnon, P., Scofield, D. E., & Jaenen, S. (2017). Testing and evaluation of tactical populations. In *NSCA's Essentials of Tactical Strength and Conditioning* (pp. 135–155). Human Kinetics.

Weakley, J., Mann, B., Banyard, H., McLaren, S., Scott, T., & Garcia-Ramos, A. (2021). Velocity-based training: From theory to application. *Strength & Conditioning Journal*, *43*(2), 31–49. https://doi.org/10.1519/SSC.0000000000000560

Weakley, J., McLaren, S., Ramirez-Lopez, C., García-Ramos, A., Dalton-Barron, N., Banyard, H., Mann, B., Weaving, D., & Jones, B. (2020). Application of velocity loss thresholds during free-weight resistance training: Responses and reproducibility of perceptual, metabolic, and neuromuscular outcomes. *Journal of Sports Sciences*, *38*(5), 477–485. https://doi.org/10.1080/02640414.2019.1706831

WeatherSTEM. (2021, June 16). WeatherSTEM Portal for Orange County, FL. https://orange.weatherstem.com/data?refer=/ucf

Weir, J. (2005). Quantifying test-retest reliability using the intraclass correlation coefficient and the SEM. *Journal of Strength and Conditioning Research*, *19*(1), 231–240.

Whitmer, T. D., Fry, A. C., Forsythe, C. M., Andre, M. J., Lane, M. T., Hudy, A., & Honnold, D. E. (2015). Accuracy of a vertical jump contact mat for determining jump height and flight time. *Journal of Strength and Conditioning Research*, *29*(4), 877–881. https://doi.org/10.1519/JSC.0000000000000542

Wilkie, D. R. (1950). The relation between force and velocity in human muscle. *The Journal of Physiology*, *110*(3–4), 249–280.

Yamashita, D., Murata, M., & Inaba, Y. (2020). Effect of landing posture on jump height calculated from flight time. *Applied Sciences*, *10*(3). https://doi.org/10.3390/app10030776