IDENTIFYING THE RELATIONSHIPS AMONG FUNCTIONAL MOTOR COMPETENCE, THE ARMY COMBAT FITNESS TEST, AND VERTICAL JUMP PERFORMANCE IN ROTC CADETS.

by

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ABSTRACT

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Under the Supervision of Associate Professor Jennifer Earl-Boehm

Context: Reserve Officers Training Corps (ROTC) cadets are at high risk of injury, which results in high medical costs and affects the longevity of our future soldiers' careers. Functional motor competence (FMC), defined as the coordination and control required to perform a wide range of motor skills, may be an underappreciated aspect of performance and injury in ROTC cadets because of how FMC is developed. Higher FMC has been speculated to be positively associated with better physical and neuromuscular fitness (power, dynamic balance, etc.), better performance on the Army Combat Fitness Test (ACFT), the Army's standardized physical test, and protective biomechanics. However, the evidence to support these relationships in ROTC cadets is limited. The majority of the evidence on FMS is from child populations and not adult tactical athletes. The overall goals of FMC in child populations is very different than that of utilizing FMC in the ROTC. Evidence is needed to support FMC and its relationships to physical and neuromuscular fitness components, physical military readiness, and biomechanics existence in adult ROTC populations to support future investigations utilizing FMC for screening and intervention protocols.

Objective: The first purpose of this study was to determine if power and dynamic balance were predictors of FMC and to determine if the relationship was moderated by previous sport participation. The second purpose of this study was to identify the relationships between performance on the ACFT and FMC composite score. The final purpose of this study was to identify if FMC is related to landing biomechanics.

Participants: 70 (49 males and 21 females) cadets were recruited from the Army ROTC Golden Eagle Battalion (GEB) which consists of 5 schools: Marquette University (Milwaukee, WI) which hosts the GEB, UW-Milwaukee (Milwaukee, WI), UW-Parkside (Kenosha, WI), Milwaukee School of Engineering (MSOE) (Milwaukee, WI), and Concordia University (Mequon, WI).

Procedures: Data collection was scheduled for two-hour sessions across four days which allowed for five flights of cadets (25 cadets total) to get through the protocol. Cadets performed a short warmup then were provided with questionnaires (demographics, previous sport participation since the age of five, and previous military experience) and the data collection sheet on a clipboard. Cadets rotated between five stations which included 1) check in/out & questionnaires 2) standing long jump (distance), 3) ball throw (velocity) and ball kick (velocity), 4) maximal vertical jump (height), and 5) Y-Balance. Station 1 involved describing the study, collecting written consent, providing participant IDs, putting cadets through the warm-up, providing all questionnaires and data collection sheets, and checking out cadets at the end of the collections. Station 2 involved cadets performing a standing long jump for maximal distance. Station 3 involved cadets throwing a tennis ball for maximal velocity at a target on a net followed by kicking an eight-inch diameter playground ball for maximal velocity. Station 4

involved cadets performing a maximal vertical jump in which 2-Dimensional (2D) video and accelerometer data were collected. Station 5 involved cadets performing the modified Y-balance which involved only completing the anterior reach portion of the protocol. The ACFT was conducted over a two-day period involving six events (maximal dead lift, standing power throw, hand release pushup, sprint drag carry, plank, and 2-mile run). ACFT data were collected by Army leaders as per standard protocol. The cadre provided height, weight, and the sex and age adjusted ACFT total and individual event scores to the research team in an excel file.

Main Outcome Measures: FMC composite score was calculated by summing the standardized best attempts of the four tasks in the FMC test battery (long jump distance, ball throw and kick velocity, and vertical jump height). Previous sport participation was collected with a self-report questionnaire and was separated into total number of years participated in sport and total number of sports participated in since the age of five. Reactive strength index (RSI) was calculated by dividing maximal jump height by time to takeoff for the vertical jump task. Dynamic balance was measured using the modified Y-balance utilizing only the anterior reach portion and the right/Left difference (R/L Diff) was used for analyses. ACFT individual event scores and total score were provided by the cadre. 2D sagittal plane angles of the trunk, hip, and knee were identified by importing 2D video into the Dartfish program. Pelvic and tibial acceleration was collected with MyoMotion IMUs to identify jump phases and to collect peak landing acceleration that was then used to calculate peak landing force in N.

Results: When added into the model with sex, RSI explained a significant amount of the variance in FMC composite score (change in R^2=.341; p<.001) whereas dynamic balance did not (change in R^2=.004; p=.382). Previous sport participation did not moderate any of the relationships between the fitness factors and FMC, but previous sport performance did have a non-linear relationship with FMC composite score. Five of the six events had significant correlational relationships with FMC however, SDC was the only event that was included in the model with sex and explained a significant amount of the variance in FMC score (change in R^2 = .210, p < .001). ACFT total score was also a significant predictor of FMC composite score when entered the model with sex, explaining a significant amount of the variance in FMC composite score (change in R^2 = .156, p <.001). Significant correlational relationships were found with all the biomechanical variables however knee flexion angle was the only biomechanical variable included in the final model with sex and accounted for a significant amount of variance in FMC score (change in R^2 = .082, p < .001).

Conclusions: This study identified relationships among physical and neuromuscular fitness factors, sport participation, and FMC which prior to this study were speculative in nature. This study confirmed the relationship between FMC and ACFT total score following the revisions to the ACFT scoring protocol and found significant positive relationships among FMC and the individual ACFT tasks which had never been investigated before. The results of this study provide valuable support for the initial phases of research investigating the relationship between FMC and ACFT in ROTC cadets. The solidification of the relationship between FMC and ACFT supports the future utilization of the easily assessed FMC as a mechanism to understand

how a cadet may perform on the ACFT. Finally, this study investigated how biomechanics were related to FMC which had never been directly compared. These results open avenues for exploration into FMC and its direct relationship with injurious biomechanics. Since FMC is often described as one's ability to move their body through space safely and effectively, there are opportunities to investigate what that truly means within the ROTC population.

To the girl who had the odds stacked against her.
My friends and family who supported me in the background.
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LIST OF ABBREVIATIONS

PMR	Physical Military Readiness
APFT	Army Physical Fitness Test
ACFT	Army Combat Fitness Test
ROTC	Reserve Officers’ Training Corps
MSKI	Musculoskeletal Injury
FMC	Functional Motor Competence
ACL	Anterior Cruciate Ligament
3D	Three-Dimensional
PSPI	Previous Sport Participation Index
RSI	Reactive Strength Index
TAA	Tibial Axial Acceleration
GRF	Ground Reaction Force
H2F	Holistic, Health And Fitness
MSC	Motor Skill Competence
KTK	KörperKoordinationtest für Kinder
M-ABC	Movement Assessment Battery for Children
BOTMP	Bruininks-Oseretsky Test of Motor Proficiency
TG-MD-2	Test Gross Motor Development
CHAMPS	Children’s Activity and Movement in Preschool Study
FMS	Functional Movement Screen
MS	Military Science

BMI	Body Mass Index
GODIN	Godin Leisure-Time Exercise Questionnaire
DVJ	Drop Vertical Jump
VJ	Vertical Jump
CMJ	Countermovement Jump
GCT	Ground Contact Time
SSC	Stretch Shortening Cycle

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Figure 1: Iceberg Effect: Teyhen, D., Bergeron, M. F., Deuster, P., Baumgartner, N., Beutler, A. I., de la Motte, S. J., ... & O'Connor, F. (2014). Consortium for health and military performance and American College of Sports Medicine Summit: utility of functional movement assessment in identifying musculoskeletal injury risk. Current sports medicine reports, 13(1), 52-63. With permission from Wolters Kluwer Health, Inc.

Figure 2: Typical GRF and TAA time histories measured for a single vertical jump and landing: Elvin, N. G., Elvin, A. A., & Arnoczky, S. P. (2007). Correlation between ground reaction force and tibial acceleration in vertical jumping. Journal of applied biomechanics, 23(3), 180-189. With permission from Human Kinetics, Inc.

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Chapter 1: Introduction to The Content Area and Line of Research

Introduction and Specific Aims

Despite the Reserve Officers' Training Corps (ROTC) providing up to 60% of commissioned officers across all military branches, ROTC cadets are experiencing overuse musculoskeletal injury (MSKI) at an alarming 40.1% rate. MSKI is multifactorial in nature and previous research within military personnel has been able to identify many nonmodifiable and modifiable MSKI injury risk factors. [1-6] Only a limited amount of the current epidemiological research surrounding MSKI risk factors in military populations includes ROTC cadets,[1,2] which is the beginning of their military career. Previous MSKI is well supported as a factor that can increase the risk of developing subsequent MSKIs therefore a MSKI sustained during ROTC could be detrimental to the longevity of a cadets' military career. [1,7] Adjustments to the current physical training doctrine have been made as a response to the epidemiological research for military populations,[8] however we are still seeing high rates of MSKI in the military.[9] Physical military readiness is defined as the ability to meet all physical demands of any combat or duty position, accomplish the mission and continue to win.[10] Strong foundational abilities, defined as muscular strength and endurance, power, agility, dynamic balance are critical for physical military readiness while also being free from MSKI.[8,11,12] The Army Combat Fitness Test (ACFT) was designed to assess physical military readiness mainly focusing on the physical and neuromuscular fitness factors and cardiorespiratory endurance required to be combat ready.[8] However, the ACFT is only able to measure physical military readiness in terms of physical fitness and not MSKI injury risk, despite needing to be free from MSKI in order to meet physical military readiness standards. An emerging issue is that cadets who are performing at a high level on the ACFT are displaying movement deficits that have been connected to increased risk of developing MSKI based on preliminary data from our lab. The movement deficits include displaying poor landing biomechanics assessed by the Landing Error Scoring System, which informs about potentially injurious movement patterns during landing.[13] Additionally, cadets have performed poorly on the Y-Balance dynamic balance test which has been connected to increased risk of developing a MSKI.[14] Cadets could still have high performance on the ACFT regardless of their landing biomechanics and dynamic balance. However, unfavorable biomechanics and less control over their dynamic balance could place the cadets in unfavorable positions during these high-level tasks which can increase load throughout the lower extremities increasing their overall MSKI risk. [15-17] Therefore, only assessing physical fitness may not be providing a holistic view for what cadets need from physical training to have high performance with minimal risk of developing an MSKI. There is a gap that is not being addressed by the current training doctrine in that is leaving cadets vulnerable to MSKI. Although it is evident there is a gap represented by cadets not being prepared for the high-performance-level required of being combat ready, there is no information about why the training doctrines are not successful. There is a desperate need to understand what factors could be leading to cadets being underprepared for high level performance and to determine screening methods to allow for early identification of cadets who may require a more focused level of training so they can get the additional training needed to decrease MSKI risk and optimize performance.

The increased need to identify potential factors that could be influencing ROTC performance and MSKI risk have prompted researchers to include additional domains outside of the traditional sports medicine domain. One of which is the motor development domain specifically identifying the role that motor competence has in ROTC populations.[11] Motor competence is a global term defined as the development and performance of human movement with proficiency in fundamental motor skills.[18,19] Motor competence is a precursor for high levels of physical activity and other positive health trajectories across the lifespan.[18,20] Fundamental motor skills include two types of skills, 1) object control (i.e., throwing, kicking, striking) and 2) locomotion (i.e., running, jumping, hopping).[21] Occasionally balance/stability is included in the discussion of fundamental motor skills because balance and stability are needed for functional movements.[21] Fundamental motor skills are required to be able to complete more complex context specific motor skills.[18] Without a strong basis of fundamental motor skills, individuals may not be able to safely perform many complex athletic tasks.[18] Due to the nature of motor competence referring to the proficiency in fundamental motor skills, the majority of motor competence literature is performed on youth populations with limited data for adult populations.[19,22] Therefore, much of the information about motor competence can only be applied to youth populations which is a major gap in the literature.

Motor competence has many different names based on the populations being examined and the domain in which the research is being conducted.[23] Functional motor competence (FMC) is a term that has been used to assess motor competence in ROTC cadets.[11,12] FMC has been previously positively related to the ACFT [11,24] with cadets with higher scores on the FMC test battery displaying higher ACFT total scores.[11] There are many foundational abilities(e.g., muscular strength and endurance, power, etc.,) that are needed to complete the ACFT, and it has been suggested that FMC could be related to these foundational abilities. [12] However, there is no data to support this within ROTC populations. Additionally, there has been speculation that inadequate development of FMC may lead to factors that increase MSKI risk,[12] however data supporting a relationship between FMC and factors that can increase MSKI risk does not exist.

Finally, previous physical activity prior to entering the military is a factor that is related to MSKI with those having lower previous physical activity having increased risk of developing a MSKI.[4,25] Since motor competence is developed through youth physical activity, it is logical to assume an indirect relationship between motor competence and MSKI risk. [18,20,22] Currently there are no standardized methods of collecting information about previous physical activity in the ROTC population. If previous physical activity is related to motor competence, then knowing this information could be useful to support cadets who enter ROTC with less physical activity who may need specific training to improve FMC.

Higher FMC has been connected to higher performance on the ACFT [11] which should be representing multiple foundational abilities, however, there is no direct connection between FMC and the physical and neuromuscular fitness factors typically assessed in the ACFT. Additionally, there is evidence to suggest that high performing cadets may display injurious movement patterns and impaired balance,[26] which contradicts the current data on motor competence since there is evidence that one should have better movement strategies with better motor competence development.[27] Therefore, there is a <u>*critical need*</u> to identify if measuring FMC would fill the gap in the current training doctrine which is resulting in underprepared cadets. Understanding the relationship between physical and neuromuscular fitness factors and FMC in this population, and how biomechanics and ACFT score are related to

FMC is essential before being able to apply FMC screening and training in ROTC cadets. Without such information, ROTC cadets may not be getting the holistic training required to ensure they are reaching physical military readiness which could result in increased rates of drop out due to injury (resulting in less leaders) and high medical costs.

My *long-term goal* is to increase physical military readiness and career longevity of ROTC cadets by decreasing MKSI risk and increasing performance. The *overall objective* of this study is to determine if FMC testing can provide useful information about cadets' motor competence that is related to biomechanics, strength, power, dynamic balance, and ultimately ACFT performance. My *central hypothesis* is that FMC would be related to power, dynamic balance, previous sport participation, biomechanics and the ACFT. This hypothesis has been formulated largely based on the previous research surrounding motor competence and the newest research including FMC in ROTC cadets. My *rationale* for this project is that FMC can be developed through neuromuscular training early in a cadets ROTC career by with exercises supplementing the current physical training doctrine. This study would provide the knowledge of the potential relationships among power, dynamic balance, previous sport participation, biomechanics, and FMC that would set the foundation for future physical training interventions.

The following specific aims were tested in this project:

1. Determine if power and dynamic balance are predictors of FMC and if the relationship is moderated by previous sport participation. My working hypothesis was that power and dynamic balance would predict FMC score with the results identifying that increases in power (identified using RSI) and dynamic balance (identified using Y-Balance) performance would be positively related to increases in FMC composite score when controlling for sex, and previous sport participation (years of sport participation and number of sports participated in since the age of 5).

2. A. Identify the relationships among the individual tasks of the ACFT and FMC composite score. My working hypothesis was that there would be significant relationships among the more complex ACFT tasks (such as sprint drag carry, standing power throw, maximal dead lift) and FMC composite score due to these tasks requiring multiple physical and neuromuscular fitness factors such as power, muscular endurance, and strength. The less complex ACFT tasks (hand release pushup, plank, and 2-mile run) would have weaker relationships to FMC composite score since these tasks may require less fundamental motor skills and foundational abilities.

AND

2. B. Determine the relationship between FMC composite score and ACFT total score. My working hypothesis was that FMC composite score and ACFT total score would relate with increases in FMC composite score being positively related to increases in ACFT total score when controlling for sex.

3. Identify if FMC composite score is related to landing biomechanics (2D sagittal plane joint angles and landing force). My working hypothesis was that 2D sagittal plane joint angles and landing force would be positively related to FMC composite score. Lower FMC score would be related to low amounts of knee, hip, and trunk flexion at maximum knee flexion during landing, and higher peak landing force which are known to be potentially injurious.

Additionally, increased FMC score would be related to greater knee, hip and trunk flexion at maximum knee flexion and lower peak landing force.

Operational Definitions:

a. Power: Reactive Strength Index (jump height divided by time to take off)[28]
b. Total years: sum of years participated in any sport since the age of five.
c. Total sports: sum of number of sports participated in since the age of five.
d. Dynamic balance: Y-balance anterior reach right/left difference normalized to height.[29-31]
e. FMC composite score: sum of the standardized Z-scores for the maximum performance on vertical jump, standing long jump, throw velocity and kick velocity.[11]
f. Biomechanics: 2D angles trunk, hip, and knee flexion at maximum knee flexion.[32,33] Tibial axial acceleration collected with MyoMotion accelerometer, converted to force in Newtons.[34]
g. Fitness factors: The physical and neuromuscular fitness factors including power, muscular endurance, strength, cardiorespiratory fitness, specifically power and dynamic balance in this study.
h. Injury risk: environmental, behavioral, or biologic factors confirmed by longitudinal studies which, if present, increase the probability of an injury or illness occurring, and if absent or removed reduces the probability.[35]

i. Injury rates: calculated using reported injuries by exposure amount or total reported injuries per a certain number of soldiers at a given time (i.e., injuries per 1000 person-years). [4,25,36-42]

Delimitations:

Sex was included as a controlling variable since the ACFT is sex and age adjusted and I want to ensure that the variation from sex and age are held constant while investigating the other independent variables that are not sex adjusted. I did not control for age in my analyses since 82% of cadets were between the ages of 18-21, 15% were between 22-23 years old, and only 1 cadet was greater than 23 years old. This study used a convenience sample of Golden Eagle Battalion ROTC cadets. Biomechanics were collected and analyzed using 2D video analysis and an IMUs placed on the lower shank and low back (accelerometer data) instead of using multiple IMUs or 3D motion capture and force plates. Both joint angles collected with 2D video analysis and tibial acceleration are common surrogates for angular and force data in in-field settings. It is essential when collecting from large groups to be as efficient as possible, for which I believe these methods allowed. This study did not collect direct MSKI risk data and only focused on factors that could be related to MSKI risk, such as landing biomechanics and dynamic balance.

Assumptions:

Cadets in this study were required to self-report previous sport history and it was assumed that they gave their honest recollection of what sports they participated in. Cadets were instructed to give maximal performance during the FMC test battery, it was assumed that cadets put in their maximal effort during the test. It is also assumed that cadre and cadet leaders collected and reported the ACFT data as accurately and honestly as possible to ensure that each cadet was represented as close to their best performance as possible.

Limitations:

I did not control for shoes and clothing other than cadets were instructed to wear their normal clothing and shoes that they would participate in during their physical training and ACFT. This decision was made to try to make the cadets comfortable and ensure consistency across the data collections since cadets typically wear a standardized Army ROTC shirt and shorts when completing the ACFT. Researchers did not collect the ACFT data as it is standard procedure for cadet and cadre leadership to collect this data. The generalizability of the results of this study is limited to uninjured ROTC cadets. I did not directly identify MSKI risk during this study and instead opted to investigate cross sectional factors that may be related to risk such as potentially injurious biomechanics. A relationship between FMC and biomechanics that are related to MSKI risk needs to be established to justify the need for a longitudinal investigation into FMC and MSKI directly since longitudinal studies can be expensive and require a large amount of time.

Background (Literature Review)

History of Army Physical Training and Assessment.

Physical Military Readiness is defined as the ability to meet all physical demands of any combat or duty position, accomplish the mission and continue to win.[10] Physical military readiness includes many physical and neuromuscular fitness factors such as muscular strength and endurance, power, dynamic balance as well as aerobic and anerobic endurance.[10,12] Physical military readiness is the standard that military personnel must meet to ensure they are combat ready and can return home safely from a mission. The Army utilizes physical training doctrines to train Army personnel to meet physical military readiness standards. With the various physical training doctrines that the Army has utilized throughout the years, each one had an associated fitness test to assess if physical military readiness standards were being met. The history of training and assessment of physical military readiness in the Army is long and has been heavily influenced by war and the testing methods occurring in traditional athletic populations throughout the 19th and 20th centuries.

The first recorded fitness test was implemented by First Lieutenant John Kelton in 1858 with cadets from the United States Military Academy.[43] Kelton's test involved many military specific tasks that would, in theory, translate into combat.[43] There was no objective measurement of individualized performance and the pass or fail grading was problematic for training purposes.[43]

1941, the Army published the first field manual (FM 21-20) physical training doctrine outlining the newest standardized testing methods and for training to be based around meeting the standards of each test.[44] Between 1941 and 1973, the FM 21-20 physical training doctrine had released multiple tests to objectively measure physical military readiness with more modern methods.[45] The tests provided in the 1973 FM 21-20 physical training doctrine included 6 events with different scoring requirements based on the test.[45] In 1978 the Army integrated males and females into a single corps which led to the development of a new fitness test of physical military readiness in both males and females, in any environment, and with minimal equipment. The Army Physical Fitness Test (APFT) was based on 1973 FM 21-20 physical training doctrine and was used to measure physical military readiness in the Army from 1980 until 2020.

The APFT included maximal repetition of sit-ups and push-ups in two-minutes followed by a timed two-mile run.[46] Scoring for the APFT was normalized for sex and age, since males and females have different physical abilities as well as soldiers of different ages.[3-5,39,47-49] The APFT focused mainly on capturing cardiorespiratory fitness factors in conjunction with some muscular fitness aspects to identify health related physical fitness measures that influenced physical military readiness requirements.[46] Although both cardiovascular and muscular fitness are important factors in physical military readiness they do not provide enough information to determine if Army personnel are meeting physical military readiness and are combat ready.[46] Despite the APFT having benefits such as ease of testing, the priority of the FM 21-20 physical training doctrine shifted from preparing soldiers for combat to preparing soldiers to pass the APFT.[50]

The FM 21-20 physical training doctrine was misaligned with the needs of combat leading to a decrease in physical military readiness which was evident during the Iraq war.[50] Deployed soldiers were exposed to urban combat, which was significantly different than what their training prepared them for. Urban combat required anaerobic endurance, or the ability to do sudden bursts of high intensity activities repetitively.[51-53] An example of anaerobic endurance tasks that military personnel would be exposed to during urban combat is sprinting to breach a door and clear a building. Other physical and neuromuscular fitness factors such as strength, power, coordination, dynamic balance, and agility were also required for urban combat.[51-53] Many physical and neuromuscular fitness factors needed for urban combat were not addressed with the current physical training doctrine since the focus of the FM 21-20 physical training doctrine had shifted towards passing the APFT.

In conjunction with inadequate training to prepare soldiers for urban combat, soldiers were required to carry greater loads than ever before.[54] It has been estimated that Army soldiers were carrying an average of 119 pounds during combat operations.[55,56] The increase in load was a massive physical burden resulting in higher heart rates, oxygen utilization, and rate of perceived exertion.[51,52,57-60] The combination of a more anaerobically demanding environment leading to musculoskeletal fatigue and the increase in load carriage resulted in decreased ability to complete the mission without injury.[57-59,61-69] Greater loads being carried also altered walking and running biomechanics unfavorably resulting in greater injury rates and limited duty days.[57,70] Research conducted during the time period when soldiers were deployed to Iraq identified postural, gait, and ground reaction force (GRF) changes in soldiers carrying increased loads.[61,70,71] Increases in postural sway[63,64,72,73] and GRF in all directions are well documented with increases in load carriage.[62,65,71,74] Increased fatigue from the physiological burden and the unfavorable biomechanics combine to increase MSKI risk especially during prolonged and high intensity load carriage activities.[59,67,68]

Lower limb musculoskeletal injuries to the knee, ankle, and foot, appear to be the most common site from increased load carried.[70,71] Overuse injuries in military personnel account for up to 82% of reported injuries.[75] A common overuse injury that occurs in military personnel and can be attributed to increased load carriage are lower limb stress fractures.[37,76-81] Although not typically discussed as a part of physical military readiness, being injury free is required to meet all the physical demands of combat. It is well supported that the FM 21-20 physical training doctrine was not able to properly prepare soldiers for the increased physiological and biomechanical strain that came with urban combat which was demonstrated by increased injury rates and limited duty days.[57,70,82]

Implementation of the H2F Doctrine and the ACFT

In 2020, the Army adjusted the goals of the physical training doctrine because of the changes in physical demand from the increased intensity and diversity of urban combat. The Holistic Health and Fitness (H2F) doctrine was implemented in 2020 and is the most recent physical training doctrine focusing on multiple aspects of human performance for tactical athletes. The H2F describes a soldier readiness system that addresses not only physical readiness but also nutritional, mental, sleep and spiritual readiness.[8] The goals of the H2F include: 1.) enhance soldier lethality and readiness, 2.) optimize physical and non-physical performance, 3.) reduce injury rates, 4.) improve rehabilitation after injury, and 5) increase overall effectiveness of the total Army.[8] The H2F physical training doctrine is focused on an interdisciplinary approach to readiness and encourages sports medicine, nutrition, and mental health professionals to be involved throughout military training.[8] Additionally, there has been a large focus on providing educational resources about health and fitness training to Army leaders.[8] The H2F doctrine provides many exercises to aid in physical training and justification for each of the new fitness test events and why they were selected.[8] The H2Fs goals are to address soldiers as individuals rather than as a group and address many of the factors that lead to soldier injury.[8] The new H2F training doctrine needed an assessment that would adequately capture physical military readiness, therefore in 2020 the Army Combat Fitness Test (ACFT) was released to replace the APFT.

Because training has become more holistic to prepare the soldiers for the challenges that come with urban combat, the ACFT also had to evolve to include more aspects of fitness and physical performance. The original ACFT (ACFT-1) measured more than just muscular and cardiorespiratory endurance as the preceding APFT had. The ACFT-1 included 6 events: standing power throw, leg tuck, sprint drag carry, hex bar deadlift, hand release pushups, and a 2-mile run.[46] Each event was chosen to measure multiple physical and neuromuscular fitness factors needed for combat.[8]

The scoring of the ACFT has gone through multiple revisions since being implemented. The scoring for the ACFT-1 did not include sex or age adjusted scoring requiring all soldiers to score at the same minimum level based upon their military occupational specialty.[8] The occupational specialty scoring was based on the rigor of the work duties using a 3-level scoring system: heavy/black, significant/silver, and moderate/gold level.[8] Issues arose with the ACFT-1 with approximately 85% of female military personnel failing the test.[83] The 2nd version of the ACFT (ACFT-2) provided some autonomy to reduce gender disparity in that soldiers could choose to do either the leg tuck event or a 2-minute plank. Additionally, the option to do a timed 2.5-mile walk was added to enable soldiers on profile with running restriction to still participate in the test,[8,46] however, high failure rates for women persisted. Version 3 of the ACFT (ACFT-3) attempted to address the persistent failure rates by implementing a new system to evaluate women's scores which involved identifying tiers to compare their scores to males. The scores were split into 5 relative tiers with platinum being the top 1% of performers for both males and females.[8,83] The ACFT-3 tiered system did not solve the drastic differences in score between males and females, therefore additional changes to the ACFT scoring were made. Finally, the ACFT version 4 (ACFT-4) was released which included the full removal of the leg tuck event, gender-normative scoring, and focusing more on testing for general physical military readiness rather than job specific skills. The current ACFT-4 version uses gender and age adjusted scoring making it the most applicable version of the ACFT.[8,46,83] For the purpose of this study the ACFT-4 was used to as a measure of performance.

To summarize, physical training doctrines and testing methods have gone through many revisions over the past few decades with major improvements in both training and testing. The H2F and ACFT-4 focus more on training the physical and neuromuscular fitness factors that are needed to achieve physical military readiness for the current demands of combat. The ACFT-4 is a rigorous assessment that requires adequate training of the physical and neuromuscular fitness factors to have high performance much different than the previous means of testing. Prior to the ACFT-4 release, training did not include training physical and neuromuscular fitness factors which is a necessity with the ACFT-4.

Entry Routes into the Military

When and how an individual enters military training can influence their readiness for military training, performance and ultimately MSKI risk. There routes to the Army including enlistment out of high school, military academies, university Reserve Officers' Training Corps (ROTC), and Officer Candidate School.[84] To be a commissioned officer you must have a 4-year degree, therefore only those who attend the military academy at West Point, are a part of the ROTC program at a university, or attend Officer Candidate School have access to becoming an officer.[84] West Point is a prestigious 4–5-year program where cadets can get a Bachelor of Science while also receiving intense military training.[84,85] West Point has high expectations when it comes to grade point average, SAT or ACT scores, and physical fitness for entry into the program.[84,85] Because of West Points prestige, entrance rates are low, and they typically only accept approximately 1000 students out of 10,000 applicants.[46] Officer Candidate School is a 12-week program that provides Army officer training to those who already have a bachelor’s degree.[84] Both civilians who have no prior military experience, and soldiers who have military experience or are active duty, can enter Officer Candidate School and utilize their degrees to advance their military rank.[84,86] Officers that graduate from Officer Candidate School who have less military training (such as civilians who have only completed basic training) will be placed in professional fields such as law, medicine, or ministry, whereas those with higher levels of military training (such as enlisted soldiers) will be commissioned to ranks higher than the customary second lieutenant.[84,86] Since West Point acceptance rates are low and Officer Candidate School is only available after receiving a 4 year degree, a more widely accessible option for receiving a 4 year degree and gaining military experience is through the ROTC. The ROTC program occurs at the collegiate level where cadets take courses dedicated to their intended major as well as courses in military science.[87,88] Upon completion of their degree cadets graduate and are commissioned as Second Lieutenant officers, making ROTC the largest commissioning source among all military branches supplying up to 60% of officers.[1,2]

Reserve Officers' Training Corps (ROTC)

Since the ROTC produces up to 60% of commissioned officers,[1,2] it is essential to ensure cadets are adequately prepared for their military careers. The ROTC is typically a 4-year program with each year having different requirements.[87,88] The first and second year are mainly focused on developing the skills needed to be enlisted into the Army including physical fitness and mental endurance.[1] The third-year places a heavy focus on physical fitness and leadership skills. [1] The final year involves administrative work and cadets are typically placed in leadership roles such as supervising the lower-level cadets.[1] Cadets physical military readiness training is grounded in the H2F doctrine, and follows a typical schedule of physical training three days a week with the addition of tactical specific skill training such as ruck marches.[8]

Although not historically discussed as a part of physical military readiness, being injury free is required to meet all the physical demands of combat. Overuse injury rates in ROTC cadets is 40.1%, most occurring to the lower extremities.[2,89] Overuse injuries are injuries that occur due to chronic overload on the tissues which leads to tissue break down over time.[90] An example of a common overuse injury that typically occurs in military populations are stress fractures.[25,37,41,47,91] Although ROTC cadets still suffer from acute injuries to the lower extremities such as anterior cruciate ligament (ACL) injury, overuse injuries appear to occur at higher rates. [2] Previous MSKI is a well-documented MSKI risk factor that can increase the risk of developing subsequent injuries.[1,7,92-96] The importance of high physical performance combined with the alarmingly high MSKI rates in ROTC cadets, has led to emerging research in these areas. However, there is a need for additional study examining physical performance and MSKI risk factors in this population. To ensure future commissioned officers can perform and reach adequate physical military readiness, researchers must first understand and identify ways to screen for MSKI risk factors in ROTC cadets.

Recruitment into the ROTC occurs late in high school or early in the collegiate career because of Army scholarship opportunities to aid students in getting a college degree. A cadet's physical abilities upon entering the ROTC program will influence how they perform on standardized testing, their MSKI risk, and their overall success in the program. Low levels of physical fitness entering military training has been connected to increased risk of MSKI. Previously, children were more active throughout, providing them with adequate physical abilities upon entering the ROTC program. However, this may no longer be the case.

Currently it is estimated that more than 70% of Americans between the ages of 17 and 24 years old may be ineligible for military service due to poor physical health.[97] Only 24% of children and adolescents meet the physical fitness guidelines set by the CDC[98] and only 20-26% of 5–19-year-olds meet the national 60-minute physical activity guidelines.[99] The gradual decrease in physical activity in children[18] is an important factor in the physical abilities of adolescents because motor skill development can only occur through physical activity. Without adequate participation in physical activity throughout youth,[19,20,22,100] cadets may enter the program with low motor skill development, resulting in greater injury risk. [11,12,24] The ROTC recruits heavily from high school aged adolescents but the current physical training does not account for the decrease in physical activity in children. Cadets entering the program may not have the motor skills to perform physical training and military specific tasks safely. The large decline in physical activity in youth could be contributing to low performance during cadet physical training and failure rates on the ACFT.[12]

Previous sport participation throughout youth could facilitate motor skill development that are typically learned during childhood physical activity.[18-20,22,101,102] Therefore, there is a need to understand how previous physical activity and sport participation could affect cadets physical training and injury risk. A decrease in motor skill development could also impact successful performance on the ACFT.[11,12,24] There are currently no standardized methods to screen for previous sport participation nor motor skill deficits in the ROTC. There is a need for the identification of how previous sport participation prior to ROTC enrollment could influence motor skill development, and ultimately performance on the ACFT. To explore these areas, it is necessary to enter the motor development literature to fully understand the development and testing of motor skills in youth.

Functional Motor Competence

Motor competence is an umbrella term that can be referred to with different terminology depending on the discipline, population, and overall objective of the research. Motor competence can generally be defined as the degree to which an individual can perform goal-directed human movement.[103] Motor competence is widely discussed within the motor development literature to encourage youth physical activity, and is directly connected to health and fitness outcomes throughout childhood and into adulthood.[12,18-20,23,101,102] The adequate development of motor competence is related to both acute and long-term health and fitness outcomes such as maintaining a healthy weight status, cardiorespiratory fitness, and musculoskeletal fitness.[12,19,20,23,100-104] The relationships between health and fitness outcomes and motor competence is stronger as age increases.[12,19,20,23,100-104] Children with well-developed motor competence will be more physically active into adulthood compared to those who have less developed motor competence.[18,22] The developed amount of motor competence will be sustained into adulthood, therefore, poor motor competence throughout youth will extend into adulthood if not addressed.[18,22] Poorly developed motor competence is directly related to negative health implications, therefore it is essential to develop adequate motor competence. Most of our knowledge about motor competence is from children and often neglects adults and highly active individuals despite the direct relationship between youth motor competence and adult motor competence.

Children develop motor competence through diverse physical activity experiences.[12,18-20,23,101,102] In early childhood (before the age of 7), children are learning fundamental skills, which are the building blocks for more advanced movement. Fundamental motor skills involve locomotion and object control.[27] Locomotive skills involve moving the body through space such as jumping, hopping, galloping, skipping, and running.[27] Object control involves manipulating and projecting objects such as catching, throwing, kicking, and striking.[27] Additionally, postural control is another aspect in fundamental motor skill development, which is necessary to perform many advanced tasks safely.[27]

Motor competence can also be described as the ability to perform the fundamental motor skills and is a precursor to context specific motor skills.[19,20,22,100,105] Context specific motor skills are a combination of multiple fundamental motor skills that are developed through more specific activity .[27,106] For example, if a child only participates in baseball after the age of 7, they will develop context specific skills surrounding baseball, such as running, sliding, hitting, and catching a ball. However, context specific skills will only develop based on the activity participated in. Therefore, if a child only participates in one sport they will only develop context specific skills associated with that sport and they may be lacking other needed skills. Context specific skills will suffer without a solid fundamental motor skill base resulting in an inability to perform context specific motor skills safely without adequate motor competence development.

Assessment of Motor Competence

Assessment of motor competence in children is grounded in both a product-oriented perspective and a process-oriented perspective.[107,108] Product-oriented perspective evaluates the outcome of a skill. An example of a product-oriented test is measuring the throwing speed of a ball over five trials, taking the highest speed for scoring. Process-oriented perspective measures how the skill is performed. An example of a process-oriented test includes measuring coordination patterns of individual components of skills. Typically, measuring the coordination patterns will require a rubric or 2-dimensional video analysis. Both process- and product-oriented test batteries exist to test for motor competence, but they are typically not tested together. There are more product-oriented test batteries than there are process oriented test batteries, potentially because product-oriented methods do not require as much training to execute nor do they require additional time for data analysis.

Although a product-oriented perspective has its benefits, one limitation is that it does not provide information about the processes behind the performance. Product-oriented measurements may stay the same, even if the process of the skill has changed thereby missing valuable performance information.[23] For example, a baseball pitcher may maintain the same throwing speed but due to maturation and growth may be throwing in a less biomechanically efficient way, that could potentially lead to MSKI. Using product-oriented measurement techniques would not catch this biomechanical change, but a process measurement such as evaluating the 2D-video of the player throwing would. Determining which testing method will work best for a study will depend heavily on the research question being asked.[23,109] Using both process and product-oriented to measure motor competence is highly recommended however, it is typically not done because process-oriented testing is time consuming to collect and expensive and therefore most protocols will opt for product-oriented testing methods.[23] There is also a lack of concise and consistent terminology with many test batteries claiming they are measuring different components of motor competence with the same tasks.[23] There is a need for additional research to identify ways to connect both process- and product-oriented testing methods and to understand how each portion of testing contributes to motor competence across the lifespan.[23]

In children there are many motor competence test batteries that can be used to assess FMC development. Examples of product-oriented test batteries include KörperKoordinationtest für Kinder (KTK),[110] Movement Assessment Battery for Children (M-ABC),[111] and the Bruininks-Oseretsky Test of Motor Proficiency (BOTMP).[112] The KTK consists of four subtests that measure gross motor coordination and include: walking backwards on a balance beam, moving sideways on boxes, hoping for height, and jumping sideways with both feet together.[110,113] The KTK can be used on children and adolescents (5-15) to assess FMC.[110,113] The M-ABC is a test that measures both gross motor coordination and fine motor skills.[111,113] There are three age groups for the M-ABC (3-6 years old, 7-10 years old, and 11-16 years old) with normative data for each group.[111,113] The BOTMP is typically used to identify movement disorders in children and young adults.[112,113] The KTK, M-ABC, and the BOTMP are consistently utilized in child populations but not regularly in adults nor individuals with high physical activity levels.[113]

Examples of process-oriented test batteries include the Test Gross Motor Development (TGMD-2),[114] and Children's Activity and Movement in Preschool Study (CHAMPS) Motor Skills Protocol.[115] The TGMD-2 measures gross movement performance based on qualitative aspects of movement skills using multiple tasks to test both locomotion and object control skills.[114] The TGMD-2 uses a rubric based scoring system with criteria to inform whether a child performing the task "correctly".[114] Like the TGMD-2, the CHAMPS assesses locomotion and object control skills using a rubric.[115] There are five to six movement characteristics that each participant must do to be considered competent at the skill.[115] Both the TGMD-2 and the CHAMPS test batteries require training and are extensive in nature and are recommended for children under 10 years old, making them unsuitable for adults.

Functional Motor Competence and Physical Military Readiness

Recently researchers have begun exploring motor competence in the ROTC population and defined it as Functional motor competence (FMC). Instead of focusing on how motor competence is related to baseline physical activity to promote long term health and wellness, FMC relates motor competence to military performance. Silvey and colleagues[12] defined FMC as the coordination and control required to perform a wide range of motor skills.[12] Although FMC is defined in a similar way to other definitions used in the motor competence literature, the population specific context is different between FMC and motor competence. Motor competence is used to promote long term health and fitness outcomes to increase childhood physical activity,[18-20,22,100-102] whereas FMC is focused on sport performance, specifically in tactical athletes.[18-20,22,100-102]

Traditional FMC skills are categorized as plyometric movements and can be found in many sport contexts.[12,23,24] FMC skills include locomotive skills (jumping, hopping, skipping, running) and object projection skills (catching, throwing, kicking and hitting) [23,27] which are required for advanced unilateral and bilateral tasks required of combat.[12] FMC development throughout youth is essential for cadets to meet physical military readiness. There is data to suggest that a direct relationship between FMC and the physical and neuromuscular fitness factors found in the H2F doctrine such as strength, power, agility, and functional movement exists.[11,24] The ACFT requires a high level of the above physical and neuromuscular fitness factors along with neuromuscular coordination to be able to perform the events successfully and safely. Testing the hypothesis that FMC is related to performance on the ACFT (which requires a high level of foundational ability) Terlizzi and colleagues[11] found a relationship between FMC level (FMC composite score split into tertials) and ROTC cadet performance on the ACFT-1. Cadets with lower FMC levels had lower scores on the ACFT compared to cadets with higher FMC levels. A limitation of this study is that it was conducted using with ACFT-1 which did not account for age and sex in the scoring. Since the ACFT is a measure of physical military readiness, having low FMC is a major obstacle to achieving physical military readiness. Cadets need a solid basis of FMC to protect them from MSKI and reach adequate physical military readiness.

Since FMC is directly and indirectly related to the development of required skills to meet physical military readiness standards, failure to develop adequate FMC early on in life can detrimentally impact future physical military readiness in military populations. Physical military readiness is currently threatened by the gradual decrease in youth physical activity.[12,18] Currently only 24% of children and adolescents meet the physical fitness guidelines set by the CDC[98] and only 20-26% of 5–19-year-olds meet the national 60-minute physical activity guidelines.[99] Low levels of FMC is related to negative long term health and fitness outcomes.[18,20,22,102] FMC requires years of structured diverse physical activity experiences to develop, emphasizing the importance of youth FMC development. As addressed previously, a solid fundamental motor skill foundation is required to be able to perform complex context specific movements to meet physical military readiness requirements.[11,12,19,22,23,100-103] Currently, it is assumed that cadets entering military training have adequate FMC, therefore it is not integrated into military training,. This expectation may be unrealistic today due to the severe decrease in youth physical activity levels and thus decreased opportunity to develop FMC.[24] Although the most effective time period to develop FMC is during early childhood, FMC can be developed later in life.[12] If deficits in FMC were identified in ROTC cadets through a screening test, physical training could be adjusted to focus on training for general fundamental skill development before complex context-specific skills with the overall goal of improving FMC. The new knowledge of the baseline state of FMC in ROTC cadets could have a major impact on future modifications of ROTC training.

Assessment of FMC in the Military

FMC has been tested in ROTC cadets in two studies.[11,12,24] Both studies investigated FMC and its relationship to ACFT performance(total score) using product-oriented test batteries designed based on various other motor competence tests used in child populations.[24,11] Terlizzi and colleagues[11] used an eight-item test battery that included: standing long jump distance, vertical jump height, hopping speed, throwing velocity, kicking velocity, throw-catch total count, walking backwards on balance beams total steps, and supine-to-stand time. Terlizzi and colleagues[11] found that only standing long jump (r=0.769), vertical jump (r=0.756) and throwing speed (r=0.682) had strong positive relationship to ACFT total score, meaning that as performance on the standing long jump, vertical jump, and throw increased so did ACFT total score. Silvey and colleagues[24](unpublished dissertation) used an eleven-item test battery that included: vertical jump, standing long jump, hopping, shuttle sprint, lateral jumps, kicking and throwing, throw and catch, supine to stand, moving sideways on blocks, balance beams. Similarly, Silvey and colleagues[24] found the vertical jump (r=0.868), standing long jump (r=0.811), kicking (r=0.716) and throwing (r=.705) tasks had a strong positive relationships to ACFT performance. Meaning that as performance on the standing long jump, vertical jump, kick, and throw increased so did ACFT total score. These two studies[24,11] provide evidence that FMC is likely related to ACFT-1 performance in ROTC cadets. However, the ACFT has gone through major scoring revisions specifically by accounting for age and sex since the completion of these two studies. Therefore, it is necessary to investigate the relationship between the current ACFT-4 and FMC. Additionally, only ACFT total score was analyzed even though the ACFT is composed of multiple events with differing levels of complexity.

It is logical to assume that the events that require more foundational abilities, such as the sprint drag carry and standing power throw, would require greater FMC compared to the events that do not require many foundational abilities, such as the plank and 2-mile run. However, testing this proposed relationship has not been done. Without understanding how

FMC and individual event performance is related, we may not be getting an accurate representation of the relationship between FMC and the ACFT. FMC includes many physical and neuromuscular fitness factors that are required to complete the ACFT safely and effectively. An FMC test battery could help to screen cadets to identify who may need additional neuromuscular training to increase their FMC to increase performance and prevent MSKI. This impact of this type of screening could be helpful for the military because researchers and cadre could use one test to identify multiple aspects related to MSKI and performance. Being able to identify cadets who may need additional training early can The adaptation of motor competence towards sport performance in tactical athletes opens a whole new chapter for the motor learning domain to support research questions surrounding physical performance and MSKI prevention in the military.

Screening tests for several aspects of performance has become common in the sport and military populations including gait analysis,[62,65,73,116] Functional Movement Screens,[117,118] and Y-balance tests[14,119]. However, these do not specifically measure all aspects of FMC (locomotion and object control) but rather only certain pieces. Gait analyses are also a measure of movement quality, not necessarily the outcome of a skill or the ability to complete the skill successfully. Functional movement screens evaluate the way a person completes tasks (process oriented) but again it is not measuring the specific aspects of FMC. Y-balance is a measure of dynamic balance and would be more of a product outcome but again since it is only measuring balance it cannot be considered a test of FMC. Adding a screening test for FMC that can be easily implemented and standardized is needed in order to be able to evaluate FMC in the ROTC cadet population. Additionally, providing evidence that an FMC test battery can measure the

FMC encompassing factors, such as foundational abilities, is needed to ensure that the FMC test battery is specific and accurately measuring FMC.

MSKI in the Military

Epidemiology

MSKI in Army personnel is a major issue threatening physical military readiness in active-duty soldiers. Currently, the incidence of MSKI reported by the Department of Defense is upwards of 2 million resulting in approximately 2.4 million medical visits, $548 million in direct patient costs, 25 million limited duty days, and approximately 1 million service members affected annully.[9,37,75] Army active duty soldiers reported 653,051 injuries in 2021 with 96% of the injuries being MSKI.[9] Of the 627,765 MSKI reported 76% of the injuries were insidious onset in nature.[9] Physical training and sport-related account for up to 90% of musculoskeletal injuries in general military populations.[25,120] A recent study investigating MSKI in 5 ROTC battalions identified similar injury rates in ROTC cadets as seen in active duty soldiers.[2] Approximately 45% of injuries in ROTC cadets occur due to physical training, with 40.1% of injuries being of insidious onset.[2] Physical training must prepare cadets to meet the needs of combat once they are commissioned. High MSKI injury rates during physical training in the ROTC period is a major threat to physical military readiness of the largest source of commissioned officers. Previous injury is a major contributor to subsequent injury within the military,[1,93] therefore the long-term goal of decreasing MSKI in ROTC cadets is essential to improve the longevity of their careers, decrease risk of future injury, and achieve physical military readiness.

Injury Risk Factors in Military Populations

Before introducing changes to physical training methods to decrease overall injury risk, it is essential to understand what factors can increase MSKI risk. Many MSKI risk factors have been identified in military populations with some being non-modifiable (age and sex) and other being modifiable (physical fitness, previous physical activity level, biomechanics, and physical and neuromuscular fitness factors such as dynamic balance). It is essential to understand the baseline MSKI risk that a population may be expressing therefore there is a need to identify both non-modifiable and modifiable risk factors.

Non-Modifiable MSKI Risk Factors

Age: Researchers have identified that age creates an inverted U shape MSKI risk curve in military populations.[4,36] Indicating that younger military personnel (<24) and older military personnel (>30) have the highest risk of developing an injury. Younger soldiers may be at greater risk due to inexperience of military tasks and they may be entering the program with low physical fitness.[1] After the age of 24 the risk of developing a MSKI increases to up to 80% in military populations.[36,39] In general muscle mass and the speed at which the muscles can shorten, producing force, declines with age.[121] Decrease in muscle fibers and decreased capillary density reducing blood flow occurs with increased age.[121] Less muscle mass and a decreased ability to produce force rapidly results in decreased power production.[121] Muscular endurance has also been noted to decrease with age, which plays a large role in functional loss which may be related to the lack of muscle fibers and lack of adequate blood flow.[121] The effects of aging on the musculoskeletal system may be responsible for the increased MSKI risk in trainees entering at an increased age. A clear difference in MSKI risk and development exists between trainees and active-duty soldiers.[92] Military trainees are all required to do the same physical training regardless of demographics.[122] Older active-duty soldiers will typically be placed in higher ranked positions such as supervisory positions which may decrease their exposure when compared to their younger counterparts.[25,39] It should be noted that the differences discussed within this section are between young and older adults, with a wide age gap. When looking at the ROTC population, cadets typically are between the ages of 18 and 21, which are in the lower MSKI risk category for age.

Sex: Female military personnel have a 1.5 to 2.0 times increased rate of MSKI when compared to their male counterparts.[3,123] Female Army Trainees reported more lower extremity injuries (45%) than males (21%).[6] Stress fractures are 4.6 times more common in females than males.[6] There are physical differences between males and females that could be contributing to MSKI risk. Decreased cardiac output, lower blood volume, less hemoglobin, and lower VO2max leads to increased intensity when doing the same tasks as males.[124] The military requires males and females to participate at the same intensity during training and testing (there no sex adjusted training or testing to decrease intensity), placing females at greater risk of lower extremity injury.[10,125] Anatomically females have a wider pelvis base which increases the angle of the femur when bringing the knees towards the midline, decreasing mechanical efficiency. [47,124] Increased intensity due to smaller stature, less type II muscle fibers, lower cardiac output and blood flow, and biomechanical differences appear to be the main differences between males and females and may contribute to the increase MSKI risk seen in females.[25,39,126] When comparing males and females of similar cardiorespiratory fitness levels, MSKI risk appears to be more even.[92] Even though there are anatomical and biomechanical differences between males and females, MSKI is multifactorial in nature and clearly needs to be investigated in that nature.

Although sex and age are non-modifiable MSKI risk factors, they need to be accounted for when exploring performance, injury risk, and when creating interventions. Without identifying these non-modifiable MSKI risk factors researchers and clinicians cannot make holistic interventions or changes to the current physical training plans. Researchers must understand what level of baseline risk a cadet in entering the has before making any changes.

Modifiable MSKI Risk Factors

Physical Fitness: Body Mass Index (BMI) is defined as a statistical index using a individual's weight and height to gain an estimate of their body fat and is calculated by the following equation bodyweight/height^2.[92,127] The number that is calculated from this equation is one's BMI number and categories have been created based on the general population to identify if an individual is underweight (<18.5 kg/m^2)m, normal weight (18.5-24.9 kg/m^2), overweight (25-29.9 kg/m^2), and obese (>30 kg/m^2).[127] BMI can be useful to estimate the relative proportion of fat mass to lean mass in most populations, but it can also be difficult to interpret for active populations.[127] Since BMI uses weight and height, some body types can be inaccurately categorized.[127] Those who are high in muscle mass typically will have greater weight compared to others of the same height.[127] Therefore, more muscular individuals may have higher BMIs despite the ratio of lean mass to fat mass being higher than others of the same height.[127] So, although BMI is good to quickly identify if someone is overweight or underweight, it may need to be interpreted with caution or used with additional assessment methods with active populations.[127]

Like age, BMI has a bimodal MSKI risk curve where low BMI and high BMI are at the greatest risk for injury.[39] Measuring BMI is common in military populations in an attempt to gather information about variations in body type in relation to performance and injury.[92] BMI can provide some information about adiposity.[92] A high BMI may be indicative of greater load being placed on the body during physical activity which increases MSKI risk.[128] A low BMI may indicate that the cadet does not have the lean body mass to support the demanding needs that come with military training.[6,39] Females with lower BMI are also prone to amenorrhea which predisposes them to osteoporosis and rigidity of collagen therefore increasing the risk of MSKI by.[6,39] Although several studies have found that there is a relationship between BMI and MSKI risk,[4,39,92,128] there are also many studies that were unable to connect BMI to MSKI risk.[3,36] It is possible that there are other MSKI risk factors that are not being measured when solely measuring BMI such as low physical fitness level or previous injury.[4]

Low levels of physical fitness, specifically cardiorespiratory fitness and muscular endurance, are the most documented MSKI risk factors for US Army populations.[4,5,39,128] Physical fitness is typically measured using the APFT[1,4,82] or ACFT,[16] but sometimes is measured using other health and fitness measurements such as VO2max.[129,130] Low muscular endurance is an inconsistently documented MSKI risk factor in military populations with findings suggesting that individuals that perform a larger number of pushups and sit ups in 2 minutes may have decreased musculoskeletal MSKI risk. [3-5,39,128] Males and females with slower run times have increased risk of MSKI .[5,39] Those with lower levels of physical fitness on entry will have higher levels of physiological strain when compared to those who are more physically fit.[51,52,58] Less physically fit individuals will be more likely to become fatigued which could alter their biomechanics unfavorably.[57,58] Unfavorable biomechanics such as an increase of the ground reaction force (GRF) or abnormal joint motion can place higher loads on the tissues, leading to increased rates of lower limb stress fractures in military populations. [76-81] It appears that the most consistent evidence supports that physical fitness and a major increase in stress placed on the tissues due to a rapid increase in physical activity contributes to increased MSKI risk.[131-134] Although low physical fitness is supported as an MSKI risk factor, MSKI may actually be occurring from unfavorable biomechanics such as increased GRF and abnormal joint motion that is a result of fatigue.

Previous and Current Physical Activity Leve: Decreased physical activity prior to military service, which we will refer to as previous physical activity, is a risk factor for MSKI.[4,130] Previous physical activity throughout youth is a precursor to the development of adequate FMC.[12,19,20,22,100] It has been suggested that a lack of physical fitness throughout childhood could be contributing to low physical fitness in young adulthood because low youth physical fitness is related to low motor skill competence, which is related to low physical fitness in adulthood.[18,20,22] Since ROTC cadets are entering the program as young adults, lower levels of previous physical activity could be resulting in ROTC cadets entering the program with low physical fitness which has been discussed above as a risk factor for MSKI.

Currently, previous physical activity is measured through self-reported surveys,[1,26,130] however, some studies have used current physical activity and fitness levels to retrospectively assume previous physical activity. A simple self-report method of measuring current physical activity is Godin Leisure-Time Exercise Questionnaire (GODIN) [125,135], and the Army typically uses ACFT to measure current physical fitness. [4,25] An issue about using current physical activity as a means of assuming previous physical activity throughout childhood is that we may be missing out on valuable information about the volume and types of activity performed throughout childhood. For example, without understanding how much, and what types of physical activity a cadet participated in, we may assume that those who have high physical fitness entering the ROTC program would have lower risk of MSKI. However, if the cadet only recently started exercising prior to entering the ROTC program they may not have developed adequate FMC and could have potentially injurious biomechanics as discussed with the modified iceberg diagram. A recent study[26] indicated that approximately 77% of cadets had at least 1 year of high school sport experience, despite this approximately 80% of cadets in the sample were considered high risk for MSKI based on their landing biomechanics and approximately 70% were at high risk based on their dynamic balance.[26] By only measuring recent previous physical activity researchers may be missing valuable information about a cadets physical activity experience. Identification of previous physical activity throughout youth and adolescence may provide a better understanding of cadets' injury risk instead of only considering current physical fitness and recent physical activity level.

There is limited research that measured previous physical activity using self-reported questionnaires, and the studies were conducted 30 years ago. Jones and colleagues[39] used a two question survey to identify previous physical activity in Army trainees that inquired about what types of physical activities and sports participated in the last 6 months, and then the number of days per week associated with each activity reported. Jones and colleagues[39] found that men with lower reported previous physical activity, higher BMI, and lower aerobic fitness had greater incidence of MSKI. In another study, Jones and colleagues[3] used a questionnaire on male Army infantry trainees to identify perceived previous physical activity involving rating their level of previous physical activity compared with others of their same age and gender (I = very inactive; 3 = “average”; and 5 = very active). Jones and colleagues[3] also inquired about running habits in the month prior to entering the Army and previous sport participation in high school and college. Low levels of previous physical activity, low running frequency, and low levels of physical fitness upon entering the Army were found to be related to increased incidence of MSKI.[3] Kowal[136] investigated previous athletic history and its relationship with injury incidence in 400 female Army recruits and found those with less athletic history had greater incidence of MSKI. These studies[3,39,136] are the only and most recent studies that used surveys to inquire about previous physical activity to connect it to injury risk and these studies are >30 years old. The amount of physical activity during childhood has dramatically reduced during the last 30 years, so new studies are needed.[98,99] Previous physical activity is connected to injury and said to be necessary for the development of FMC, but previous physical activity has not been connected to FMC directly. There is a need to identify a standardized method of collecting information about previous physical activity to identify if previous physical activity is related to FMC. I intend to develop a more current questionnaire to inquire about previous sport participation throughout youth that will be used in this study based on the few studies that have collected previous sport history from >30 years ago.[3,39,136]

Landing biomechanics: A common movement screening for MSKI risk in military populations is by evaluating jump landing biomechanics.[26,33,137] Jump landing tasks are widely used to assess MSKI risk in both civilian and military populations due to the dynamic nature of the task[33,137-148] and the established relationships to both acute injuries such as anterior cruciate ligament injury[149-151] and overuse injuries such as patellofemoral pain syndrome and exertional medial tibial pain syndrome.[152-156] The exact biomechanical risk profile has not been established due to the complex nature of movement but multiplane movement variations during landing have been found to increase acute and overuse MSKI risk.[33,145,157-168] In-laboratory methods of evaluating biomechanics include using 3D motion capture to collect kinematic data and force plates to collect kinetic data.[169,170] Other methods of collecting in-laboratory biomechanics data involve using inertial measurement units[171,172] and accelerometers.[34,173,174] In-laboratory biomechanics assessment can be expensive and time consuming, which led to the establishment of multiple methods of simpler in field testing including 2D video analysis[175-177] and the Landing Error Scoring System.[13,17,33,151,178-180] This section will provide information about current methods of assessing biomechanics in jumping and jump landing tasks.

Jump Landing Tasks: Many variations of the jump landing task can be used to assess biomechanics with the most common being a double leg drop vertical jump (DVJ) and a jump landing task.[17,33,147,178,181,182] The DVJ task involves individuals standing on a standardized box, they then drop off onto the ground and then immediately upon landing they jump for maximal height.[181,182] The jump landing task involves a similar set up, with individuals standing on a standardized box, but instead of dropping off they jump for depth into a designated area and immediately upon landing they jump for maximal height.[33,143,178] The main difference between tasks is where the individual lands when leaving the box. For the DVJ they drop off the box, so they land directly in front of the box with minimal distance in between the individual and the box. Whereas in the jump landing task they are jumping off the box for distance, so they are landing away from the box. There are variations for both tasks that can involve adding or removing the jump after landing or adding in an additional goal for individuals to try to reach during their maximal jump.[142,145,148,183,184] Regardless, most of the research assesses biomechanics during the first landing off the box.[33,137,147,151,163,178,185] Typically, biomechanical factors like joint angles are assessed at two time points, initial contact or when the feet first touch the ground, and maximal knee flexion.[33,137,147,151,163,178,185] Initial contact is assessed because initial contact is when the load is first being placed on the body and during a period of rapid deceleration.[17,168,178] Therefore, potentially injurious biomechanics at initial contact could result in increased load being placed on the tissues in unfavorable ways.[17,168,178] Maximum knee flexion is in theory the point at which joints are at their maximal range of motion.[17,168,178] Maximal knee flexion can inform researchers and clinicians about biomechanical factors that are related to how load will be placed on the lower extremities.[17,168,178] Specific biomechanical factors that are related to MSKI will be discussed later in this review.

When connecting MSKI and performance in movement quality, there is some debate about which landing should be assessed.[33,143,160,162,186] As stated, most tasks are assessed during the first landing that occurs off the box.[13,17,33,137,140,143,168] Bate and colleagues[160,186] investigated the biomechanical differences between the initial landing off the box, and the second landing from the jump. Although there were no differences between peak vertical GRF values between the jumps, the first jump had shorter time to peak GRF, which may increase strain on the ACL. Bates and colleagues found that the first jump had greater hip adduction and knee abduction angles and moments associated with it, which are related to MSKI. Greater side to side differences and less knee and hip flexion angles were found during the second landing which are also related to MSKI. Therefore, it was determined that if the research question is surrounding knee valgus or time to peak GRF then the first landing should be utilized, whereas if the research question is investigating sagittal plane or side to side differences then the second landing should be utilized. Overall, Bates and colleagues suggested that the second landing may be a more rigorous task and may be more related to perturbations that are relative to sport related ACL injury indicating that the second landing may be more beneficial to examine for sagittal plane risk factors.[160,162,186] Both landings have their benefits for assessment and there are arguments that can be made based on the research question under investigation to support the use of either landing. ROTC cadets have higher rates of overuse MSKI compared to acute MSKI and elevated peak GRF is related to increased risk of developing overuse MSKI.[2] Total peak GRF does not differ between the first and second landings,[160] supporting the use of the second landing to assess biomechanics that can be related to injury. I plan to focus on the landing that occurs after a vertical jump in this study since it may be a more relative measurement for ROTC cadets based on the MSKI injury risk they display.

Injurious Movement Patterns

Dynamic knee valgus was originally thought to be the most injurious movement pattern during landing.[166,187] Dynamic knee valgus is the combination of excessive hip adduction and internal rotation, knee abduction, and external tibial rotation and is visually present in the knee collapsing inward towards the midline of the body.[33] Dynamic knee valgus can increase the load to the knee joint, specifically the ACL placing individuals at increased risk of ACL injury and other overuse injuries such as stress fractures.[33,145,157-168] More recently, conflicting evidence exists as to whether dynamic knee valgus is related to bone stress injury with some studies finding no connection[168,178] and another finding a relationship between dynamic knee valgus and bone stress injuries.[17] Dynamic knee valgus has been thought to be a primary mechanism related to ACL injury however, more recently investigations into military injury mechanism has changed and suggest dynamic knee valgus may not be the primary mechanism of injury.

Another biomechanical pattern that has gained more attention recently is landing style of “stiff” or “soft”.[17,157,178] “Stiff” landing styles are characterized by landing with limited sagittal plane trunk, hip, knee and ankle flexion and high landing force.[157] “Soft” landing styles are characterized by landing with large amounts of sagittal plane trunk, hip, knee and ankle flexion and low landing force.[157] A literature review by Yu and Garrett[166] identified that strain to ACL increases substantially when knee flexion is less than 60 degrees, with the most strain occurring between 15 and 30 degrees whereas greater than 60 degrees does not strain the ACL.[166] Less knee and hip flexion during the deceleration phase of landing was related to increased frontal plane knee valgus and knee abductor moments in female soccer players.[188] Supporting the theory of limited sagittal plane motion will encourage a landing style that relies on passive frontal plane restraining mechanisms to control the deceleration of the body increasing ACL injury risk. Greater knee flexion angles (“soft landings”) are associated with better impact absorption, reducing the load placed on the lower extremities which is related to BSI.[17,33,157,178] Limited sagittal plane motion at the ankle during jump landings have been connected to increased MSKI risk of BSI.[17,178] Both the increased impact absorption and decreased strain on the ACL provides support for the “soft” landing style over the “stiff” landing style to decrease risk of injury.

Although “soft” landing styles, with greater sagittal plane flexion, are protective against lower extremity injury,[166,187] softer landings may affect an individual’s ability to reach maximum power and jump performance. [157,189] It is common for athletes to adopt a stiffer landing style to increase their vertical jump performance.[166,187] Guy-Cherry and colleagues[32] investigated the effect that landing style has on knee flexion angle, knee valgus angle, peak pressure, and power measured by Relative strength index (RSI). Three landing styles were tested 1) "soft" landing style, where participants were instructed to land with at least 60 degrees of knee flexion; 2) self-selected landing style, where participants were instructed to land at their preferred squat depth; and 3) "stiff" landing style, where participants were instructed to land with their knees as straight as possible.[32] All three landing styles were performed in random order and were a part of a DVJ task, so after participants landed they immediately jumped for maximal height.[32] Knee flexion angle was significantly different between all three styles with soft ranging from 111 – 120 degrees, self-selected ranging from 73-95 degrees, and stiff ranging from 55-65 degrees. Knee valgus angle was not significantly different between landing styles.[32] Peak pressure was significantly different between groups with the lowest amount of pressure occurring during the soft landing (1.3 %body weight), followed by self-selected (1.5 %body weight) and then stiff landing (1.8 %body weight).[32] RSI was significantly lower in the soft landing style compared to the stiff and self-selected styles which were not significantly different.[32] The results found by Guy-Cherry and Colleagues[32] support that softer landing styles are beneficial for MSKI prevention due to better force attenuation compared to stiffer landing styles. However, vertical jump performance was also worse in the soft-landing style compared to the stiff and self-selected styles.[32] The stiff and self-selected landing styles produced the same performance on the vertical jump task lending to the idea that there may be ceiling point where performance cannot improve after decreasing knee flexion to certain degree.[32] The results from Guy-Cherry and colleagues[32] are valuable because they support the hypothesis that there can be a certain window of knee flexion that can be protective, and still produce adequate power. It should be noted that the stiff landing group landed within 60 degrees of knee flexion which is still the range of minimal strain to the ACL. [157,32] The results from Guy-cherry and colleagues[32] are similar to those of Dai and colleagues,[157] who found softer landing styles decreased GRF and knee extensor moment, but also decreased jump height.

To conclude, stiffer landings are more preferable for performance, however, stiffer landings may not be favorable for MSKI risk. There seems to be a balance that needs to be achieved within training that would protect cadets from MSKI and allow for greater performance. Without considering both perspectives training could become unbalanced and focus on either performance, resulting in increased injury risk, or focus on MSKI prevention, resulting in decreased performance.

Dynamic Balance

Dynamic balance is defined as the ability to move the body while staying in its base of support, or the ability to maintain postural control.[190] Poor dynamic balance has been related both retrospectively and prospectively to MSKI in multiple active populations, primarily traditional athlete populations.[29,31,119,138,191-194] A common method to test dynamic balance is by using the star excursion balance test which involves an individual reaching in 8 directions (anterior, anteromedial, medial, posteromedial, posterior, posterolateral, lateral, and anterolateral) with their non stance leg while balancing on their stance leg. The star excursion balance test has been simplified down to 3 reaches in some studies to reduce redundancy (anteromedial, medial, and posteromedial).[195] The Y-Balance test is essentially a simplified version of the star balance test only including 3 reach directions (anterior, posteromedial, and posterolateral) tested on each leg. Both the star balance test and Y-balance tests have been used in multiple populations and are reliable for measuring dynamic balance in the field.[29-31,194-198] In both traditional and tactical athlete populations anterior reach differences, specifically the difference in reach distances between the right and left limbs, are related to MSKI prospectively and retrospectively. Athletes with left and right anterior reach differences of greater than 4 cm were 2.5 times more likely to sustain a lower extremity MSKI.[31] Recently dynamic balance has been assessed in military populations using the Y-Balance test finding that 36% of marines,[197] 31.3% of active duty service members,[198] and 21.8% of ROTC cadets[26] were at high risk according to their left and right anterior reach difference. Tactical athletes participate in taxing and unique training such as traversing rough terrain wearing heavy equipment.[57] Dynamic balance is essential to be able to safely and effectively traverse many obstacles in military populations, however, it is often left out of physical training.

Functional Motor Competence (FMC)

FMC is has been speculated to be related to injury risk in ROTC cadets.[12] FMC development includes being able to do advanced bilateral and unilateral movement patterns that involve multiple motor unit recruitment and coordination.[12] FMC is necessary to have adequate neuromuscular control, therefore without adequate FMC development deficits in neuromuscular control may occur increasing MSKI risk.[12] FMC is needed to safely complete advanced neuromuscular tasks indicating that FMC may be an underappreciated factor influencing MSKI risk in military populations.[12] FMC development has been speculated to promote dynamic joint stability and balance, which has been highlighted in previous research to be lacking in ROTC cadets.[26] A lack of dynamic balance is well documented in both military and traditional athletic populations to increase MSKI risk.[29,195] FMC development is connected to bone density development through the increased load placed on the body during physical activity.[199,200] Being able to attenuate load placed on the body during locomotion decreases the risk of stress fractures which are a common lower extremity overuse MSKI in military populations.[25,37,47,48,76,91,201-203] Although attempts have been made to understand how FMC influences MSKI risk in military population, the theory behind FMC being related to MSKI risk in military populations is purely speculative and based on the motor competence literature in child populations.

The Iceberg Effect Diagram for Military Performance and Injury

As described in the previous sections, there are some factors that may be desirable in one direction to reduce injury risk but produce an undesirable performance outcome. For example, more knee flexion during landing can be protective against knee ligament strain and decrease the risk of anterior cruciate ligament (ACL) injury. However, increasing knee flexion also decreases muscular stiffness needed to produce optimal power and decreases one's performance during jump landing tasks. There is a fine balance between injury prevention and performance goal that should inform training programs, Whereas if training is solely focused on performance, too little knee flexion could be implemented leading to better performance but increased MSKI risk. The current method of assessing performance and the effectiveness of physical training in the Army is using the ACFT. However, one major gap that arises through only measuring performance through the ACFT is that many factors that are related to increased risk of developing MSKI are not assessed. Soldiers could be performing at a high level with high AFCT sores yet with unfavorable biomechanics which could place them at an increased risk of developing a MSKI.[25,67,68,92,130,204]

In an attempt to simultaneously investigate MKSI and performance in military populations a conceptual diagram was developed by Teyhen and colleagues[119] during an American College of Sports Medicine summit. They termed “The iceberg effect” (Figure 1) to show the necessary skills that are needed to execute high performance with low injury risk.[119] The factors that are above the waterline are typically indirectly tested with standardized testing in the military, whereas the factors under the waterline are not. The iceberg effect diagram shows the importance of having a strong physical and neuromuscular fitness base for high performance and lower injury risk. The iceberg effect diagram describes how performance, termed functional fitness, is less of an expression of military and athletic skills and more dependent on factors that are elements of functional movement (i.e., strength, neuromuscular control, endurance). Teyhen and colleagues identify how muscular imbalances, inadequate core stability, and altered kinematics from fatigue or other injury related imbalances could be major contributors to neuromuscular deficits that are present in military populations. Although these factors may be influencing neuromuscular control, they may not provide the entire picture. A main takeaway recommended by Teyhen and colleagues was that researchers need to include more assessments for MSKI risk to account for the physical and neuromuscular fitness factors under the water.

There are some issues with the iceberg effect diagram that may not allow the iceberg effect diagram to be applicable currently. First, the iceberg effect diagram was created when the Army was utilizing the APFT, which as discussed earlier assessed significantly different factors than the ACFT. Additionally, current research within our lab indicates that cadets may be performing at a high level with poor foundational abilities, specifically unfavorable biomechanics and dynamic balance.[26] Perhaps the relationship between performance and MSKI risk is not pyramidal since many physical and neuromuscular fitness factors can be trained and adapted quickly without having a solid motor skill base. For example, power, cardiorespiratory fitness, and muscular strength and endurance can all be trained with noticeable positive results occurring in a few weeks.[190] However, performing at high levels without a solid FMC base could leave cadets at an increased risk of MSKI. Without a solid FMC base proper coordination and effective and safe movement patterns may not be present. Performing at high levels without proper movement efficiency may place the body in unfavorable biomechanical situations. The iceberg effect diagram may not apply to the current needs of the Army supported by cadets performing at high levels without having a physical and neuromuscular fitness and motor skill base. Research is needed to understand how FMC is related to MSKI risk, movement, and the physical and neuromuscular fitness components in the iceberg diagram is needed.

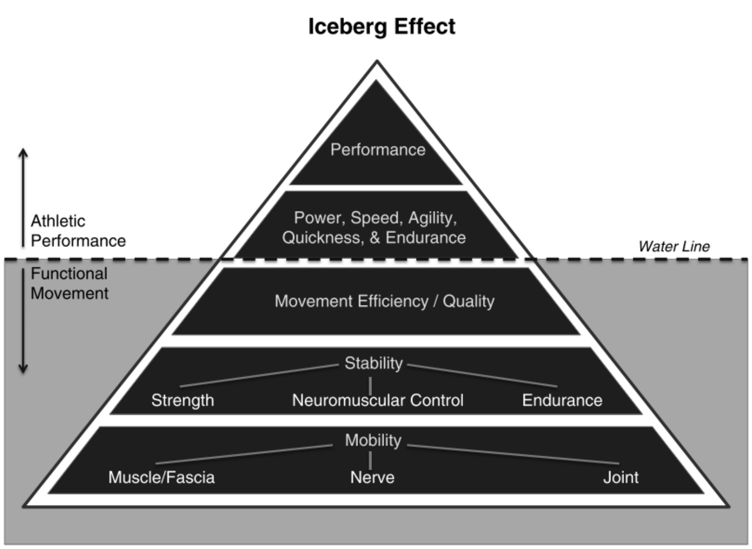

Figure 1

Although the iceberg effects diagram may not be appropriate for the current needs of the Army, the diagram still has its benefits. One benefit of the iceberg effect diagram is the identification that performance and MSKI are multifactorial and should be assessed together to get a more holistic view of the physical training needs of a cadet. Teyhen and colleagues also discussed for the need of more assessments used in the military to understand where physical training may need to focus. Ideally, researchers should introduce screening to measure multiple foundational abilities, MSKI risk factors, along with performance in the Army. However, implementing multiple screening tests is time consuming, requires training, and can be costly. There is a need to identify a screening method that can inform clinicians, researchers, and Army leaders about multiple factors that are affecting MSKI risk and performance in ROTC cadets. Prior to being able to identify a screening protocol researchers must identify what factors need to be included and what factors are missing from the current screening methods.

The Role of FMC in Performance and Injury

The current iceberg effect diagram does not account for potential motor skill development issues which can lead to potentially injurious biomechanics despite FMC being a combination of fundamental motor skill development and associated physical and neuromuscular fitness factors (power, speed, agility etc.).[12,24] FMC may be able to capture man of the functional movement and performance factors discussed by Teyhen and colleagues.[119] One major takeaway recommended by Teyhen and colleagues[119] was that it is essential to implement more functional movement assessments to capture more than just performance measures and assess MSKI injury risk. Some common movement screens used in military populations include the functional movement screen(FMS).[12,14,118], Y-balance test, and a triple crossover hop test and these assessments should measure aspects of functional movement and FMC.[14,196] Poor performance on the FMS, Y-balance test, and triple crossover hop test is related to increased risk of developing a MSKI in military populations.[14,196] Although the FMS, Y-balance test, and triple crossover hop test all measure aspects of functional movement and FMC, they are unable to measure FMC directly, lacking important factors of FMC like object control. However, these studies[14,196] are recent attempts to bridge the gap among the sport performance, motor development, and sports medicine domains. Since FMC is a combination of fundamental motor skill development and associated physical and neuromuscular fitness factors (power, speed, agility etc.)[12,24] and FMC test batteries are easy, cost and time effective, FMC test batteries could be implemented into military populations to gain a better understanding behind performance on the ACFT.

Measurements

Power

Vertical Jump: Vertical jump (VJ) height is a measure that is typically used in the sport performance realm as a measure of power but has recently been included in sports medicine research in relation to MSKI risk.[146,159,174,205,206] The VJ task involves participants completing a maximal vertical jump within a designated target area. Counter movement jump (CMJ) is often used to measure VJ height, with varying methods that influence VJ performance. Some CMJ protocols require strict form which may not be a representation of an individual's preferred jump mechanics. Other protocols allow for autonomy allowing individuals to use a preferred method to complete making it more relatable to the VJ task.

Both CMJ and VJ have been connected to potentially injurious biomechanics related to injury. Bird and colleagues assessed Marines for CMJ performance prior to entry into Officer Candidates School.[207] Throughout the 10-week programs injuries were monitored. Following the 10 weeks movement cluster categories were created for those who sustained injuries.[207] Clusters were based on how many injuries were sustained during the training.[207] Bird and colleagues found that those with low-risk had better CMJ efficiency than those in the moderate- and high-risk clusters.[207] The connection of typical CMJ performance measures used in sport and injury may support the use of CMJ in screening. Cesar and colleagues performed a frontal plane comparison between DVJ and VJ tasks.[159] When comparing mean differences between tasks, no differences were found for knee valgus angle between tasks, but the DVJ task elicited greater internal adductor moments compared to the VJ.[159] Although differences were present in the means, correlations between tasks indicated strong relationships for both knee valgus angle and knee internal adductor moments.[159] The DVJ task includes a maximal VJ within the protocol, which may support the use of VJ as an assessment tool since Bates and colleagues[160,162] identified poor movement qualities related to MSKI during the second landing. The current literature supports that both CMJ and VJ could potentially be used to assess biomechanics for landing tasks.[34,146,159,189,205,206,208-211] VJ is also a task that is used to assess FMC in many product-oriented test batteries which could provide for a direct comparison of biomechanics and FMC level which has not been done previously.

Reactive Strength Index: Muscular power is the amount of force than be produced rapidly over time and is calculated with the following equation: $\frac{Force \times Distance}{Time}$ and is expressed in Watts. Measuring power requires instruments that can measure force directly, such as a force plate or dynamometer. Reactive strength index (RSI) is a common surrogate measure for directly measuring power when a direct measurement of force isn't available.[211-213] It has been traditionally used to identify performance on DVJ protocols because ground contact time (GCT) is needed to calculate RSI.[212] RSI is defined as a measure of force and the time it takes to develop said force and GCT is the time between initial contact and take off.[28] RSI is also described as the ability to change from an eccentric to a concentric contraction quickly.[214] Eccentric muscle contractions occur when the muscle is lengthening, like the hamstrings during the lowering portion of a Romanian dead lift.[214] Concentric muscle contractions occur when a muscle is shortening, like the biceps during a biceps curl.[214] To produce power, the body must utilize the stretch-shortening cycle (SSC), or when a muscle is actively stretched (eccentric contraction) then actively shortened (concentric).[215,216] SSC is often said to form the basis of human locomotion and is required for many plyometric movements in sport.[215] Since RSI is the measure of the ability to switch from eccentric to concentric contractions, it is representative of the SSC.

There are two different ways to calculate RSI using GCT; 1) Jump height/GCT and 2) Flight time (or time spent in the air)/GCT. RSI is a reliable method of quantifying jump performance[212] and is often used to identify the quality of a training program.[211] Additionally, RSI is used in athletes with previous ACL injury to identify functional ability.[209,212,217] Ebben and colleagues[28] tested a modified version of calculating RSI without using GCT to enable the use of RSI to quantify jump performance across plyometric tasks. Since all plyometric tasks use the SSC to produce power, it is extremely beneficial to be able to measure RSI in other plyometric movements.[215,216] Especially since there is variation in movement with sport and exercise.

Ebben and colleagues[28] found the modified calculation of RSI (jump height/time to take off) to be comparable to the original calculation of RSI supporting the use of the modified RSI.[28] RSI can now be used to test vertical jump performance in CMJ and other jumping tasks.[28]

Dynamic balance

Testing Methods: As mentioned previously there are two main dynamic balance assessments that are used consistently which includes the Star excursion balance test and the Y-Balance test.

To review the star excursion balance test involves standing on one leg and reaching with the other leg in eight directions (anterior, anteromedial, medial, posteromedial, posterior, posterolateral, lateral, and anterolateral). The star excursion balance test has been simplified down to 3 reaches in some studies to reduce redundancy (anteromedial, medial, and posteromedial).[195] The star balance test has shown reliability across athletic populations displaying high interclass correlation coefficient of >.85. The Y-Balance test is essentially a simplified version of the star balance test only including 3 reach directions (anterior, posteromedial, and posterolateral) tested on each leg. The Y-Balance test is comparable to the star excursion balance test with the main difference between the assessments being that larger anterior reach distances and shorter time to completion were observed in the star excursion balance test.[30,218,219] Some speculation about these differences comes from the difference in postural-control strategies may be different between each test.[218,219] Despite these differences, the Y-Balance test has been found to be reliable in measuring dynamic balance with interrater test-retest reliability for maximal reach distance and average reach having interclass correlation coefficients between .80 and .93.[198,220] Both the star balance test and Y-balance tests have been used in multiple populations and are reliable for measuring dynamic balance in the field.[29-31,194-198]

Landing biomechanics

In-Lab: Typically, landing biomechanics are evaluated using a process-oriented perspective with advanced technology like high-speed camera based 3-Dimensional (3D) motion analysis or inertial measurement unit (IMU) based technology. 3D motion analysis has been identified as the "gold standard" for measuring movement patterns during many tasks.[169,170] The procedure of collecting 3D kinematic data involves a standing calibration trial and then dynamic trials.[221] At least two cameras are required to collect data and the assumption of rigidity of the segments is needed.[221] Each segment created by reflective markers creates a local coordinate system that is fixed in the global coordinate system.[221] Joint angles from the local coordinate system are then created and depending on the joint could be in reference to another segment (i.e., knee flexion is shank relative to thigh) or to the global coordinate system (i.e., pelvic tilt is pelvis relative to global).[221] The global coordinate system collects in three planes: mediolateral (X), anteroposterior (Y), and vertical (Z).[221] Force plates are often used in conjunction with 3D motion capture to provide information about the load placed on the joints. Force plates can collect information on vertical and shear forces in the anteroposterior, transverse, and vertical planes during tasks.[221,222] Force data collected from force plates can then be processed through the associated system to identify relative ground reaction force (GRF) and joint moments.[221,223] Force plates are the only direct way to measure force placed on the body, which leads to many constraints since they are expensive and can create an environment where a participant alters their typical biomechanics.[223] 3D motion analysis can be time consuming, expensive and require advanced training to complete, making it a non-viable option for field based testing which is preferable in military populations.

Another method of collecting 3D biomechanical data is using inertial measurement units (IMUs) which have been validated against the gold standard 3D motion capture.[172,224] IMUs are electronic devices that can be strapped to an individual to measure biomechanics using accelerometers, gyroscopes, and magnetometers.[224] IMUs do not require an extensive lab set up like 3D motion capture does. The equipment needed for data collection with IMUs typically involve a computer to run the system's program for data processing, a receiver where the IMUs are tethered to (typically using Bluetooth methods) which is where the calibration is based on, and the IMU devices themselves.[224] Indirect force data can be calculated using acceleration data collected from an IMU placed on shank typically aligned with the distal portion of the tibia.[225,226] IMUs collect changes in position relative to the original calibration file and in relation to each sensor.[224] The positional data is then processed and filtered through the system's program as relative joint angle and acceleration data. IMUs are a better option for in-field collection compared to 3D motion capture but still have their limitations. Metal in the floor of the data collection area can cause noise and even interrupt data collection since IMUs use magnetometers. Additionally, IMUs require electrical power sources for the receiver. Although IMUs may not be the best choice for in-field testing, they do still allow for more options for where data can be collected, making it a preferable option over 3D motion capture.

Accelerometry has been used as a field friendly alternative for identifying force-time characteristics in many tasks including running,[171,226-229] jump landings,[173,230,231] and vertical [34,232,233] and countermovement[230] jumps. Accelerometers are small devices that can be affixed to various parts of the body like the hip, abdomen (nearest to center of mass) or the tibia to measure acceleration.[34,76,173,174,230] Cabarkapa and colleagues[233] compared the impact of placement of accelerometers on vertical jump parameters and identified that both the abdomen and the hip were comparable for all the measurements except vertical jump height. The hip accelerometer underestimated the vertical jump height by 1.2cm, which although statistically significant, might not be as practically applicable.[233] Additionally jump height is weakly correlated with both peak tibial acceleration and peak vertical GRF force indicating that if the goal is to identify potentially injurious biomechanics like increased impact, jump height may not be a variable that needs to be considered.[34] Apart from vertical jump height, it appears placement of the accelerometers does not influence reliability or validity of the tool;[233] however, it is recommended that accelerometers be placed near the place of interest.[232] For example, if the task is running, it makes sense to place an accelerometer on the tibia. Accelerometry measures have been validated against GRF data collected by the gold standard force plate in many studies.[173,230-232,234,235] Figure 2 depicted by Elvin and colleagues[34] presents vertical GRF and tibial axial acceleration graphs for a free vertical jump. Figure 2 shows what vertical GRF, and tibial acceleration look like throughout a vertical jump. Gravitational acceleration (*g)* is the unit of measurement used to measure acceleration during movement and is also referred to as standard acceleration, standard gravity, and acceleration due to gravity. *G* is the rate of change of velocity and can be calculated by dividing velocity (m/s) by time in seconds (s), so the unit of measurement for *g* is m/s^2. Newton's second law explains the conversion of acceleration values to force and is calculated using the following equation: force = mass x acceleration.[236] Peak acceleration variables have been validated against GRF force data and are often used.[34,173,225,228,230,231,233,235] Peak tibial acceleration is used when the accelerometer is placed on the shank and has been validated in many tasks including CMJs and vertical jumps.[34,228,234,237] Because accelerometry being a valid alternative to GRF for measuring impact on the body, there is justification to use accelerometers when direct force cannot be collected such as in field settings.

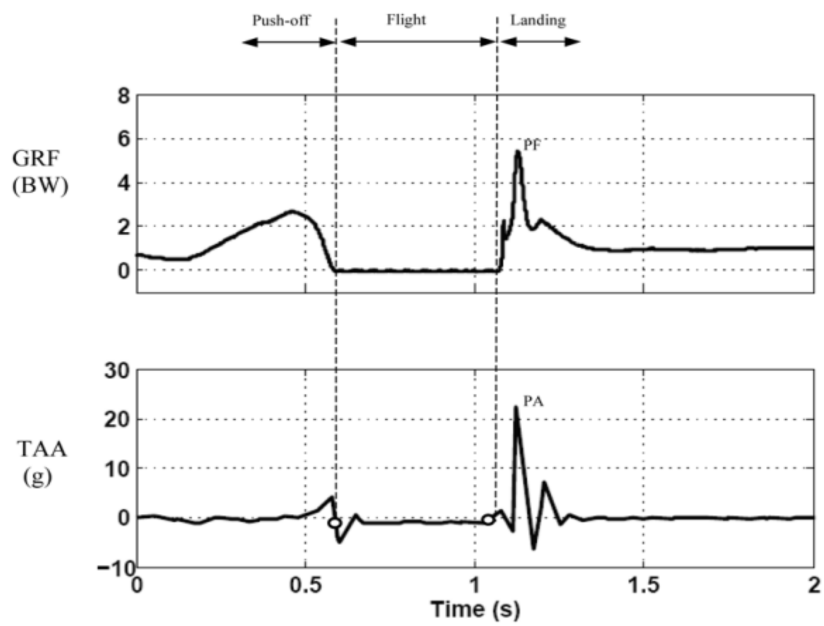

Figure 2:[34] Typical GRF and TAA time histories measured for a single vertical jump and landing. Dashed lines identifying the different periods are based on vertical GRF. Open circles on the TAA time history plot correspond to take-off and landing. Peak ground reaction force and peak tibial axial acceleration are labeled as PF and PA, respectively.

In-Field: Although the gold standard 3D motion analysis is the preferred method for collecting data for its robust data, it is typically not accessible in many settings such as within military populations. Using a standard video camera to record single-plane 2-dimmensional (2D) joint angles is another way that researchers and clinicians can assess biomechanics during a jump landing task and has been used in military populations.[33,137] Typically, one to two cameras will be placed around the individual performing the jump, one to the side to capture sagittal plane movement and one in front to capture frontal plane movement. The research question will determine how many cameras will be placed and in which locations. 2D video will be transferred to a computer where analysis software, such as Dartfish (Dartfish USA, Inc., Alpharetta, GA), can be used to measure joint angles. Identifying joint angles provides information about movement and can inform about potentially injurious biomechanics. 2D video analysis is comparable to 3D motion analysis for both single leg and double leg tasks. In jump landing tasks 2D video analysis has been found to have good to excellent reliability and excellent validity for identifying joint angles, in the frontal plane, there was more variation with good to excellent reliability but poor to moderate validity. Indicating that 2D video analysis may be a viable alternative for in-field testing when compared to 3D motion capture during jump landing tasks to measure joint angles in the sagittal plane.

To make MSKI risk screening more accessible for in-field data collections, rubrics have been developed to analyze single-leg and double-leg squats and jump landings. The most utilized tool is the Landing Error Scoring System (LESS) was created and validated in military populations to measure unfavorable movement patterns during landing tasks.[33] The LESS is a 17-question rubric that is used to assess jump landing movement quality. The LESS requires at least two 2D video cameras to record the drop landing trials, then a trained researcher will review the videos and score them using the LESS rubric.[33] Video is collected in both the frontal and sagittal planes.[33] Higher LESS scores indicate more errors in movement while landing, indicating that the participant has poor landing quality.[33] Lower scores indicate less errors and better landing mechanics.[33] The LESS has been prospectively validated to identify MSKI risk profiles in military populations.[33] Although, the LESS is more field friendly than traditional in-lab data collections, it still requires some training, equipment, and time outside of data collection to analyze.

Further attempts to make the LESS more field friendly include the LESS-real time (LESS-RT) and Automated LESS. The LESS-RT evaluates ten jump landing characteristics divided into five frontal plane and five sagittal plane characteristics. The LESS-RT is scored while an individual is completing the jump landing. The scoring sheets instructions require at least four trials to complete to be able to observe all the individual items. During the first two trials, frontal plane motion is observed and during the second two trials sagittal plane motion is observed. The LESS-RT has interrater reliability like that of the LESS allowing for scoring to occur at the time of collection.[13,180] Only two studies exist testing the reliability of the LESS-RT, both of which found the LESS-RT to be comparative to the original LESS.[13,180] The LESS-RT is arguably the most field friendly version of the LESS due to not needing any additional equipment or time outside of collection. However, the LESS-RT may introduce some level of measurement error since it is happening in real time and the jump landing task is a fast dynamic task especially after observing many jumps. Although the LESS-RT has been found to be reliable, both studies had relatively small sample sizes (n=43[13] and 22[180]) compared to the original LESS reliability studies (n= 2691)[33] which may impact the result, therefore results of these studies should be interpreted with that in mind. It is possible that potentially injurious movement patterns may get missed due to the nature of the task. The LESS-RT was not able to predict ACL injury within a prospective cohort of 2474 Israeli soldiers.[238] Since the LESS-RT was not able to predict ACL injury, it may not be a preferable tool for identifying MSKI risk.

Recently, the LESS has been automated using a depth camera (Microsoft Kinect) and a marker less motion-capture system (Physimax Technologies Ltd). The depth camera and marker less motion capture system work together to capture full-body kinematics that are then processed via machine learning algorithms.[179] The automated LESS was found to be reliable[179] against expert raters and has moderate concurrent validity against 3D motion capture.[185,239] The automated LESS is relatively new and has limited studies supporting its accuracy and no studies identifying prospective use. The equipment for the automated LESS is expensive, making it less ideal in a field setting where funds are limited.

Biomechanics are an essential aspect of both sports medicine and sport performance but is often utilized by each discipline with limited crossover. Biomechanics can be assessed reliably using many variations for landing and jumping tasks including DVJ, jump landing, VJ, and CMJ. These tasks are used to identify injurious movement patterns in both tactical and traditional athletes such as knee valgus collapse and stiff landing style, which are both related to ACL injury and overuse injury. Although softer landings can be beneficial in an MSKI prevention lens, increased knee flexion can be detrimental to power production supporting the idea that there needs to be communication between the sports medicine and sport performance disciplines. Finally, there are many ways to measure biomechanics both in the laboratory and in the field. The gold standard includes methods of 3D motion capture, force plates and IMUs and although these methods provide accurate and robust data, they are expensive, require training and time to operate, making them less field friendly. In field biomechanics assessments are reliable against gold standard 3D motion capture. Biomechanics can be assessed in the field using 2D video analysis and by using LESS, LESS-RT, and the automated LESS. Although there are many ways to measure biomechanics in and out of the field, the current methods require training to administer and time outside of collection for analysis. Because of this, biomechanics assessment is often underutilized in military populations. There is a desperate need for a user-friendly screening tool that can indicate which cadets and soldiers could be at increased risk of developing an MSKI. Although FMC has been described as the ability to move one's body through space[2] identifying if biomechanics is related to FMC is needed.

Summary of the gaps of knowledge

There is a major issue threatening physical military readiness in ROTC cadets that has yet to be addressed despite the ROTC providing over half of commissioned officers across all branches of the military. The Army has made changes to the physical training doctrine and testing by implementing the H2F doctrine and ACFT. However, MSKIs are still very prevalent in ROTC cadets and potential causes of these injuries are still unknown. FMC may be an underappreciated risk factor in cadet MSKI and performance however, FMC did not have scientific support prior to this study. Understanding if FMC encompasses the physical and neuromuscular fitness factors was necessary before further research could utilize FMC assessments to screen incoming cadets. Since the Army had adjusted the ACFT since the initial investigations about the relationship between FMC and the ACFT, it was essential to understand if the relationship between FMC and the ACFT still existed. Further information was needed to understand if certain events required better developed FMC since it has been speculated that better FMC is required for more advanced movement patterns. Finally, FMC has been described as the ability to move one's body through space, however, it had not been direct connected made between FMC and biomechanics. Understanding the relationship that FMC has with movement was essential to provide evidence to support FMC as a conceptual idea. The first step before research can focus on how FMC is related to MSKI and potential interventions to protect cadets and increase performance was to provide scientific support for FMC as a concept which was the goal of this study.

Innovation

This study provided highly innovative improvements on the current condition of the epidemiological and performance research in military populations that have persisted for decades. This study supplied overall evidence for the theory that is the basis for the development of functional motor competence (FMC). Currently the theory behind FMC was based on the motor competence literature that exists in child populations to promote youth physical activity. FMC was developed based on the plethora of evidence from motor competence literature. However, FMC is focused on adult tactical athletes and sport performance which is vastly different than the goals of motor competence. Therefore, support for the theory behind FMC is needed before implementation of FMC screening assessments can be investigated. Currently, it is only speculated that FMC encompasses many physical and neuromuscular fitness factors such as power and dynamic balance. Therefore, the first innovation is that I identified factors that had only been speculated to be related to functional motor competence (FMC) and had not yet been supported by data. Identifying relationships among foundational abilities, sport participation, and FMC provided essential evidence to support the use of the FMC test battery to screen for deficiencies that incoming cadets may have upon entering the ROTC program. Recent research has investigated the relationship between FMC and ACFT performance, however, since this research was conducted there have been major changes to the ACFT, specifically in the addition of sex and age adjusted scoring. Because of this change additional research confirming this relationship needs to be done. In theory it is reasonable to assume that ACFT events that require multiple physiological systems of the body and high level of motor skill development would require better FMC. However, this is currently only speculative and the relationships between FMC and the individual tasks are unknown. Therefore, the second innovation of this study is that I not only provided supporting evidenced for whether there was a relationship between FMC and ACFT total scores following the revisions to the ACFT scoring protocol, but I also investigated the relationships among FMC and the individual ACFT tasks. Confirming the relationship between FMC and ACFT total score was a critical first step in understanding if FMC testing could be used as a method of screening cadets to identify those who may need additional training prior to participating in the ACFT. Investigating how individual event scores are affected by FMC provided valuable information about whether one of the events required better FMC development than others which could inform future training protocols. FMC is often described as the ability to move one's body through space, however, there was no evidence to support this description. Evidence was needed to support the speculation that FMC is required for safe and effective movement. Therefore, the final innovation of this study was that I investigated how biomechanics were related to FMC composite score. No previous study had made direct comparisons between FMC composite score and biomechanics.

Chapter 2

Manuscript 1: The Relationship Among Power, Dynamic Balance, and Functional Motor Competence in Army Reserve Officer Training Corps Cadets.

Abstract

INTRODUCTION: Despite the Reserve Officers' Training Corps (ROTC) providing up to 60% of commissioned officers across all military branches, ROTC cadets are experiencing overuse musculoskeletal injury (MSKI) at an alarming rate of 40.1%. Physical military readiness (PMR) is defined as the ability to meet all physical demands of any combat or duty position, accomplish the mission and continue to win, which includes being free from MSKI. Strong physical and neuromuscular fitness factors such as power and dynamic balance are critical to reach PMR standards. Functional motor competence (FMC) is defined as the coordination required to perform a wide range of motor skills in tactical athletes, specifically Army ROTC cadets. FMC develops through youth physical activity (PA) and it is speculated that having adequate FMC is required to develop long-term fitness (power, dynamic balance, etc.). Drastic declines in youth PA may be threatening the development of FMC and potentially PMR. Additionally, no standardized method to collect previous physical activity information, such as previous sport participation, exist nor are there direct connections between previous PA and FMC in ROTC cadets. Therefore, the purposes of this study were to determine if the power and dynamic balance are predictors of FMC and to determine if the relationship is moderated by previous sport participation (PSP). **METHODS:** 70 Cadets (female n=21; male n=49; age; 20.20±1.57yrs; height 174.98±9.36cm; weight 77.67±14.32kg; BMI 25.32±4.06) participated in this study. Cadets completed an FMC test battery consisting of four tasks (long jump ball throw, ball kick, and vertical jump) and one dynamic balance task (modified Y-Balance). Cadets completed self-

reported demographic and previous sport participation questionnaires. Best attempts were taken for each task, standardized, and then summed to calculate FMC composite score. The right and left limb difference (R/Ldiff) was calculated for the anterior reach portion of the Y-Balance. Reactive strength index (RSI) was calculated as the measurement of power. PSP was split into total years of sport (total years) and total number of sports (total sports) participated in since the age of five. To assess if PSP moderated the relationship between FMC and RSI and FMC and R/Ldiff, linear regressions with interaction of both PSP variables and RSI and R/Ldiff (α=.01). A hierarchical regression was utilized to identify if RSI and R/Ldiff were predictors of FMC when controlling for sex. **RESULTS:** PSP did not have a moderating effect for FMC and either RSI or R/Ldiff. Sex explained 33.1% of the variance in FMC score(R^2=.331), RSI with sex explained 67.2% of variance in FMC score (change in R^2=.341; $p<.001$), dynamic balance did not explain significant variance in FMC score (change in R^2=.004; p=.382). **CONCLUSION**: Opportunity exists to investigate screening protocols utilizing PSP and FMC for incoming cadets informing cadre and research teams about potential motor skill deficits. Future research then can investigate interventions to train for FMC and increase the longevity and improve the performance of the Army's ROTC cadets.

Introduction

A major concern for the Army is reaching Physical Military Readiness which is defined as the ability to meet all physical demands of any combat or duty position, accomplish the mission and continue to win.[11] Physical military readiness (PMR) includes many aspects of physical and neuromuscular fitness such as muscular strength and endurance, power, dynamic balance as well as aerobic and anerobic endurance.[11,13] PMR is measured using the Army Combat Fitness

Test (ACFT) which is the standardized fitness assessment used in the Army. PMR may be currently threatened by the gradual decrease in youth physical activity because individuals may be entering the Army unprepared for the rigorous training that comes with tactical training.[13,19] Currently only 24% of children and adolescents meet the physical fitness guidelines set by the CDC[98] and only 20-26% of 5–19-year-olds meet the national 60-minute physical activity guidelines.[99] The Reserve Officers Training Corps (ROTC) is a popular entry method into the Army providing up to 60% of commissioned officers across all military branches.[84] Since the ROTC is a 4-year collegiate program, ROTC leaders will focus on recruiting individuals who are approaching the end of high school or who have recently started college.[84] ROTC cadets are required to take collegiate courses and participate in physical training to maintain PMR which includes prolonged bouts of intensive tactical training involving running, crawling, limited sleep, limited access to food and water.[8,10,84] A cadet's physical abilities upon entering the ROTC program influences performance on standardized testing, their overall success in the program, and ultimately their job placement upon graduation.

In previous decades children were more active, providing them with adequate physical abilities upon entering the ROTC program, however this may no longer be the case. Despite the decline in youth physical activity occurring for multiple decades, physical training in the Army has not adapted. Motor skill development can only occur through diverse physical activity experiences. Without adequate participation in physical activity throughout youth [18,19,20,22,100] cadets may enter the ROTC program with motor skill deficits resulting in an inability to perform physical training and military specific tasks safely.[11,12,24]

Recent research focused on identifying methods to screen for potential motor skill deficiencies in ROTC cadets and understand how these deficiencies may impact PMR.[11] Functional Motor Competence (FMC) assessment is a method to screen for motor skill deficiencies and has been tested in ROTC cadets.[11] FMC is defined as the coordination and control required to perform a wide range of motor skills[12] and is based on the literature surrounding motor competence in children. Motor competence is generally defined as the degree to which an individual can perform goal-directed human movement[103] and is developed through diverse physical activity experiences throughout youth.[12,18-20,23,101,102] Although FMC is defined in a similar way to motor competence, the population specific context is different between FMC and motor competence. Motor competence is used to promote childhood physical activity and to increase long term health and fitness outcomes,[19-21,23,100-102] whereas FMC is focused on sport performance, specifically in tactical athletes.[19-21,23,100-102]

Although there is a plethora of evidence supporting the relationship between the development of motor competence and physical activity in youth[20,22,102,240-244], there is no established evidence to support that previous physical activity is related to FMC in ROTC cadets. Only three studies conducted over thirty years ago have investigated previous physical activity and sport participation in military populations, and the studies focus was on MSKI risk[3,39,136] The only study that measured previous sport participation investigated sport participation in women entering the Army and utilized a scale of 1 being inactive and 5 being very active.[136] This study found that lower sport participation was connected to increased risk of MSKI.[136] This was a first attempt to identify how previous sport participation impacts PMR and also subsequently the last attempt. Since the publication of these studies[3,39,136] youth physical activity has drastically declined[98] increasing the necessity to reinvestigate the benefits that previous sport participation questionnaires could provide to both cadre and researchers regarding PMR in incoming cadets. Since FMC is developed through childhood physical activity and less physical activity upon entering the military is related to an increased risk of developing MSKIs, FMC may be a missing link between youth physical activity and MSKI. Additionally, if relationships between previous sport participation and FMC can be established, then there is potential to utilize self-reported surveys to inform cadre about potential motor skill deficits and allow for immediate intervention upon entering the ROTC program.

FMC development throughout youth may also be an essential component for cadets meeting PMR. Traditional FMC skills are categorized as plyometric movements and include locomotive skills (jumping, hopping, skipping, running) and object projection skills (catching, throwing, kicking, and hitting),[24,28] which are required for advanced unilateral and bilateral tasks required for combat.[13] Speculations have been made that a relationship between FMC and physical and neuromuscular fitness factors (e.g., muscular strength and endurance, power, dynamic balance, etc.,) exists, but direct connections have not been made.[12,25] This study focused specifically on exploring power and dynamic balance because they are two fitness factors that are needed for tactical skills and are relatively easy to measure in the field. Power is defined as one's ability to produce maximal force while changing from an eccentric to concentric contraction.[214] Power is required for many tactical skills such as breaching buildings and jumping over obstacles in the field. Dynamic balance often falls under the functional movement umbrella and is defined as the ability to move the body while staying in its base of support, or the ability to maintain postural control.[190] Dynamic balance is important for many tactical skills since it is required to stay upright while traversing one's environment such as safely maneuvering rough terrain, jumping on any narrow walkway, and changing from laying prone on the ground to running/walking.

Currently, there is a lack of awareness of what FMC is and how it may be impacting cadet performance and injury, leading to a lack of training to Improve baseline motor skills in FMC, which may be perpetuating the problem. Due to the severe decrease in youth physical activity levels[98]Due to the severe decrease in youth physical activity levels[98] cadets may not have opportunity to develop FMC potentially threatening PMR.[25] Although the most effective time period to develop FMC is during early childhood, FMC can be developed later in life.[13] If deficits in FMC were identified in ROTC cadets through a screening test, physical training could be adjusted to focus on training for general fundamental skill development before complex context-specific skills with the overall goal of improving FMC. [98] cadets may not have opportunity to develop FMC potentially threatening PMR.[25] Although the most effective time period to develop FMC is during early childhood, FMC can be developed later in life.[13] If deficits in FMC were identified in ROTC cadets through a screening test, physical training could be adjusted to focus on training for general fundamental skill development before complex context-specific skills with the overall goal of improving FMC. Due to the severe decrease in youth physical activity levels[98] cadets may not have opportunity to develop FMC potentially threatening PMR.[25] Although the most effective time period to develop FMC is during early childhood, FMC can be developed later in life.[13] If deficits in FMC were identified in ROTC cadets through a screening test, physical training could be adjusted to focus on training for general fundamental skill development before complex context-specific skills with the overall goal of improving FMC. However, the concept of FMC and its inclusion of physical and neuromuscular fitness factors is speculative with limited supporting evidence, creating a need to directly connect FMC to foundational abilities. Therefore, the purpose of this study was to determine if power and dynamic balance are predictors of FMC and to determine if the relationship is moderated by previous sport participation. Currently, there is a lack of awareness of what FMC is and how it may be impacting cadet performance and injury, leading to a lack of training to Improve baseline motor skills in FMC, which may be perpetuating the problem. Due to the severe decrease in youth physical activity levels[98] cadets may not have opportunity to develop FMC potentially threatening PMR.[25] Although the most effective time period to develop FMC is during early childhood, FMC can be developed later in life.[13] If deficits in FMC were identified in ROTC cadets through a screening test, physical training could be adjusted to focus on training for general fundamental skill development before complex context-specific skills with the overall goal of improving FMC. However, the concept of FMC and its inclusion of physical and neuromuscular fitness factors is speculative. There is a need to directly connect FMC to physical and neuromuscular fitness factors. Therefore, the purpose of this study was to determine if power and dynamic balance are predictors of FMC and to determine if the relationship is moderated by previous sport participation.

Methods

Participants: 70 Cadets were recruited from the Golden Eagle Battalion (GEB) which consists of 5 schools: Marquette University (Milwaukee, WI) which hosts the GEB, UW-Milwaukee (Milwaukee, WI), UW-Parkside (Kenosha, WI), Milwaukee School of Engineering (MSOE) (Milwaukee, WI), and Concordia University (Mequon, WI). Descriptives by sex can be viewed in table 1. Consent was obtained through distribution of a written document, answering questions, and cadets providing written consent on the day of data collection. Inclusion criteria included: 1) being between the ages of 18-40; 2) being injury and pain free and being able to participate in normal physical training sessions; 3) actively enrolled in the ROTC program. Exclusion criteria included: 1) actively on profile for an injury/have physical activity restrictions that would prevent them from completing the study requirements; 2) is a course participant and not officially enrolled as an ROTC cadet. Cadets who met the inclusion criteria and gave written consent were entered into the study and were provided with a participant ID. All research team members were trained on all the stations with multiple practice sessions and pilot testing with the ROTC cadets. Additionally, all measures were objectively collected using reliable and valid tools and were not subject to interpretation by the research team.

Procedures: Cadets were divided into flights of five cadets scheduled every 30 minutes which provided adequate time to get through the stations before the next flight arrived. Data collection was scheduled for two-hour sessions across 4 days which allowed for five flights cadets (25 cadets total) to get through the protocol. Cadets wore an Army issued T-shirt and shorts, and tennis shoes for testing. Cadets were asked to do a short warmup including two laps around the gym (approximately 400m total) followed by 20 jumping jacks, 15 squat jumps, and 10 burpees. Cadets rotated between five stations which included 1) Check in/out & questionnaires 2) standing long jump (distance) 3) ball throw (velocity) and ball kick (velocity), 4) maximal vertical jump (height), and 5) Y-Balance. To try to decrease the risk of cadets standing and waiting for a station, the order that cadets completed the stations was not controlled. The cadets were directed to go to the next open station by the research team member at the station they were currently at. Cadets were encouraged to work on their questionnaires if there was downtime in between stations.

STATION 1: Check in/out & questionnaires - Cadets were assigned a participant ID number and were provided with a demographics survey, a Previous Sport History Survey, and a Previous Military Participation Survey. In addition to the surveys, cadets were provided with the data collection sheet on a clipboard. The cadets brought the clipboards with them to each station which were then handed to the research personnel. When the cadets completed all the stations and associated paperwork, they returned to the check-in station to turn in the completed surveys and data collection sheet. The researcher at the check-in station verified that all the sections were completed properly before dismissing the cadet.

Questionnaires:

Demographics: Age, height, weight, and sex were collected to characterize the sample. Gender was collected to characterize the sample and to acknowledge those who may identify as something other than their sex assigned at birth. Sex was collected because differences in jump landing biomechanics and MSKI risk exist between males and females.[33,138,139,144-147,245-248] Previous military experience was collected to characterize the sample. Those who have prior military experiences may have more experience in the tactical training and have more experience in participating in the ACFT compared to those without prior military experience which could allow for greater performance on the ACFT despite their FMC.

The previous sport questionnaire was designed by combining the evidence surrounding the development of fundamental motor skills and questionnaires that were used to measure previous physical activity and sport from early studies on military MSKI.[5,39,104,136] Total number of years and total number of sports since the age of five was used in analysis and to characterize the sample. The total number of years was calculated by taking the sum of the number of years reported since the age of five. The total number of sports was calculated by taking the sum of the number of individual sports reported since the age of five. Each sport was only counted once so if a cadet participated in the same sport across 3 years the total number of sports would be 1.

STATION 2: Standing Long Jump Distance (Part of FMC Battery) The equipment used in this station included athletic tape, to indicate where a cadet would start and a tape measure, to measure the distance the cadet jumped. Cadets were instructed to stand with their toes behind a tape line which was perpendicular to the tape measure. Cadets were instructed to complete the task with a form that is most comfortable for them but specifying that the cadets must jump with both feet and stick the landing. The distance jumped was taken from the back of the cadet’s heel closest to the starting position. Five trials were recorded and the furthest distance of the five trials was taken for analysis. A trial was considered unsuccessful if the cadet lost balance resulting in their feet moving from landing position, the cadet jumped with one foot instead of two, or if the cadet jumped vertically for height instead of jumping forward for distance.

STATION 3: Throwing and kicking velocity (Part of FMC Battery) The equipment that was utilized to measure throwing and kicking velocity included tennis balls for throwing and 20cm playground balls for kicking, athletic tape to mark the starting position and target, a radar gun (Bushnell Outdoor Products, Overland Park, KS) to measure the velocity of the ball being thrown or kicked, and a net to protect the researcher recording the data and catch the balls. For both the throw and kick cadets were instructed to stand behind a tape line seven meters away from a net. Facing the net, the cadets were instructed to aim for a tape target but were informed it was not necessary for them to hit the target. Cadets were instructed to use a form that was most comfortable for them without any additional wind up meaning that both feet needed to remain planted for the throw and the stance leg needed to remain planted for the kick. Ball speed was recorded using a radar gun in miles/hour, which was later converted to meters per second (m/s) during data processing. Five trials were recorded, and the fastest trial was used for analysis. A trial was considered unsuccessful if the ball did not reach the radar gun or if the cadet moved their feet from the starting position.

STATION 4: Vertical Jump Height (Part of FMC Battery) The equipment that was utilized for this station included two MyoMotion inertial measurement units (IMU) (Noraxon USA, Scottsdale, AZ) with the needed setup to use them (i.e., a computer, transducer, etc.,) were used to measure pelvic and tibial axial acceleration, a 2D video camera (Insta360 One RS 4K action camera, Arashi Vision Inc., Guangdong, China) was used to record video and to help with the identification of the jump phases, and athletic tape was used to indicate the starting position. One of the IMUs was affixed to the cadets' distal medial tibia of the right limb and a second IMU was affixed to the posterior pelvis to collect acceleration data at 200Hz. The acceleration data were collected to define jump phases. Both 2D video and accelerometers are common methods to collect biomechanical data during landing tasks.[158,171,173,177,208,230,231,234,249-254] Cadets were instructed to stand with the center of their feet on a tape line placed approximately two meters away from the 2D camera in the sagittal view. Then cadets were instructed to jump for maximal height trying to land as close to the starting position as possible to ensure they are as close to center frame for the camera and reduce visual distortion.[255] Cadets were instructed to complete the task with a form that is most comfortable for them, having some form of landing, cued by telling the cadets to not land with straight legs and to return to the starting position after landing. No additional instruction about how the cadets should jump, or land was provided. The highest jump of the three jumps was used for analysis. A trial was considered unsuccessful if the cadet landed on one-foot, lost balance during landing, or if they landed outside of the camera frame.

STATION 5: Y-Balance The equipment utilized for this station included a Y-Balance kit. Only the anterior reach portion of the Y-balance protocol was included in the test battery because differences between right and left anterior reach is related to increased risk of developing an MSKI.[29,31] Cadets were instructed to remove their shoes and socks and stand with one limb at the center of the Y-balance kit. Six practice trials were provided for each limb and three trials were recorded as per standard protocol. The protocol involved standing with one foot on the test kit and using the free non-stance limb to push the measurement indicator as far in the anterior direction as possible. It was required that the stance limb heel remained in contact with the kit throughout the trial. Cadets performed three trials with each limb and researchers recorded each trial in cm on the data collection sheet. A trial was considered unsuccessful if the cadet lost their balance, touched the ground with their non-stance limb, or brought their heel up off the kit while testing. Cadets were able to assume bilateral stance in between trials.

Data Analysis:

Data were filtered through the MyoMotion system to eliminate noise and correct drift then visually inspected to ensure the MyoMotion algorithm adequately filtered the data. The specifics of the filtering and drift correction parameters are proprietary to the MyoMotion software and were not able to be accessed despite contacting the company directly. Three time points were identified visually in the synched video within the MyoMotion application, and the identification labels of "start", "take off", and "initial contact" were placed. The "start" time point was identified as the frame where the hips begin to move in the posterior direction visible in the 2D video. "Take off" was defined as the point where the feet were no longer in contact with the ground in the 2D video. "Initial contact" was the time point when the feet first touched the ground immediately after jumping. All MyoMotion acceleration data were exported directly into an excel spreadsheet for analysis including the identified labels. FMC represents one's ability to move their body through space therefore it was essential to provide the cadets autonomy in the way the jump was accomplished. Therefore, cadets were able to use any form that was comfortable for them which did not allow for one specific standard way that a cadet completed the task. Due to the novelty of the protocol used in this study, previous protocols for identifying events using acceleration data were not applicable. Therefore, visual identification and labeling of the time points was utilized. The labeled acceleration data were processed with a MATLAB code that identified the labels and reported the time points that had been placed by the investigator. “Time to take off” was defined as the time from the “start” of the countermovement until “take off”. Jump height was calculated using the following equation: $\frac{9.81 \times (\text{flight time})2}{8}$.[28] Flight time was collected from the accelerometer data and was defined as the duration of time spent in the flight phase calculated by subtracting time of “initial contact” by the time of “takeoff”.

Reactive Strength Index (RSI): RSI was the measurement unit that I used as a surrogate to measure power because a force plate was not available for use in the field setting. RSI measures the stretch shortening cycle or the ability to change from an eccentric to concentric muscular contraction as quickly as possible. RSI has been found to be reliable and it is considered to be the “gold standard” alternative measurement for measuring power directly.[28,210,212,256] Since the goal is to quickly move from eccentric to concentric muscular contraction, the ideal jump would be maintaining a short duration of time in the countermovement phase while maintaining a longer duration of time in the flight phase. The longer the duration of time spent in the countermovement action results in less muscular stiffness, and thus lower jump height.[28,32,209-212,256] RSI was calculated by dividing maximal jump height by “time to takeoff” the vertical jump task.[28]

Dynamic Balance: The anterior reach distances of the Y-Balance data were normalized to height by taking the distance reached (cm) divided by the cadet’s height (cm) and multiplied by 100 for both limbs.[257] The average of the 3 trials was calculated and the right and left difference (ANT R/L diff) was taken for analysis.

Functional motor competence: FMC composite score was calculated using the standardized best score from each of the FMC tasks (standing long jump distance, ball throwing velocity, ball kicking velocity, and vertical jump height). Since all the tasks in the test battery measured different skills and had different units of measurement, it was necessary to standardize the scores. Therefore Z-scores were calculated from the best attempt of each task by subtracting the mean from each score and dividing that by the standard deviation.[11] The mean and standard deviations for each task were: long jump (cm) = 197.28 ± 37.38; Throw (m/s) = 19.35 ± 3.96; Kick (m/s) = 17.59 ± 2.75; Vertical Jump (m) = 0.39 ± 0.10. Then FMC composite score was calculated by summing the z-scores for each task.[11] Negative values for FMC composite score were the result of a cadet performing the task below the population mean, so when the mean was subtracted, a negative number was presented. Positive values for FMC composite scores indicated were the result of a cadet performing the task above the population mean, so when the mean was subtracted, a positive number was presented. Since the standardization of the tasks are population based, FMC composite score can only be interpreted within the population.

Statistical analysis:

Descriptive statistics were run for the demographic variables of age, sex, height, weight, and previous military experience. Data were tested for normality using QQ plots, histograms, and Shapiro-Wilks tests. All data were found to have approximately normal distribution. Since most cadets were between the ages of 18-21, age was not included in the regression analyses. Sex was coded using dummy coding since it is categorical. The determination of the functional form of the relationship was determined to consider the possibility of non-linear relationships. The process of determining the functional form involved making scatter plots with FMC composite score on the Y axis and sport participation (either total years or total sports) was on the X axis. Then investigating linear, quadratic, and cubic fit lines for each scatter plot and assessing R-squared values. Then investigating linear models to assess which relationship functional type was the best fit for previous sport participation by adding in the original variable, then the quadradic and finally cubic and assessing the significance of the models.

Individual linear regressions were completed to assess if previous sport participation moderates the relationship between power and FMC and between balance and FMC. Interaction variables were created by taking the product of each of the following variables: number of years and RSI, number of sports and RSI, number of years and R/L diff, and number of sports and R/L diff. Each interaction variable was entered into individual simple linear regression models with FMC composite score as the dependent variable. If the interaction was found to be significant at alpha <.01 then it was concluded that previous sport participation has a moderating effect on the relationship. Due to the size of the sample, it was recommended to use a small level of significance for identifying a moderating relationship therefore the more conservative value of <.01 was used to identify if there was a moderating effect.

A hierarchical linear regression was used to identify if power (RSI) and dynamic balance (R/L diff) were predictors of FMC score after controlling for sex and any moderating factors identified. Sex was added into the model simultaneously first, then RSI was added, followed by R/L diff. Alpha was set at .05 and change in r-square values were be assessed. All variables were tested for multicollinearity as well as normality tests. If any variables had a variance inflation factor of >10, multicollinearity was determined to be present.

Results

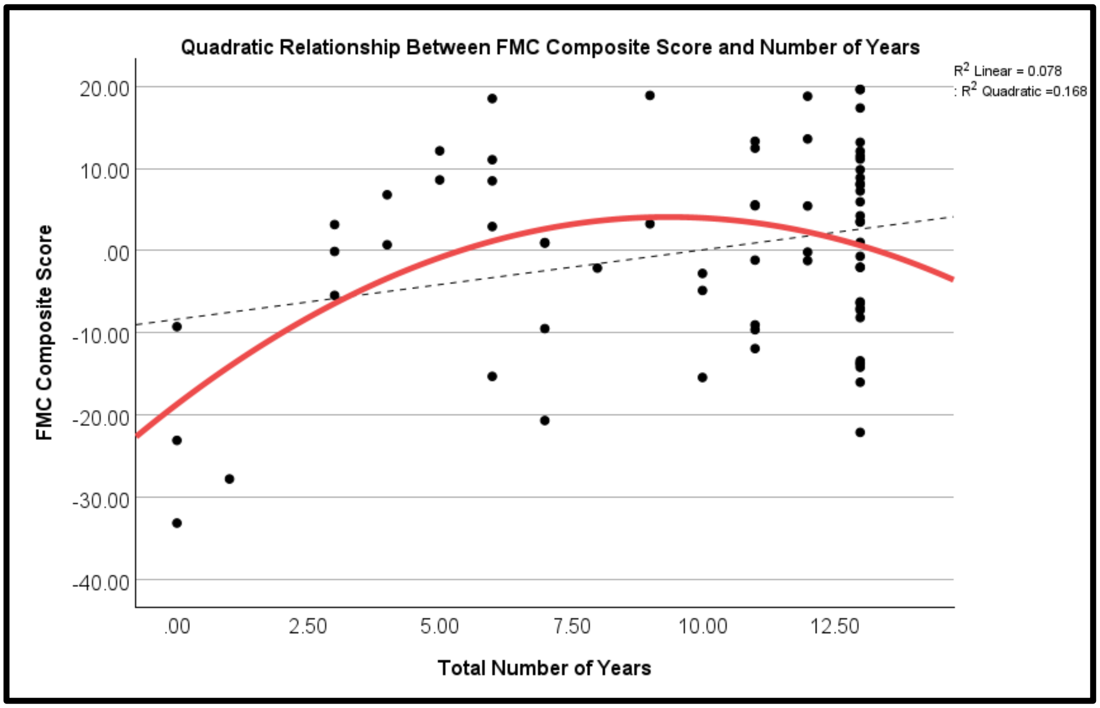

Figure 3: the red line is the best fit quadratic relationship; the dotted line is the linear relationship

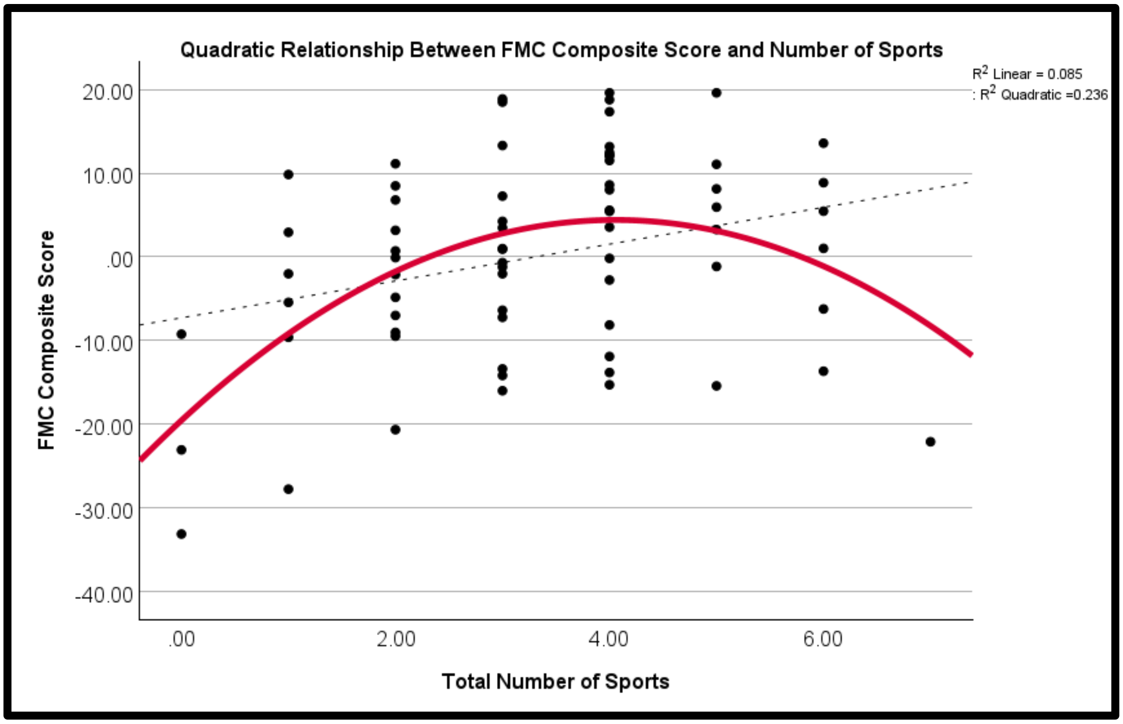

Figure 4: the red line is the best fit quadratic relationship; the dotted line is the linear relationship

Table 1 Descriptive statistics by sex

Variable	***Females (mean +/- SD)*** *(n = 21)*	***Males (mean +/- SD)*** *(n = 49)*	***Combined (mean +/- SD)*** *(n = 70)*
Age (years)	20.61 ± 2.08	20.02 ± 1.28	20.20 ± 1.57
Height (cm)	166.91 ± 7.00	178.44 ± 8.06	174.98 ± 9.36
Weight (kg)	66.20 ± 9.93	82.58 ± 13.09	77.67 ± 14.32
Total Years (years)	10.19 ± 4.23	9.77 ± 3.86	9.90 ± 3.95
Total Sport (# sport)	3.38 ± 2.08	4.26 ± 2.00	4.00 ± 2.05
FMC Composite Score	-10.43 ± 9.94	4.47 ± 9.80	0.00 ± 11.94
Reactive Strength Index	0.31 ± 0.11	0.42 ± 0.10	0.39 ± 0.11
Y-Balance R/L Difference (cm)	1.02 ± 0.87	1.50 ± 1.35	1.35 ± 1.24

The mean and standard deviations of the descriptives for each variable can be viewed in table 1. Overall, 70 cadets (women n = 21; age =20.20 ± 1.57, height = 174.98 ± 9.36; weight = 77.67 ± 14.32) volunteered for participation in this study. There was a relatively even distribution of cadets in terms of Military Science (MS) year with 24.2% being MSI, 31.4% being MSII, 24.2%

being MSIII, and 20% being MSIV. Approximately 45% of the cadets participating in the study reported being on an ROTC related competitive team (e.g. Ranger buddies, etc.) and approximately 39% of cadets reported doing some form of exercise the morning of collection. Women represented 30% of the cadets that participated in this study which is larger than the previous study investigating FMC and ACFT performance[11] and the reported 15.6% of women in the Army.[258] Additionally, 25.7% of cadets had at least 1 year of previous military participation with majority being from the national guard.

Three cadets reported not participating in any sport, twenty-eight cadets participated in 1 to 3 sports, and just over half participated in ≥4 sports with the highest number of sports reported as 7 sports. Only seven cadets reported participating in <3 years of sport, with three of the cadets reporting zero years and just under half of the cadets reporting participating in sport for thirteen years which was also the maximum amount that could be reported since the age range of reporting was from 5 to 18 years old. A non-linear relationship was found between FMC composite score and total number of years of sport participation ($p = .009$) and a non-linear relationship was found between FMC composite score and total number of participated in ($p > .001$). Which can be interpreted as there is a larger increase in FMC composite score from 0 to 5 years and then after the 5 year point this increase in FMC score tapers off (Figure 3). Similarly, there is a larger increase until about four sports and then after that there appears to be a decrease (Figure 4). The total number of years participated in sport was not a significant ($p = .203$) moderating factor in the relationship between RSI and FMC, nor the relationship between dynamic balance and FMC ($p = .326$). Total number of sports participated in was not a significant (p =.02, alpha <.01) moderating factor in the relationship between RSI and FMC nor between dynamic balance and FMC (p=0.267).

Sex was a significant predictor of FMC composite score explaining 48% (R^2= .48) of the variation in FMC composite score. When controlling for sex, RSI was found to be a significant (p <.001) predictor of FMC composite score, explaining an additional 28.7% (R^2=.767) of the variance in the model. When controlling for sex and RSI, dynamic balance (R/L diff) was not a significant predictor (p= .425) and did not explain any significant additional percentage of the variance in the FMC composite score (change in R^2=.002).

Discussion

The purpose of this study was to determine if the physical and neuromuscular fitness factors of power and dynamic balance were predictors of FMC and to determine if the relationship was moderated by previous sport participation when controlling for sex. The evidence that supports FMC as a concept exists in the motor competence literature in child populations, but there was limited research investigating FMC in ROTC cadet populations. This study is the first study to investigate physical and neuromuscular fitness factors that have been speculated to be related to FMC but have never been directly evaluated. Both sport participation variables (total years and total sports) had significant relationships with FMC, but neither variable was a moderating factor in the relationship between FMC and power nor dynamic balance. The relationship between FMC and power, and FMC and dynamic balance did not change depending on the cadets' previous sport participation. Power was found to be a significant predictor of FMC score and explained a significant portion of the variance. Dynamic balance was not a significant predictor for FMC score and did not explain a significant portion of the variance in FMC score.

FMC is primarily developed through diverse physical activity experiences throughout youth. Since there is not a standardized method of retrospectively reporting on youth physical activity, self-reported sport participation was utilized as done previously.[3,39,136] Previous sport participation did not have a linear relationship with FMC composite score. Both total years of sport participation and total number of sports participated in were found to have non-linear relationships with FMC composite score. Figures 3 shows the non-linear relationship between FMC and total years with best fitted line and shows that there is a larger more drastic increase in FMC composite score from 0 to 5 years and then after the 5 year point this increase in FMC score tapers off. This can be interpreted as the benefits of sport participation for the first five years have a large effect on FMC, but the effect tapers off with less improvements in FMC after that point. A similar relationship was portrayed with total sports and FMC. Figure 4 depicts this relationship with best of fit line showing that there is larger increase until about four sports and then after that there appears to be a decrease. However, the decrease after four sports should be interpreted with caution since is limited data after the six-sport point so it may be that there is a plateau in FMC score after four sports. Motor skills are developed through diverse physical activity experiences and initially, a substantial increase in motor skills will be seen through repeated practicing of movement. However, the degree of improvement in motor skills will gradually lessen and eventually near a steady state.[259] The relationship between previous sport participation and FMC follows this theory that there is an initial considerable increase in FMC with increased number of years and number of sports but then FMC development tapers off.

The results show that less experience in sport and less sport diversity is related to lower FMC which provides some evidence to support the theory greater participation in physical activity during youth, measured by sport participation in this study, allows for better FMC. Although direct comparisons should not be made between amount of sport participation and FMC since sport participation is only capturing some physical activity factors throughout youth, there is opportunity to utilize previous sport participation as a recruitment method or as a means to screen for cadets who may need additional training prior to FMC testing. Low previous sport participation could inform Army leadership about potential deficits in motor skill development a cadet may have and allow for early intervention prior to additional testing and screening protocols.

Power is a necessary neuromuscular fitness component needed for many tactical skills such as breaching buildings in the field and jumping over obstacles. The results of this study found a positive linear relationship between power and FMC with those who had greater power having greater FMC. To understand if power is influenced by the amount of physical activity during youth, this study tested the moderating effect of previous sport participation on the relationship between power and FMC. Previous sport participation did not moderate the relationships between FMC and power which can be interpreted as regardless of the amount of previous sport participation, the relationship between power and FMC did not change. This is not that surprising since power can be developed in a short period of time with neuromuscular adaptations occurring in the first few weeks of training and muscular adaptations following over a longer period of training.[260] Since power can be developed quickly, it could be speculated that cadets could develop power during ROTC physical training regardless of the amount of previous sport participation they had. However, since there was a significant positive relationship between power and FMC, there may be other underlying factors at play that are associated with this relationship. Higher FMC has been speculated to be associated with better coordination and bodily control during dynamic tasks.[12] Kyrolainen and colleagues[261] discussed how after 15 weeks of power training a percentage of the enhanced performance visible at the end of the study could be explained by modification in joint control strategies. It would be logical to assume that those who have better FMC would have better motor skills and could adapt to more efficient techniques sooner than those who have lower FMC and less motor skills. It is logical to assume that by developing FMC earlier in life cadets may adapt to training faster when entering the ROTC. Adapting to training will increase a cadets PMR which in turn will provide the Army with more prepared future soldiers. Further investigation into the mechanisms behind the relationship between FMC, and physical and neuromuscular fitness factors is needed.

Dynamic balance is necessary for many functional and tactical skills such as traversing rough ground in the field and staying upright with uneven carried weight distribution. Despite dynamic balance being necessary for many situations, the results of this study determined that dynamic balance was not a significant predictor of FMC. To understand if dynamic balance is influenced by the amount of physical activity during youth, this study tested the moderating effect of previous sport participation on the relationship between dynamic balance and FMC. Previous sport participation did not moderate the relationships between FMC and dynamic balance which can be interpreted as regardless of the amount of previous sport participation, the relationship between dynamic balance and FMC did not change. There are a few reasons why there may not be a relationship between dynamic balance and FMC. Dynamic balance has only more recently been included as a traditional FMC skill[262] whereas previously dynamic balance skills were categorized as underlying abilities for locomotive skills as opposed to stand-alone FMC skills.[263-265] It would be logical to suspect that there may be an indirect relationship between dynamic balance and FMC instead of a direct relationship based on the disagreement in the literature. The use of the anterior R/L difference has been identified as a reliable and valid method to measure dynamic balance in screening protocols for MSKI.[29,31,194,219] However, there are potential constraints with any tool, specifically that only measuring one direction allows for potential discrepancies. Decreased dorsiflexion has been found to limit one's ability to reach in the anterior direction.[191,257,266,267] It is possible that a cadet could have adequate dynamic balance that may not be captured by the modified Y-Balance because of limited dorsiflexion at the ankle limiting a cadet's reach. Contrarily, the relationship between dynamic balance and FMC may not have been captured simply due to the limited amount of cadets expressing poor dynamic balance. Only approximately 6% of this sample had R/L differences of ≥4cm which would place them at high risk of developing a MSKI, approximately 19% of cadets had between 2-3cm difference and the vast majority (approximately 76%) had differences <2cm. These results are like those of a study that was conducted previously on GEB ROTC cadets. Ericksen and colleagues[26] found that approximately 78% of cadets fell into the low-risk category for the anterior reach R/L difference. Due to a lack of diversity of the sample in terms of dynamic balance outcomes, it is quite possible that the relationship between FMC and dynamic balance could not be captured. Further research with a sample that includes a greater range of dynamic balance outcomes may provide clarity about whether the relationship between FMC and dynamic balance exists.

This study is the first to investigate the relationship between physical and neuromuscular fitness components and FMC in an ROTC population. No prior evidence supporting that FMC captures power exists. This study was the first study to establish a relationship between FMC and youth physical activity measured by previous sport participation. Additionally, the relationship between FMC and previous sport participation was nonlinear and followed similar trends found within the motor development literature where motor skills are learned more rapidly at the start of activity, then taper off due to a ceiling effect. In addition to the novelty of my study there were other strengths as well. There was no missing data in my study, which could be attributed to the chosen methods. Each research team member had to sign off on the data collection sheet prior to letting the cadet leave the station. Also, the research team member at the check in/out station reviewed the data sheet for completion before dismissing the cadets. Having this set up prevented cadets leaving without finishing the questionnaires or missing a station.

No study is without limitations, one limitation is that cadets reported some of the FMC task protocols as awkward. For example, the throw and kick did not allow for additional wind up prior to throwing or kicking, which is often a natural way to perform these tasks. This study did not allow for additional wind up to only capture the skill intended to be measured. For example, the throw should be a measure of object control, however, if a cadet takes multiple steps, they may include locomotion skills, which was not the goal of the task. Additionally, cadets did not have a target to aim for while jumping and were instructed to have a controlled landing during the vertical jump task in the FMC test battery. There may have been an opportunity for cadets to have better performance on the vertical jump had they had a target to reach for such as a Vertec. However, the Vertec has been noted by previous studies to overestimate true jump height and may actually be measuring reach ability instead.[268-270]Cadets also may have been able to jump higher and have greater power production had the landing been their choice of style. It was necessary to control the landing to have standard protocol and to satisfy the needs of the larger study which investigated landing biomechanics. In an attempt to combat the reported awkwardness of the tasks, multiple warmup trials were allowed until the cadets felt comfortable enough to perform the task as described. The FMC tasks were all measured by members of the research team which could leave room for measurement error. However, all the FMC measurements were objective measures, and all researchers were trained in the task in which they were measuring in an attempt to decrease the risk of measurement error. Researchers were trained in the task of measuring and had adequate practice including a pilot testing day with the cadets. The cadets that volunteered for the sample were recruited from a convenience sample which may allow for some selection bias since the recruitment was not randomly from a large sample. I chose to recruit from a convenience sample because I wanted to have the largest possible sample for collection which I was able to achieve. Another limitation of this study was that previous sport participation was self-reported by the cadets. Self-reporting was the only way to collect the data in this case. Additionally, previous research has indicated that self-reporting physical activity is reliable,[271] and the previous sport participation survey was based on previous methods used in military populations.[5,39,104,136] Additionally, there are many variables that could not be captured by this study including, intensity, duration, and frequency of participation in sport. Also, in the quantification of how much previous sport participation an individual had, one year of sport participation included if a cadet participated in a sport seasonally. Additionally, previous sport participation is not a direct surrogate for physical activity throughout youth since it only captures sport participation and no other physical activities such as participation in physical education. Cadets may not have participated in extracurricular athletics but could have participated in physical education courses which could provide adequate diverse physical activity experiences to encourage motor skill development. This study was the first study attempting to collect previous sport participation since the age of five, and to quantify the data in a simple and digestible method, it was decided to include seasonal sports as a single year of participation. Despite not including the multiple external variables related to sport such as intensity and frequency, this study did find a significant relationship between previous sport participation and FMC which mirrored previous research investigating motor development. Therefore, although there is room for improvement to capture greater information about previous sport participation, the questionnaire from this study can still provide valuable information about FMC to cadre and researchers alike.

Conclusion:

This study found that previous sport participation, both in years and number of sports, is positively related to FMC in ROTC cadets. The findings of this study support that youth sport participation can increase FMC into adulthood. This is beneficial because previous sport participation is relatively easy to assess with a questionnaire and can provide information about FMC in incoming cadets. Additionally, this study found that power explains a significant amount of variance in FMC score. Silvey and colleagues[12] speculated that physical and neuromuscular fitness factors would lead to better FMC in ROTC cadets, and this study supports that claim. There is opportunity to investigate screening protocols involving screening for previous sport participation and FMC in incoming cadets to inform cadre and research teams about potential motor skill deficits needing to be addressed early in a cadet's career. Research teams then can investigate potential training interventions that could train for FMC and increase the longevity and improve the performance of the Army's ROTC cadets. Continuing this line of research can provide avenues for increasing PMR in our Army and increase the longevity of our soldiers.

Chapter 3

Manuscript 2: Relationships Among the Individual Events of The Army Combat Fitness Test and Functional Motor Competence

Abstract

INTRODUCTION: Decreases in youth physical activity may be threatening physical military readiness (PMR) in the Army. PMR is measured by the Army Combat Fitness Test (ACFT) which includes six events (maximum deadlift - MDL, standing power throw - SPT, hand release pushups - HRP, sprint drag carry - SPD, plank -PLNK, and a 2-mile run -2MI). Functional motor competence (FMC) is developed through youth physical activity and may be an underappreciated factor of PMR. Currently there is limited evidence of how FMC is related to ACFT performance with the current information completed on previous versions of the ACFT. Therefore, the purposes of this study were to 1) identify the relationships among the individual events of the ACFT and FMC composite score and 2) determine the relationship between FMC composite score and ACFT total score. **METHODS**: 70 healthy cadets (female n=21; male n=49; age; 20.20±1.57yrs; height 174.98±9.36; weight 77.67±14.32) volunteered for this study. Cadets completed demographic questionnaires and an FMC test battery consisting of four tasks (long jump, ball throw, ball kick, and vertical jump). Best attempts were taken for each of the tasks, standardized, and then summed to calculate FMC composite score. The ACFT was completed using standard Army protocol. A stepwise multiple regression was utilized to assess the relationship between FMC and individual ACFT events and a multiple regression was used to ass the relationship between FMC and ACFT total score when controlling for sex. Alpha <.05 and change in R^2 values were assessed. **RESULTS:** SDC was the only event that was included in the model with sex and explained a significant amount of the variance in FMC score (R^2 = .541, p <

.001). ACFT total score was also a significant predictor of FMC composite score when entered into the model with sex, explaining a significant amount of the variance in FMC composite score ($p < .001$, $R^2 = .487$). **CONCLUSION:** High performance on the ACFT is related to better developed FMC. FMC may be an underappreciated factor in PMR and could be easily assessed early on in a cadet's career to inform cadre about potential ACFT performance. Future research should continue to investigate the relationship between FMC and PMR and potential screening and intervention protocols for ROTC cadets to increase PMR and the longevity of soldiers' careers.

Introduction

Reaching Physical Military Readiness (PMR), defined as the ability to meet all physical demands of any combat or duty position, accomplish the mission and continue to win[11] is a major concern for the Army. PMR requires a high level of neuromuscular and physical fitness such as muscular strength and endurance, power, dynamic balance as well as aerobic and anerobic endurance.[11,13] Decreases in youth physical activity in recent decades may threatening PMR because individuals may be entering the Army underprepared for the intense physical training associated with tactical training.[13,19] It is estimated that only 24% of children and adolescents meet the physical fitness guidelines set by the CDC[98] and only 20-26% of 5–19-year-olds meet the national 60-minute physical activity guidelines.[99] The Reserve Officers Training Corps (ROTC) is a collegiate military program providing up to 60% of commissioned officers across all military branches. The ROTC is typically a 4-year program with recruiting beginning in late high school and early college.[84,88]

ROTC cadets are required to take collegiate courses and participate in physical and tactical specific training to maintain PMR which includes running, crawling, limited sleep, limited access to food and water.[8,10,84] A cadet's physical abilities upon entering the ROTC program influences performance on standardized testing, their overall success in the program, and ultimately their job placement upon graduation. The current training protocols have not been adjusted to account for the current state involving the decreases in youth physical activity. Motor skills can only develop through structured diverse physical activity experiences. Without adequate participation in physical activity throughout youth cadets may enter the ROTC program with motor skill deficits resulting in an inability to perform physical training and military specific tasks safely[11,12,24,19,20,22,100] which could be influencing the high rates of musculoskeletal injury in ROTC cadets.[1,2]

PMR is currently measured using the Army Combat Fitness Test (ACFT) which is an intense six event fitness assessment. The ACFT was implemented in 2019 and has gone through many major revisions including changes to scoring and removal of the leg tuck event (replaced by the plank). The original version of the ACFT did not include sex and age adjusted scoring as scoring was based on the type and expectations of different job duties. Due to approximately 85% of female military personnel failing the test[83] major changes were made to how the ACFT was scored. The current version of the ACFT includes six events (hex bar deadlift, standing power throw, hand release pushups, sprint drag carry, plank, and a 2-mile run) and scoring is sex and age adjusted.[8,46,83]

Recent declines in youth physical activity may be leading to decreased motor skill competence in young adults entering the ROTC. This has led to research focused on identifying methods to screen for potential motor skill deficiencies in ROTC cadets and to try to understand how these deficiencies may impact PMR.[11] Functional motor competence (FMC) is defined as the coordination and control required to perform a wide range of motor skills[12] and was developed based on the literature surrounding motor competence in children. Motor competence is developed through diverse physical activity experiences throughout youth and is generally defined as the degree to which an individual can perform goal-directed human movement.[12,18-20,23,101,102,103] FMC and motor competence are defined similarly but the population specific context is different. Motor competence is used to promote childhood physical activity to increase long term health outcomes,[19-21,23,100-102] whereas FMC is focused on tactical physical performance performance.[19-21,23,100-102] Traditional FMC skills are plyometric movements which include locomotive skills like jumping, hopping, skipping, running and object projection skills like catching, throwing, kicking and hitting.[24,28] Both locomotive and object projection skills are required for the advanced unilateral and bilateral tasks in combat.[13]

The only published study investigating FMC in ROTC cadets is by Terlizzi and colleagues[12] who identified a relationship between FMC level (FMC composite score split into tertials) and ROTC cadet performance on the ACFT. Cadets in the low FMC category (<25th percentile) had lower scores on the ACFT compared to cadets in the high (>75th percentile) FMC category. This study was conducted with the original version of the ACFT which did not account for age and sex in the scoring. Since the ACFT is a measure of PMR, having low FMC could be a major obstacle to high performance on the ACFT and thus achieving PMR. The relationships between individual ACFT event performance and FMC is also unknown. Each event measures different physical abilities and requires unique motor skills to accomplish. It is logical to assume that some events in the ACFT would require greater FMC than others, such as the sprint drag carry versus the plank. Each event measures different physical abilities and requires unique motor skills to accomplish. It is logical to assume that some events in the ACFT would require greater FMC than others, such as the sprint drag carry versus the plank. The sprint drag carry is a multi-system, multi-joint event that requires not only high cardiorespiratory and muscular endurance but also a high amount of coordination. Whereas the plank is stationary and is only considered a measure of muscular endurance. If the speculations about what FMC measures are correct then the events that require more advanced motor skills would have stronger relationships with FMC than the events that require less advanced motor skills. Since the ACFT is utilized by the Army as their measure of PMR, understanding if ACFT total score is predictive of FMC can shed light on the relationship between FMC and PMR. There is a need to investigate the relationship between each ACFT event and FMC to support the use of FMC screening to determine specifically how improving FMC can inform training for the ACFT.

Currently there is only one published study identifying the relationship between FMC and ACFT performance, this study only investigated FMC and total score of the original ACFT. It is logical to assume that some of the events may require more motor skills than others (i.e., sprint drag carry vs plank) therefore only testing ACFT total score may not be providing the entire picture. Additionally, the revisions of the ACFT have been significant so it is essential to determine if the relationship between FMC and the current ACFT exists. Therefore, the purposes of this study are 1) identify the relationships among the individual events of the ACFT and FMC composite score and 2) determine the relationship between FMC composite score and ACFT total score.

Methods

Participants: 70 Cadets were recruited from the Golden Eagle Battalion (GEB) which consists of 5 schools: Marquette University (Milwaukee, WI) which hosts the GEB, UW-

Milwaukee (Milwaukee, WI), UW-Parkside (Kenosha, WI), Milwaukee School of Engineering (MSOE) (Milwaukee, WI), and Concordia University (Mequon, WI). Descriptives by sex can be viewed in table 1. Consent was obtained through distribution of a written document, answering questions, and cadets providing written consent on the day of data collection. Inclusion criteria included: 1) being between the ages of 18-40; 2) being injury and pain free and being able to participate in normal PT sessions; 3) being actively enrolled in the ROTC program. Exclusion criteria includes: 1) actively on profile for an injury/have physical activity restrictions that would prevent them from completing the study requirements; 2) is a course participant and not officially enrolled as an ROTC cadet. Cadets who met the inclusion criteria and gave written consent were entered into the study and were provided with a participant ID. All research team members were trained on all the stations with multiple practice sessions and pilot testing with the ROTC cadets. Additionally, all measures were objectively collected using reliable and valid tools and were not subject to interpretation by the research team.

Procedures: Cadets were divided into flights of five cadets. The flights were scheduled every 30 minutes which provided cadets adequate time to get through the stations before the next flight arrived. Data collection was scheduled for two-hour sessions across four days which allowed for up to five flights cadets (25 cadets total) to get through the protocol per data collection session. Cadets wore their standard training attire consisting of a standard issue Army black T-shirt and shorts and tennis shoes. Cadets were asked to do a short warmup which involved taking two laps around the gym (equating to approximately 400m) and then completing 20 jumping jacks, 15 squat jumps, and 10 burpees.

As part of the protocol for a larger study cadets rotated between 5 stations which included 1) Check in/out & questionnaires 2) standing long jump (distance) 3) ball throw (velocity) and ball kick (velocity), 4) maximal vertical jump (height), and 5) Y-balance. However, for this study only the data from stations 1-4 were used. To try to decrease the risk of cadets standing and waiting for a station, the order that cadets completed the stations was not controlled. The cadets were directed to go to the next open station by the research team member at the station they were currently at. Cadets were encouraged to work on their questionnaires if there was downtime in between stations.

STATION 1: Check in/out & questionnaires - A member of the research team oversaw checking cadets in, obtaining written consent, providing participant ID numbers and paperwork, and then checking cadets out at the completion of all tasks. Cadets were assigned a participant ID number which was used throughout the study to protect their privacy. Cadets were provided clipboards and pens to fill out the demographics survey and a Previous Military Participation Survey. Paper copies of each survey were chosen to decrease the risk of missing data due to cadets not having access to a phone or computer, not having access to Wi-Fi, and/or any other technical difficulties. In addition to the surveys, cadets were provided with the data collection sheet. The cadets brought the clipboards with them to each station which were then handed to the research personnel at each station. When the cadets had completed all the stations and associated paperwork, they returned to the check-in station to turn in the completed surveys and data collection sheet. The researcher at the check-in station verified that all the sections were completed properly before dismissing the cadet.

Questionnaires: Demographics: Age, height, weight, if the cadets participated on an ROTC related team (e.g., ranger buddies, etc.,), whether the cadet exercised or not the day of collection, and sex were collected to characterize the sample. Gender was collected to characterize the sample and to acknowledge those who may identify as something other than their sex assigned at birth. Sex was collected because differences in jump landing biomechanics and MSKI risk exist between males and females. Previous military experience was collected to characterize the sample and to be used in analysis if determined to be an impacting factor. Those who have prior military experiences may have more experience in the tactical training and have more experience in participating in the ACFT compared to those without prior military experience which could allow for greater performance on the ACFT despite their FMC.

STATION 2: Standing Long Jump Distance (Part of FMC Battery) The equipment used in this station included athletic tape, to indicate where a cadet would start and a tape measure, to measure the distance the cadet jumped. Cadets were instructed to stand with their toes behind a tape line which was perpendicular to the tape measure. Cadets were instructed to complete the task with a form that is most comfortable for them but specifying that the cadets must jump with both feet and stick the landing. The distance jumped was taken from the back of the cadet's heel closest to the starting position. Five trials were recorded and the best of the five trials was taken for analysis. A trial was considered unsuccessful if the cadet lost balance resulting in their feet moving from landing position, the cadet jumped with one foot instead of two, or if the cadet jumped for height instead of depth.

STATION 3: Throwing and kicking velocity (Part of FMC Battery) The equipment that was utilized to measure throwing and kicking velocity: tennis balls for throwing and 20cm playground balls for kicking, athletic tape to mark the starting position and target, a radar gun (Bushnell Outdoor Products, Overland, KS) to measure the velocity of the ball being thrown or kicked, and a net to protect the researcher recording the data and catch the balls. For both the throw and kick cadets were instructed to stand behind a tape line seven meters away from a net. Facing the net, the cadets were instructed to aim for a tape target but informed it was not necessary to hit the target. Cadets were instructed to use form that was most comfortable for them without any additional wind up meaning that both feet needed to remain planted for the throw and the stance leg needed to remain planted for the kick. Ball speed was recorded using a radar gun in miles/hour, which was later converted to m/s during data processing. Five trials were recorded, and the fastest trial was used for analysis. A trial was considered unsuccessful if the ball did not reach the radar gun or if the cadet moved their feet from the starting position.

STATION 4: Vertical Jump Height (Part of FMC Battery) The equipment that was utilized for this station included two MyoMotion inertial measurement unit (IMU) (Noraxon USA, Scottsdale, AZ) with the needed setup to use them (i.e., a computer, transducer, etc.,), to measure pelvic and tibial axial acceleration; a 2D video camera (Insta360 One RS 4K action camera, Arashi Vision Inc., Guangdong, China), to record video to help with the identification of the jump phases; and athletic tape, to indicate the starting position. One MyoMotion IMU was affixed to the cadets' distal medial tibia of the right limb and a second IMU was affixed to the posterior pelvis to collect acceleration data at 200Hz. The accelerometer data and video data were collected to define jump phases. Both 2D video and acceleration are common methods to collect biomechanical data during landing tasks.[158,171,173,177,208,230,231,234,249-254] Cadets were instructed to stand with the center of their feet on a tape line placed approximately 2 meters away from the 2D camera in the sagittal view, and to jump for maximal height trying to land as close to the starting position as possible to ensure they are as close to center frame for the camera and reduce visual distortion.[255] Cadets were instructed to complete the task with a form that is most comfortable for them, having some form of landing, cued by telling the cadets to not land with straight legs, and then returning to the starting position. No additional instruction about how the cadets should jump, or land was provided. The highest jump of the three jumps was used for analysis. A trial was considered unsuccessful if the cadet landed on one-foot, lost balance during landing, or if they landed outside of the camera frame.

The Army Combat Fitness Test (ACFT): The ACFT was conducted at Marquette University in early spring and within 3 weeks of the initial testing day a make-up testing day was conducted for those who were graders for the first test and/or those who were unable to participate in the earlier date. The ACFT was conducted in a standard protocol with Army personnel.

ACFT events: The ACFT includes six events: 1) Three Repetition Maximum Deadlift (MDL), 2) Standing Power Throw (SPT), 3) Hand Release Push-Up (HRP), 4) Sprint-Drag-Carry (SDC), 5) Plank (PLK), and 6) Two-Mile Run (2MR). The MDL involves lifting the maximum amount of weight possible using a hex bar for three reps and maximal weight was used for scoring. The SPT involves throwing a 10 lbs. medicine ball backward and overhead for maximum distance and the greatest distance thrown was used for scoring. The HRP involves completing as many hand-release push-ups as possible in two minutes. Total amount of reps was used in scoring. The SDC involves conducting a 5 x 50-meter shuttle for time. The cadets start out by sprinting, then dragging a sled with 90 lbs. in plates, then lateral shuffling, then a kettlebell farmers carry, then finish with a sprint. Total time of completion was used for scoring. The plank event involves maintaining a plank for as long as possible with total time held in plank event was used for scoring. The 2MR involves running two miles for time on a measured outdoor course with total time used for scoring. An excel document including both individual event scores and total score was provided by the cadre for analysis.

Data Analysis:

Data were filtered through the MyoMotion system to eliminate noise and correct drift then visually inspected to ensure the MyoMotion algorithm adequately filtered the data. The specifics of the filtering and drift correction parameters are proprietary to the MyoMotion software and were not able to be accessed despite contacting the company directly. Three time points were identified visually in the synched video within the MyoMotion application, and the identification labels of "start", "take off", and "initial contact" were placed. The "start" time point was identified as the frame where the hips begin to move in the posterior direction visible in the 2D video. "Take off" was defined as the point where the feet were no longer in contact with the ground in the 2D video. "Initial contact" was the time point when the feet first touched the ground immediately after jumping. All MyoMotion acceleration data were exported directly into an excel spreadsheet for analysis including the identified labels. FMC represents one's ability to move their body through space therefore it was essential to provide the cadets autonomy in the way the jump was accomplished. Therefore, cadets were able to use any form that was comfortable for them which did not allow for one specific standard way that a cadet completed the task. Due to the novelty of the protocol used in this study, previous protocols for identifying events using acceleration data were not applicable. Therefore, visual identification and labeling of the time points was utilized. The labeled acceleration data were processed with a MATLAB code that identified the labels and reported the time points that had been placed by the investigator. "Time to take off" was defined as the time from the "start" of the countermovement until "take off". Jump height was calculated using the following equation: $\frac{9.81 \times (\text{flight time})2}{8}$.[28] Flight time was collected from the accelerometer data and was defined as the duration of time spent in the flight phase calculated by subtracting time of "initial contact" by the time of "takeoff".

FMC composite score was calculated using the best score from each of the FMC tasks (standing long jump distance, ball throwing velocity, ball kicking velocity, and vertical jump height). Since all the tasks in the test battery measured different skills and had different units of measurement it was necessary to standardize these scores. Therefore Z-scores were calculated for the best attempt of each task by subtracting the mean from each score and dividing that by the standard deviation.[11] The mean and standard deviations for each task were: long jump (cm) = 197.28 ± 37.38; Throw (m/s) = 19.35 ± 3.96; Kick (m/s) = 17.59 ± 2.75; Vertical Jump (m) = 0.39 ± 0.10. Then FMC composite score was calculated by summing the z-scores for each task.[11] Negative values for FMC composite score were the result of a cadet performing the task below the population mean, so when the mean was subtracted, a negative number was presented. Positive values for FMC composite scores indicated were the result of a cadet performing the task above the population mean, so when the mean was subtracted, a positive number was presented. Since the standardization of the tasks are population based, FMC composite score can only be interpreted within the population.

ACFT data was obtained from the cadre in a spreadsheet which included all cadets' individual event scores and total scores. The adjusted scores were transferred to a deidentified spreadsheet for analysis. The best attempt for each event was used for individual event scoring and the total score was the sum of the individual event scores. The event score card can be viewed in APPENDIX I.

Statistical Analysis:

Descriptive statistics were run for the demographic variables of age, sex, height, weight, and previous military experience (table 1). Data were tested for normality using QQ plots, histograms, and Shapiro-Wilks tests. All data were found to have approximately normal distribution. Since most cadets were between the ages of 18-21, age was not included in the regression analyses. Age should be accounted for in comparisons between prepubescent vs pubescent individuals, due to the significant growth that comes with puberty, or comparisons between young adults vs older adults, due to the differences in muscle mass and bone integrity. Sex was included as a controlling variable since FMC score is not sex adjusted. Military science year was also included as a controlling variable since cadets who have been in the ROTC program longer may have more experience participating in the ACFT which could influence how they perform on the ACFT regardless of FMC score. Sex will be coded using dummy coding since it is categorical.

Table 12 Descriptive Means by Sex for All Variables

Variable	***Females* *(mean ± SD)*** *(n = 21)*	***Males* *(mean ± SD)*** *(n = 49)*	***Combined* *(mean ± SD)*** *(n = 70)*
Age (years)	20.61 ± 2.08	20.02 ± 1.28	20.20 ± 1.57
Height (cm)	166.91 ± 7.00	178.44 ± 8.06	174.98 ± 9.36
Weight (kg)	66.20 ± 9.93	82.58 ± 13.09	77.67 ± 14.32
ACFT Total Score	534.04 ± 39.87	543.10 ± 50.55	540.38 ± 47.50
Deadlift score	92.90 ± 8.79	94.30 ± 7.38	93.88 ± 7.79
Standing Power Throw Score	87.57 ± 9.74	85.20 ± 10.72	85.91 ± 10.42
Hand Release Pushup Score	91.71 ± 7.34	90.91 ± 9.23	91.15 ± 8.66
Sprint Drag Carry Score	92.85 ± 0.87	92.65 ± 1.35	92.71 ± 8.66
Plank Score	86.00 ± 13.05	93.02 ± 10.67	90.91 ± 11.79
2 mile run Score	83.00 ± 12.81	87.00 ± 16.89	85.80 ± 15.79
FMC composite score	-10.43 ± 9.94	4.47 ± 9.80	0.00 ± 11.94

A stepwise multiple linear regression was used to determine the relationship between individual ACFT events (deadlift, standing power throw, hand release push up, sprint drag carry, plank, 2-mile run) FMC composite score with the inclusion of the controlling variables of sex and military science year. Since the relationship between the individuals ACFT events and FMC is unknown a stepwise entry method was utilized. A multiple regression was utilized to assess the if ACFT total score was a predictor for FMC score while controlling for sex and military science year. The variables were entered if they reach a significance level of <0.05 and removed if significance was >.100. Correlations were run for all ACFT scores and FMC scores within the models and can be found in table 3 and were interpreted with the following scale: very strong correlation (0.90-1.0), strong correlation (0.70-0.90), moderate correlation (0.50-0.70), weak correlation (0.30-0.50), and negligible correlation (0-0.30). All variables were tested for multicollinearity as well as normality tests. If any variables had a variance inflation factor of >10, the variable was removed from analysis. Alpha was set at .05 and change in r-square values were assessed.

Results

The mean and standard deviations of the descriptives for each variable can be viewed in table 2. Overall, 70 cadets (women n = 21; age =20.20 ± 1.57, height = 174.98 ± 9.36; weight = 77.67 ± 14.32) volunteered for participation in this study and no cadets were excluded for any reason and there was no missing data in my study. There was a relatively even distribution of cadets in terms of Military Science (MS) year with 24.2% being MSI, 31.4% being MSII, 24.2% being MSIII, and 20% being MSIV. Approximately 45% of the cadets participating in the study reported being on an ROTC related competitive team (e.g. Ranger buddies, etc.) and approximately 39% of cadets reported doing some form of exercise the morning of collection. Women represented 30% of the cadets that participated in this study which is larger than the previous study investigating FMC and ACFT performance[11] and the reported 15.6% of women in the Army.[258] Additionally, 25.7% of cadets had at least 1 year of previous military participation with majority being from the national guard.

Significant positive correlational relationships were found between five of the six ACFT events. SDC had the strongest relationship with FMC ($r = .452$; $p < .001$) followed by the 2mi run ($r = .387$, $p < .001$), then maximal deadlift ($r = .386$, $p < .001$), then plank ($r = .352$, $p < .001$), and then the standing power throw ($r = .316$, $p = .004$). The hand release push up was the only event that did have a statistically significant relationship with FMC ($r = .169$, $p = .081$).

The only variables that explained a significant amount of the variance in the model and thus were included in the regression model were sex ($p < .001$, $R^2 = .331$), SDC score ($p < .001$, change in $R^2 = .210$), and military science year ($p = .014$, change in $R^2 = .032$). The remaining five events did not significantly contribute to the model after accounting for sex and SDC and therefore were not included in the model. Sex alone contributed to 33.1% of the variance and the inclusion of SDC score explained for an additional ~21% of the variance in FMC score. The inclusion of military science year accounted for ~3% of the variance in FMC score.

ACFT total score had a significant positive relationship with FMC composite score (r = .708, p <.001). The ACFT total score was a significant predictor (<.001) for FMC score, accounting for ~17% of the variance in FMC score ($p < .001$, change in R^2 =.171). Military science year was also a significant predictor and accounted for ~4% of the variance in FMC score ($p = .014$, change in R^2 =.044).

Table 3 **Pearson Correlation Values Between FMC, ACFT Scores, Sex, and Military Science Year**

	ACFT total score	*MDL score*	*SPT score*	*HRP score*	*SDC score*	*PLNK score*	*2MI score*	*SEX*	*MS year*
FMC composite score	.708***	.386***	.316**	.169	.452***	.352***	.387***	.576***	-.077

** Indicates significance of <.05; ** indicates significance of <.01; *** indicates significance of <.001. MDL = maximal deadlift, SPT = standing power throw, HRP = hand release pushup, SDC = sprint drag carry, PLNK = plank, 2MI = 2-mile run, MS year = Military science year.*

Discussion

The first purpose of my study was to identify the relationships among the individual events of the ACFT and FMC composite score. The results of my study found significant positive relationships between five of the ACFT events and FMC (Table 3). However, only sex , SDC score and military science year were found to explain a significant amount of the variance in FMC score. The second purpose of my study was to determine the relationship between FMC composite score and ACFT total score. Additionally, sex, military science year, and ACFT total score were found to be significant predictors for FMC composite score and explained a significant amount of the variance in FMC.

Our results are comparable to the only other published study investigating FMC and ACFT performance in ROTC cadets.[11] Terlizzi and colleagues[11] found that FMC and ACFT total score had a significant positive relationship (r = 0.762) which is like the results my study found (r = .708). Terlizzi and colleagues[11] investigated FMC as a predictor for ACFT total score, whereas my study investigated ACFT as a predictor of FMC since the ACFT is the Army's method of assessing PMR and therefore should include all the fitness factors encompassed by FMC. Despite these differences, my study had many similarities with Terlizzi and colleagues'[11] study. One major consistent finding between studies included women having lower FMC composite score compared to males. Both studies had less females than males with my study reporting 30% of the sample being female and Terlizzi and colleagues reporting 24% of the sample being female. The FMC mean composite scores between sex were similar for both studies with females having negative mean and males having positive mean and the total mean being zero. Terlizzi and colleagues[11] investigated FMC in categories (low: <25 percentile; moderate: 25=75 percentile; high: >75 percentile) and found no females falling into the high category for FMC composite score. Although I did not categorize by FMC score, I found that the range of FMC composite score for females was between -33.14 and 5.43 whereas the range for males was between -23.08 and 19.60. The FMC composite score mean for females in my study was -10.43±9.94 and males was 4.47±9.80. My results were like Terlizzi and colleagues[11] with females having a mean FMC composite score of −6.08±2.67 and males having a mean of 1.97±4.74. The mean for FMC in females was lower in my study than in the previous study.

Which could possibly be explained by the differences in population between studies, with my study having a smaller sample size with a higher percentage being female allowing for a larger percentage of the sample having negative FMC compared to the previous study. It is evident that a large amount of the females in my study made up the bottom percentile of FMC composite score for the population based on the mean and the range reported. This is a rather concerning finding for both studies since women are at increased risk of sustaining a MSKI compared to men.[77,93,145,155,176,272-275] Further research is needed to understand why females have lower FMC composite scores and if there is a relationship between FMC and MSKI.

I decided to do a post hoc analysis investigating if FMC is predictive of ACFT performance to make my data more comparable to the existing literature and because FMC can be assessed relatively easily. If FMC can predict ACFT performance, then these results would further support the utilization of FMC assessments early in a cadet's career. Individual linear regressions were run for each of the ACFT events as the dependent variables and FMC as the independent variable. Sex was included in the models, and FMC was found to be a significant predictor for five of the six individual ACFT events and ACFT total score. My results are like those found in the previous study,[11] with FMC explaining a significant amount of variance in ACFT total score when added into the model with sex ($R^2 = .261$, $p < .001$). In my model, sex alone only accounted for 0.8% of the variance in ACFT total score, this is logical since the ACFT now utilizes a sex and age adjusted scoring method. Terlizzi and colleagues found that sex accounted for 62% of ACFT performance and age accounted for an additional 5% of ACFT performance. I found FMC explained 25.3% of the variance in ACFT total score, which is unlike the results from Terlizzi and colleagues[11] who found FMC to explain 9% of the variance in ACFT total score with sex and age. However, when they investigated FMC and ACFT in only men with age as the sole controlling variable, FMC was more comparable to my study with FMC accounting for 25.9% of variance in ACFT total score. Although FMC scores were similar between studies,[11] ACFT total scores were not. As stated, since the completion of Terlizzi and colleagues'[11] study the ACFT has undergone major changes including the removal of the leg tuck event, replaced by the plank, and the addition of sex and age adjusted scoring. Terlizzi and colleagues[11] reported the ACFT total score mean for females and males as 273.8±67.4 and 459.2±62.3 respectively. Whereas my study reported the ACFT total score mean for females and males as 534.04 ± 39.87 and 543.10 ± 50.55 respectively. Although it is possible that some variation in the scores could be from the sample in my study having better performance, it is also possible that the differences are from the new method of scoring implemented by the Army. Females scoring significantly lower on the ACFT in Terlizzi and colleagues'[11] study may explain why FMC contributed more in the model based on male cadets as opposed to when combined with both sexes. The results of my study are encouraging since I was able to find that FMC accounted for 25.3% of variance in ACFT total score in a combined sex sample.

Terlizzi and colleagues[11] did not investigate the relationship between individual ACFT event scores and FMC making it difficult to compare to my study. However, Terlizzi and colleagues reported the means for each event for each FMC category. Across all events there appears to be an increase in performance from the low FMC category to the high FMC category. Our study showed similar trends with positive relationships between FMC score and ACFT event score. One main difference between my study and the previous study is I investigated if the events had statistical relationships with FMC composite score through a stepwise multiple regression analysis and the associated Pearson's correlations. SDC was found to be the only event included in the final model with sex out of all the six events meaning that SDC explained a significant amount of the variance in FMC composite score. SDC score had a statistically significant positive relationship with FMC (r=.452), the deadlift, 2mi run, plank, and standing power throw also had smaller statistically significant positive relationships with FMC ranging from .316-.387. This can be interpreted as there may be meaningful relationships between the individual events and FMC but when all the events are put into the model together the variation that the deadlift, 2mi run, plank, and standing power throw events explain is already accounted for by SDC and thus is not needed in the final model. So, it is not that deadlift, 2mi run, plank, and standing power throw do not have meaningful relationships with FMC, it is simply that they are accounted for in the final model by SDC. This finding is logical because the SDC event has the most components and therefore challenges multiple physiological systems (cardiorespiratory, muscular, etc.). The Army describes the SDC event as testing for four physical and neuromuscular fitness factors including muscular strength and endurance, and anaerobic power and endurance.[8,10,46,276] The SDC is the only event listed to work on multiple physiological systems out of all the six events and is the event that is often considered to be a difficult event for cadets to complete. FMC is developed through the learning of locomotion and object control skills and has been speculated to be related to multiple fitness factors such as muscular strength, power, and agility. Many of the traditional FMC skills are classified as plyometric movements, which are often used in training to promote increased muscular power.[277,278] Cardiorespiratory and muscular endurance is also indirectly trained through the activities that develop FMC (such as structured sport performance).[20,104,241] Therefore, it makes sense that the events that include multiple physiological systems would have stronger relationships with FMC. The HRP was the only event that did not have a statistically significant relationship with FMC and only had a negligible relationship with FMC (r=.169). A potential reason for why the HRP event was the only event to not have a relationship with FMC could be due to how it is performed. For the HRP event, cadets are required to perform as many HRPs in 2 minutes as possible, whereas the other events do not have a specific time restriction. Perhaps this does not allow for an accurate representation of muscular endurance based on the time restriction.

In my post hoc analysis I found that when accounting for sex, FMC was a significant predictor for five of the six events. Due to the sex and age adjusted scoring, sex was not found to be a significant predictor in any of the individual events other than the plank (R=.075; p = .021) and the range of the R^2 values were .000 - .075, so sex did not account for more than 7.5% of any of the events. Like my initial findings, FMC explained the most amount of variance in the SDC event. FMC explained 31.4% of variance in the SDC and the order of the ACFT individual events based on the percentage of variance explained by FMC was 1) SDC (R^2 = .314, p <.001), 2) standing power throw (R^2 = .222, p <.001), 3) deadlift (R^2 = .178, p <.001), 4) 2-mile run (R^2 = .167, p <.001), 5) plank (R^2 = .132, p =.041), and 6) hand release pushup (R^2 = .058, p = .050). These results make sense since the individual ACFT events that require multiple systems had the most variance explained by FMC. It is also encouraging that FMC is a significant predictor for the SDC and standing power throw since cadets commonly struggle with those events. Our results are a positive step in identifying if FMC is an appropriate assessment tool to identify deficits in incoming cadets that can provide information about where a cadet may need to improve to reach PMR. Future research should focus on potential screening mechanisms for FMC and how they are related to performance on the ACFT and future interventions that could account for deficiencies that cadets may be entering the program with.

Table 4 Post Hoc Analysis of FMC as a predictor of ACFT Performance.

	ACFT total score	*MDL score*	*SPT score*	*HRP score*	*SDC score*	*PLNK score*	*2MI score*
SEX	.008	.007	.011	.002	.000	.075*	.014
FMC composite score and SEX	.261***	.178***	.222***	.058	.314***	.132*	.167***

*R^2 values from the linear regressions. * Indicates significance of <.05; ** indicates significance of <.01; *** indicates significance of <.001. MDL = maximal deadlift, SPT = standing power throw, HRP = hand release pushup, SDC = sprint drag carry, PLNK = plank, 2MI = 2-mile run.*

Overall, FMC has a strong relationship with ACFT total score and its individual events. Since the ACFT is the standardized method of assessing PMR in the Army, FMC may be an underappreciated contributor for PMR. This is important because assessing FMC is relatively easy and requires minimal equipment. Scientific evidence supports neuromuscular training can be implemented to increase motor competence and physical performance in youth athletes.[279-282] Although neuromuscular training to improve FMC has not been investigated in ROTC cadets, it is logical to assume that FMC can be trained and improved over time even into adulthood. Therefore, assessing FMC may be a valuable method to screen for deficits and implementing additional training interventions to ensure cadets are able to consistently meet PMR standards early in a cadet's career.

My study was the first study to investigate the relationship between FMC and individual ACFT events and ACFT total score with the new age and sex adjusted scoring. Since there is only one other study in existence investigating FMC in ROTC cadets and ACFT scores, my study has provided further evidence to support the relationship between FMC and PMR. In addition to the novelty of my study there were other strengths as well. There was no missing data in my study, which could be attributed to the chosen methods. Each research team member had to sign off on the data collection sheet prior to letting the cadet leave the station. Also, the research team member at the check in/out station reviewed the data sheet for completion before dismissing the cadets. Having this set up prevented cadets leaving without finishing the questionnaires or missing a station. Another strength in this study was the distribution of sex within my sample. Terlizzi and colleagues[11] had a larger sample size than my study, with the final sample being 90 cadets after accounting for drop out and missing data. Although my study only had 70 cadets, my study had a higher distribution of female cadets than the previous study.[11] The previous study,[11] authors reported having just over 24% of their sample being female, whereas my study reported 30% female participation. The inclusion of more female participants provides further support for that the relationship between FMC and ACFT performance exists regardless of sex.

Limitations exist in every study and my study is no exception. One limitation of this study is that cadets reported some of the FMC task protocols as awkward. For example, the throw and kick did not allow for additional wind up prior to throwing or kicking, which is often a natural way to perform these tasks. This study did not allow for additional wind up to only capture the skill intended to be measured. For example, the throw should be a measure of object control, however, if a cadet takes multiple steps, they may include locomotion skills, which was not the goal of the task. The FMC tasks were all measured by members of the research team which could leave room for measurement error. However, all the FMC measurements were objective measures and all researchers were trained on the task in which they were measuring in an attempt to decreased the risk of measurement error. Researchers were trained in the task that they were measuring and had adequate practice including a pilot testing day with the cadets. The cadets that volunteered for the sample were recruited from a convenience sample which may allow for some selection bias since the recruitment was not randomly from a large sample. I chose to recruit from a convenience sample because I wanted to have the largest possible sample for collection which I was able to achieve.

Conclusion

FMC development throughout youth is essential for high performance on the ACFT especially on the SDC event. The decline in youth physical activity may be threatening PMR across the Army. Our study identified positive relationships between FMC and ACFT performance. This may suggest that FMC may be an underappreciated contributing factor to PMR. Future research is needed to identify how assessing FMC may be utilized in the ROTC for screening and training protocols to account for the lack of FMC development in youth. Perhaps early intervention in the junior ROTC programs in high school could be beneficial in increasing performance and the longevity of cadets' careers, however, this is speculative and requires scientific support.

Chapter 4:

Manuscript 3: The Relationship Between Functional Motor Competence and Drop-Landing Biomechanics in Army Reserve Officers Training Corps Cadets.

Abstract

INTRODUCTION: The drastic decline in physical activity throughout youth may be threatening physical military readiness (PMR) in the Army. PMR is made up of not only the ability to physically meet the demands of all duty positions but also being free from injury. Diverse physical activity during youth is essential for the development of Functional Motor Competence (FMC) which may be an underappreciated factor of PMR. FMC is described as the ability to move one's body through space with better FMC development allowing for more effective and safer movement. Despite this, FMC has never been directly connected to biomechanics. Biomechanical analyses of landing tasks are a common way that injury risk is assessed in the military but require a large amount of time and training to utilize. FMC screening is time efficient and requires minimal training, therefore if FMC is related to biomechanics there is opportunity for FMC to be utilized to screen for potentially injurious biomechanics. Therefore, the purpose of this study is to identify if FMC is related to the landing biomechanics of 2D sagittal plane joint angles and landing force. **METHODS**: 70 healthy cadets (female n=21; male n=49; age; 20.20±1.57yrs; height 174.98±9.36; weight 77.67±14.32) volunteered for this study. Cadets completed demographic questionnaires and an FMC test battery consisting of four tasks (long jump, ball throw, ball kick, and vertical jump). Best attempts were taken for each of the tasks, standardized, and then summed to calculate FMC composite score. 2-dimensional sagittal plane trunk, hip, and knee joint angles were extracted from the point of maximum knee flexion during the landing of the vertical jump task. Additionally, IMU acceleration data was collected to calculate peak landing force in Newtons. A stepwise multiple regression was utilized with FMC as the dependent variable and the biomechanical variables as the independent variables. Alpha <.05 and R^2 values were assessed. **RESULTS:** Significant correlational relationships were found with all the biomechanical variables. Knee flexion angles was the only variable included in the final model with sex and accounted for a significant amount of variance in FMC score (R^2 = .413, p < .001). **CONCLUSION**: FMC is highly correlated with landing biomechanics with greater amounts of trunk, hip, knee flexion during landing being associated with greater FMC. Cadets with higher FMC had more favorable landing biomechanics which could be protective against MSKI. There is potential for future research to focus on how FMC may be related to potentially injurious biomechanics and thus screening protocols for incoming cadets to decrease MSKI and increase PMR in the Army.

Introduction

Declines in youth physical activity have threatened the Army in reaching Physical Military Readiness (PMR) which is defined as the ability to meet all physical demands of any combat or duty position, accomplish the mission and continue to win.[11] PMR not only includes a soldiers physical ability to perform any task assigned to them but also remaining free from injury.[11,13] The Reserve Officers Training Corps (ROTC) is a 4-year collegiate military program that provides scholarships to aid in obtaining a college degree.[84,88] Therefore, recruiting typically begins late in high school and early in college.[84,88] The ROTC provides up to 60% of commissioned officers making it the largest source officers across all military branches[84,88] but have alarmingly high rates of musculoskeletal injury (MSKI) at 40.1%.[2] It is required of ROTC cadets to maintain PMR while taking classes and participating in physical training involving many physically and mentally demanding tactical tasks such as prolonged running, crawling, limited sleep and limited access to food and water.[8,10,84] A cadet's physical abilities upon entering the ROTC program can influence their performance on standardized testing, their overall success in the program, and ultimately their job placement upon graduation. Currently only 24% of children and adolescents meet the physical fitness guidelines set by the CDC[98] and only 20-26% of 5–19-year-olds meet the national 60-minute physical activity guidelines.[99] Cadets may not be exposed to adequate amounts of physical activity throughout youth which could be resulting in cadets entering the program with an inability to meet PMR. Despite the negative trajectories in child physical activity, adjustments to the current training protocols have not been made to account for potential deficits in incoming cadets. The motor skills develop through diverse structured physical activity experiences and without these experiences an individual may not have the motor skills to safely accomplish advanced tasks.[11,12,24,19,20,22,100] Specifically, without adequate participation in physical activity throughout youth cadets may enter the ROTC program with motor skill deficits resulting in an inability to safely perform physical training and military specific tasks [11,12,24,19,20,22,100] which could be influencing the high rates of musculoskeletal injury in ROTC cadets.[1,2]

The decline in youth physical activity has prompted research focused on identifying methods to screen for potential motor skill deficiencies in ROTC cadets and understand how these deficiencies may be impacting PMR.[11] FMC is defined as the coordination and control required to perform a wide range of motor skills[12] and is based on the literature surrounding motor competence in children. Motor competence is generally defined as the degree to which an individual can perform goal-directed human movement[103] and is developed through diverse physical activity experiences throughout youth.[12,18-20,23,101,102] FMC is defined similarly to motor competence however the population specific context is different between FMC, which is focused on physical performance in tactical athletes, and motor competence, which is focused on promoting childhood physical activity.[19-21,23,100-102] Traditional FMC skills are considered plyometric movements and include locomotive skills (jumping, hopping, skipping, running) and object projection skills (catching, throwing, kicking and hitting) [24,28] which are required for advanced unilateral and bilateral tasks required of combat.[13]

Since FMC development includes being able to do advanced movement patterns that involve recruitment and coordination of multiple muscle groups, FMC has been speculated to be related to injury risk in ROTC cadets.[12] Adequate neuromuscular control is speculated to require a high amount of FMC development, therefore without sufficient FMC deficits in neuromuscular control may exist which could increase MSKI risk.[12] Adequate development of FMC during childhood may be an underappreciated factor influencing the ability to safely complete advanced neuromuscular tasks, and thus related to MSKI risk in military populations.[12] There are no current connections between FMC and known MSKI risk factors in military populations such as faulty movement patterns.

A common method to screen for faulty movement patterns in military populations is by evaluating jump landing biomechanics.[26,33,137] Jump landing tasks are widely used to assess MSKI risk in both civilian and military populations due to the dynamic nature of the task[33,137-148] and the established relationships to both acute MSKIs[149-151] and overuse MSKIs.[152-156] The exact biomechanical risk profile has not been established due to the complex nature of movement but multiplane movement variations during landing have been found to increase acute and overuse MSKI risk.[33,145,157-168]

Traditionally jump landing biomechanics have been assessed with in-laboratory methods such as using 3D motion capture and force plates.[169,170] However, in-laboratory biomechanical assessment is expensive and time consuming, making it unsuitable for field settings. 2D video analysis[175-177] is a field friendly alternative to reliably measure joint angles during landing in military populations.[33,137] 2D video analysis is comparable to 3D motion analysis for jump landing tasks having good to excellent reliability and excellent validity for identifying sagittal plane joint angles.[177,251,254] Therefore, 2D video analysis is a viable alternative for in-field testing when compared to 3D motion capture during jump landing tasks to measure joint angles in the sagittal plane.

Landing style is starting to be assessed with biomechanical analyses as a screening method for MSKI.[17,157,178] “Stiff” landing styles are characterized by landing with limited sagittal plane trunk, hip, knee, ankle flexion and high landing force.[157] “Soft” landing styles are characterized by landing with large amounts of sagittal plane trunk, hip, and knee flexion and low landing force.[157] A literature review by Yu and Garrett[166] identified that strain to ACL increases substantially when knee flexion is less than 60 degrees, with the most strain occurring between 15 and 30 degrees, whereas greater than 60 degrees does not strain the ACL.[166] Limited sagittal plane motion will encourage a landing style that relies on passive frontal plane restraining mechanisms to control the deceleration of the body increasing ACL injury risk.[188] Greater knee flexion angles, which is a characteristic of “soft” landing styles, are associated with better impact absorption, reducing the load placed on the lower extremities which is related to bone stress injuries.[17,33,157,178] Both the increased impact absorption and decreased strain on the ACL provides support for the “soft” landing style over the “stiff” landing style to decrease risk of injury.

Despite FMC often being described as the ability to move one’s body through space[2], research investigating the relationship between FMC and biomechanics does not exist in ROTC populations. Many speculations suggest that the amount of FMC a cadet has should directly influence their biomechanics,[11,12,20,22,23,283,284] however, there is no data to support these speculations. This is a major gap that needs to be addressed not only to provide evidence to support FMC as a concept, but also to support FMC being used to screen incoming cadets for potential movement deficits. Therefore, the purpose of this study was to identify if FMC is related to the landing biomechanics of 2D sagittal plane joint angles and landing force.

Methods

Participants: Seventy Cadets from were recruited from the Golden Eagle Battalion (GEB) which consists of 5 schools: Marquette University (Milwaukee, WI) which hosts the GEB, UW-Milwaukee (Milwaukee, WI), UW-Parkside (Kenosha, WI), Milwaukee School of Engineering (MSOE) (Milwaukee, WI), and Concordia University (Mequon, WI). Descriptives by sex can be viewed in table 1. Consent was obtained through distribution of a written document, answering questions, and cadets providing written consent on the day of data collection. Inclusion criteria included: 1) being between the ages of 18-40; 2) being injury and pain free and being able to participate in normal PT sessions; 3) being actively enrolled in the ROTC program. Exclusion criteria includes: 1) actively on profile for an injury/have physical activity restrictions that would prevent them from completing the study requirements; 2) is a course participant and not officially enrolled as an ROTC cadet. Cadets who met the inclusion criteria and gave written consent were entered into the study and were provided with a participant ID. All research team members were trained on all the stations with multiple practice sessions and pilot testing with the ROTC cadets. Additionally, all measures were objectively collected using reliable and valid tools and were not subject to interpretation by the research team.

Procedures: Cadets were divided into flights of up to five cadets. The flights were scheduled every 30 minutes which provided cadets adequate time to get through the stations before the next flight arrived. Data collection was scheduled for a two-hour session on four different days which allowed for up to five flights of cadets (25 cadets total) to get through the protocol. Cadets wore their standard training attire consisting of a standard issue Army black T-shirt and shorts and athletic shoes. Cadets were asked to do a short warmup which involved taking two laps around the gym (equating to approximately 400m) and then completing twenty jumping jacks, fifteen squat jumps, and ten burpees.

As part of a protocol for a larger study, cadets rotated between five stations which included 1) Check in/out & questionnaires 2) standing long jump (distance) 3) ball throw (velocity) and ball kick (velocity), 4) maximal vertical jump (height), and 5) Y-balance. However, for this study only the data from stations 1-4 were used. To try to decrease the risk of cadets standing and waiting for a station, the order that cadets completed the stations was not controlled. The cadets were directed to go to the next open station by the research team member at the station they were currently at. Cadets were encouraged to work on their questionnaires if there was downtime in between stations.

STATION 1: Check in/out & questionnaires - A member of the research team oversaw checking cadets in, obtaining written consent, providing participant ID numbers and paperwork, and then checking cadets out at the completion of all tasks. Cadets were assigned a participant ID number which was used throughout the study to protect their privacy. Cadets were provided clipboards and pens to fill out the demographics survey and a Previous Military Participation Survey. Paper copies of each survey were chosen to decrease the risk of missing data due to cadets not having access to a phone or computer, not having access to Wi-Fi, and/or any other technical difficulties. In addition to the surveys, cadets were provided with the data collection sheet. The cadets brought the clipboards with them to each station which were then handed to the research personnel at each station. When the cadets had completed all the stations and associated paperwork, they returned to the check-in station to turn in the completed surveys and data collection sheet. The researcher at the check-in station verified that all the sections were completed properly before dismissing the cadet.

Questionnaires: Demographics: Age, height, weight, sex, if the cadets were a part of an ROTC associated team, and if they had exercised the day of data collection were collected to characterize the sample. Gender was collected to characterize the sample and to acknowledge those who may identify as something other than their sex assigned at birth. Sex was collected because differences in jump landing biomechanics and MSKI risk exist between males and females.

STATION 2: Standing Long Jump Distance (Part of FMC Battery) The equipment used in this station included athletic tape, to indicate where a cadet would start and a tape measure, to measure the distance the cadet jumped. Cadets were instructed to stand with their toes behind a tape line which was perpendicular to the tape measure. Cadets were instructed to complete the task with a form that is most comfortable for them but specifying that the cadets must jump with both feet and stick the landing. The distance jumped was taken from the back of the cadet's heel closest to the starting position. Five trials were recorded and the furthest distance of the five trials was taken for analysis. A trial was considered unsuccessful if the cadet lost balance resulting in their feet moving from landing position, the cadet jumped with one foot instead of two, or if the cadet jumped for height instead of depth.

STATION 3: Throwing and kicking velocity (Part of FMC Battery) The equipment that was utilized to measure throwing and kicking velocity: tennis balls for throwing and 20cm playground balls for kicking, athletic tape to mark the starting position and target, a radar gun (Bushnell Outdoor Products, Overland, KS) to measure the velocity of the ball being thrown or kicked, and a net to protect the researcher recording the data and catch the balls. For both the throw and kick cadets were instructed to stand behind a tape line seven meters away from a net. Facing the net, the cadets were instructed to aim for a tape target but informed it was not necessary to hit the target. Cadets were instructed to use form that was most comfortable for them without any additional wind up meaning that both feet needed to remain planted for the throw and the stance leg needed to remain planted for the kick. Ball speed was recorded using a radar gun in miles/hour, which was later converted to m/s during data processing. Five trials were recorded, and the fastest trial was used for analysis. A trial was considered unsuccessful if the ball did not reach the radar gun or if the cadet moved their feet from the starting position.

STATION 4: Vertical Jump Height (Part of FMC Battery) The equipment that was utilized for this station included: two MyoMotion inertial measurement unit (IMU) (Noraxon USA, Scottsdale, AZ) with the needed setup to use them (i.e., a computer, transducer, etc.,), to measure pelvic and tibial axial acceleration; a 2D video camera, to record 2-Dimensional (2D) sagittal plane biomechanics; and athletic tape, to indicate the starting position. One MyoMotion IMU was affixed to the cadets' distal medial tibia of the right limb and a second IMU was affixed to the posterior pelvis to collect acceleration data at 200Hz. A 2D video camera, Insta360 One RS 4K action camera (Arashi Vision Inc., Guangdong, China), was placed approximately two meters away from the cadet viewing the right side of the cadet. The 2D video camera was recording the sagittal plane view of the cadet during the vertical jump task. Cadets were instructed to stand with the center of their feet on a tape line placed approximately 2 meters away from the 2D camera in the sagittal view, and to jump for maximal height trying to land as close to the starting position as possible to ensure they are as close to center frame for the camera and reduce visual distortion.[255] Cadets were instructed to complete the task with a form that is most comfortable for them, having some form of landing, cued by telling the cadets to not land with straight legs, and then returning to the starting position. No additional instruction about how the cadets should jump, or land was provided. The highest jump of the three jumps was used for analysis. A trial was considered unsuccessful if the cadet landed on one-foot, lost balance during landing, or if they landed outside of the camera frame.

Data Analysis:

Data were filtered through the MyoMotion system to eliminate noise and correct drift then visually inspected to ensure the MyoMotion algorithm adequately filtered the data. Three time points were identified visually in the synched video within the MyoMotion application, and the identification labels of “start”, “take off”, and “initial contact” were placed. The “start” time point was identified as the frame where the hips begin to move in the posterior direction visible in the 2D video. “Take off” was defined as the point where the feet were no longer in contact with the ground in the 2D video. “Initial contact” was the time point when the feet first touched the ground immediately after jumping. All MyoMotion acceleration data were exported directly into an excel spreadsheet for analysis including the identified labels. FMC represents one’s ability to move their body through space therefore it was essential to provide the cadets autonomy in the way the jump was accomplished. Therefore, cadets were able to use any form that was comfortable for them which did not allow for one specific standard way that a cadet completed the task. Due to the novelty of the protocol used in this study, previous protocols for identifying events using acceleration data were not applicable. Therefore, visual identification and labeling of the time points was utilized. The labeled acceleration data were processed with a MATLAB code that identified the labels and reported the time points that had been placed by the investigator. “Time to take off” was defined as the time from the “start” of the countermovement until “take off”. Jump height was calculated using the following equation: $\frac{9.81 \times (\text{flight time})2}{8}$.[28] Flight time was collected from the accelerometer data and was defined as the duration of time spent in the flight phase calculated by subtracting time of “initial contact” by the time of “takeoff”.

Peak TAA was identified using tibial IMU acceleration data and is defined as the largest positive peak immediately following the start of the landing phase.[34] Peak TAA was exported from MyoMotion in units of mG and then converted to force in Newtons for better comparisons to the existing epidemiological and performance literature. The following conversions will occur to get mG to N: $N = [(mG * 0.001) * 9.80665] * mass\ (kg)$

2D Biomechanics: The 2D videos[198,241-244] were analyzed using Dartfish Live S (Dartfish USA, Inc., Alpharetta, GA) by a single researcher with six years of experience, to measure sagittal plane trunk, hip, and knee joint angles during the landing phase of the vertical jump task. Trunk flexion was defined as the angle created by bisecting the trunk and a horizontal line with the apex of the angle at the center of the lateral hip approximately where the greater trochanter would be. Hip flexion was defined as the angle created by bisecting the thigh with a line parallel to the top of the thigh and bisecting the trunk with the apex of the angle at the center of the lateral hip approximately where the greater trochanter would be. Knee flexion was defined as the angle created by bisecting the shank and bisecting the thigh with a line parallel to the top of the thigh and the apex of the angle at the center of the lateral knee. Trunk, hip, and knee joint angles were collected at the point of maximum knee flexion and averaged over the three trials.

Functional Motor Competence (FMC): FMC composite score was calculated using the standardized best score from each of the FMC tasks (standing long jump distance, ball throwing velocity, ball kicking velocity, and vertical jump height). Since all the tasks in the test battery measured different skills and had different units of measurement it was necessary to standardize these scores. Therefore Z-scores were calculated for the best attempt of each task by subtracting the mean from each score and dividing that by the standard deviation.[11] The mean and standard deviations for each task were: long jump (cm) = 197.28 ± 37.38; Throw (m/s) = 19.35 ± 3.96; Kick (m/s) = 17.59 ± 2.75; Vertical Jump (m) = 0.39 ± 0.10. Then FMC composite score was calculated by summing the z-scores for each task.[11] Negative values for FMC composite score were the result of a cadet performing the task below the population mean, so when the mean was subtracted, a negative number was presented. Positive values for FMC composite scores indicated were the result of a cadet performing the task above the population mean, so when the mean was subtracted, a positive number was presented. Since the standardization of the tasks are population based, FMC composite score can only be interpreted within the population.

Statistical Analysis:

Descriptive statistics were run for the demographic variables of age, sex, height, and weight. Data were tested for normality using Q-Q plots, histograms, and Shapiro-Wilks tests. All data were found to have approximately normal distribution. Since most cadets were between the narrow range of ages of 18-21, age was not included in the regression analyses. Sex will be coded using dummy coding since it is categorical. The determination of the functional form of the relationships was determined to consider the possibility of non-linear relationships. This process involved assessing FMC composite score and the biomechanical variables both visually and statistically individually. Scatter plots were made with FMC composite score on the Y axis and biomechanics (trunk, hip, or knee flexion or peak landing force) was on the X axis. This process involved investigating linear, quadratic, and cubic fit lines for each scatter plot and assessing R-squared values. Followed by investigating linear models to assess which relationship functional type was the best fit for the biomechanical variables by adding in the original variable, then the quadradic and finally cubic and assessing the significance of the models.

A multiple linear regression was used to determine the relationship between landing biomechanics and FMC composite score when controlling for sex. Landing biomechanics were defined as the average trunk, hip, knee joint angle extracted at maximum knee flexion and peak landing force calculated using the IMU acceleration data. Since the relationships among biomechanics and FMC are unknown a stepwise entry method was utilized. The variables were entered if they reach a significance level of <0.05 and removed if significance was >.100. All variables were tested for multicollinearity as well as normality tests. If any variables had a variance inflation factor of >10, the variable will be removed from analysis. Alpha was set at .05 and change in r-squared values were assessed.

Results

Table 5 Descriptives for All Variables by Sex

Variable	***Females (mean ± SD)*** *(n = 21)*	***Males (mean ± SD)*** *(n = 49)*	***Combined (mean ± SD)*** *(n = 70)*
Age (years)	20.61 ± 2.08	20.02 ± 1.28	20.20 ± 1.57
Height (cm)	166.91 ± 7.00	178.44 ± 8.06	174.98 ± 9.36
Weight (kg)	66.20 ± 9.93	82.58 ± 13.09	77.67 ± 14.32
FMC composite score	-10.43 ± 9.94	4.47 ± 9.80	0.00 ± 11.94
Peak Landing Force (N)	8264.54 ± 2412.90	11668.73 ± 1913.55	10647.47 ± 2589.14
Average Trunk Angle (degrees)	34.60 ± 12.45	40.13 ± 14.64	38.47 ± 14.16
Average Hip Angle (degrees)	83.63 ± 20.81	97.94 ± 28.12	93.65 ± 26.82
Average Knee Angle (degrees)	84.73 ± 12.11	91.56 ± 17.54	89.51 ± 16.32

Table 6 Pearson's Correlation Coefficients among Biomechanics and FMC Composite Score

	FMC composite score	
	Pearson's Coefficient (R)	Sig. (p)
Trunk Angle	.264	.014
Hip Angle	.342	.002
Knee Angle	.419	.000
Peak Landing Force	.240	.023

The mean and standard deviations of the descriptives for each variable can be viewed in table 5. Overall, seventy cadets (women n = 21; age =20.20 ± 1.57, height = 174.98 ± 9.36; weight = 77.67 ± 14.32) volunteered to participle in the study. There was a relatively even distribution of cadets in terms of Military Science (MS) year with 24.2% being MSI, 31.4% being MSII, 24.2% being MSIII, and 20% being MSIV. Approximately 45% of the cadets participating in the study reported being on an ROTC related competitive team (e.g. Ranger buddies, etc.) and approximately 39% of cadets reported doing some form of exercise the morning of collection. Women represented 30% of the cadets that participated in this study which is larger than the previous study investigating FMC and ACFT performance[11] and the reported 15.6% of women in the Army.[258] Additionally, 25.7% of cadets had at least 1 year of previous military participation with majority being from the national guard.

All the biomechanical variables had significant positive relationships with FMC as determined by the Pearson correlation coefficients (trunk flexion angle [R=.264. p = .014], hip flexion angle [R=.342, p = .002], knee flexion angle [R= .419, p = <.001], and peak landing force [R=.240, p = .023]). The only variables that contributed a significant amount of the variance in FMC and thus were included in the final model was sex (p< .001, R^2 = .322) and knee flexion angle (p = .001, change in R^2 = .091). Trunk and hip flexion angles and peak landing force were not included in the final model. Sex alone contributed to 32.2% of the variance and the inclusion of knee angle explained for an additional ~9% of the variance in FMC score. Peak landing force was the only biomechanical variable with a non-linear relationship with FMC composite score (Figure 5) and since Pearson's correlations assume a linear relationship, it should be interpreted with caution.

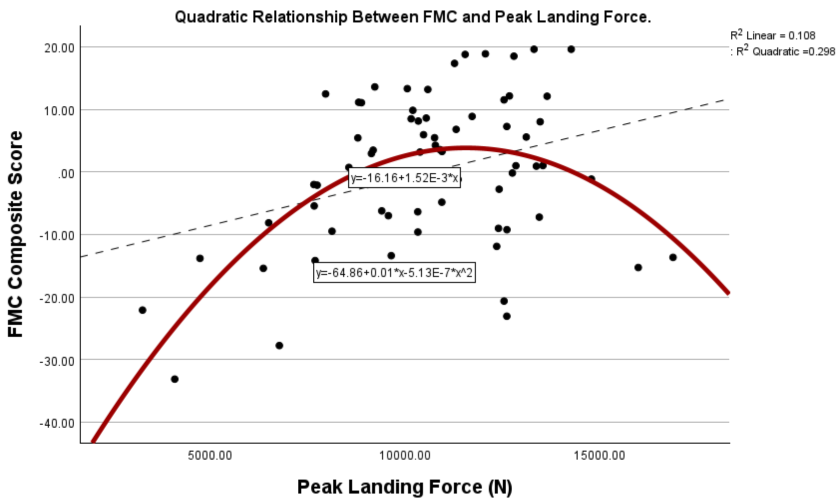

Figure 5 **the red line is the best fit non-linear line, the dotted line is the linear relationship**

Discussion

To my knowledge, my study is the first to investigate the relationship between FMC and biomechanics in an adult ROTC population. The purpose of my study was to identify the nature of the relationship between FMC and landing biomechanics. My study found that only knee flexion angle during landing explained a significant amount of the variance in FMC score when added into the model with sex. Neither trunk and hip flexion angle nor landing force contributed significantly to the model, however they did have significant correlational relationships with FMC. Trunk, hip, and knee flexion all had significant positive relationships with FMC indicating that those with greater trunk, hip, and knee flexion, which are protective against MSKI especially at the knee,[32,148,157,166,167,188,248] had higher FMC.

FMC has been speculated to be related to injury risk in ROTC cadets.[12] FMC development includes being able to do advanced bilateral and unilateral movement patterns that involve multiple motor unit recruitment and coordination.[12] FMC is required to have adequate neuromuscular control, deficits in neuromuscular control may increase MSKI risk potentially suggesting that FMC is an underappreciated factor influencing MSKI risk in military populations.[12] FMC is commonly described as the ability to move one's body through space safely and effectively.[27] However, FMC had not been directly connected to landing biomechanics in ROTC cadets previously. I found that only knee angle during landing explained a significant amount of variance in FMC and that cadets with greater knee flexion angles having greater FMC composite score. These results may provide some insight into how FMC may influence movement and potentially be related to injurious biomechanics.

Previous research supports that "soft" landings, characterized by greater trunk, hip, and knee flexion during landing tasks, can attenuate load placed on the body specifically at the knee.[32,140,148,157,166,167,188] Knee flexion angles during landing of less than 60 degrees increases the risk of MSKI such as ACL injury substantially.[166] Additionally, knee flexion angels of >90 degrees is protective due to multiple mechanisms including co-contraction of the hamstrings and decreases in ground reaction force.[166] My study found that only one cadet had knee flexion angles of <60 degrees, 54.3% of cadets had knee flexion angles of <90 degrees and 45.7% of cadets had knee flexion angles of ≥90 degrees. Even though a large percentage of cadets exhibited knee flexion angles of ≥90 degrees with varying FMC composite scores, the majority of cadets had knee flexion angles ranging from 48 to 90 degrees during landing. Since increased knee flexion is protective against MSKI, the significant positive relationship between knee flexion and FMC may provide insight towards how FMC may impact MSKI risk.

Increased trunk and hip flexion angles are also protective against MSKI[32,148,165,166,188,248,285,286] and my results indicated significant positive relationships with FMC for both trunk and hip flexion. However, my results did not find trunk angle nor hip angle to explain a significant amount of variance in FMC score when knee flexion was added into the model which was why they were not included in the final model. This can be interpreted as there may be meaningful relationships between the individual variables and FMC but when the biomechanical variables are put into the model together the variation that trunk and hip flexion angle explain is already accounted for by knee flexion and thus is not needed in the final model. So, it is not that trunk and hip flexion do not have meaningful relationships with FMC, it is simply that they are accounted for in the model by knee flexion. More trunk, hip, and knee flexion was significantly correlated to higher FMC. This finding is a very important first step to understanding how FMC may impact MSKI risk in ROTC cadets. Although I did not directly investigate MKSI risk in this study, evidence supports that greater trunk, hip, and knee flexion during landing is protective against MSKI.[32,148,165,166,188,248,285,286] Further research investigating the relationship between FMC and biomechanics across tasks is needed to establish if FMC can be utilized as a screening protocol for potential movement deficits. My study suggests that FMC may be able to capture individuals who have biomechanics related to MSKI.

An interesting finding in my study was the non-linear relationship between peak landing force and FMC, characterized by those on the low end of peak landing force and those on the high end of peak landing force had the lowest FMC. Due to these findings, I conducted post-hoc analyses to determine if there were similar trends with peak landing force and maximum jump height and power as measured by reactive strength index (RSI). Interestingly, peak landing force had a similar non-linear relationship with both jump height and RSI (Figures 6 and 7). This could be interpreted as those who jumped the highest had peak landing force that was around 1000N. Initially I hypothesized that those with high FMC would have lower peak landing force, which is still true in this sample, however, there were cadets with lower FMC who had lower peak landing force than the cadets with higher FMC. Potential reasons why this non-linear relationship exists is because those who produce low peak landing forces were producing limited power and subsequently did not jump high. The cadets on the high end of peak landing force also produced limited power and did not jump high. This finding may be due to allowing cadets to choose whatever jump form that felt comfortable for them.

Thirteen cadets chose to perform their maximal jump in a tuck jump style which involves jumping for maximal height and while in the air they bring their knees up towards their chest. Tuck jumps are often used in military training as per recommendations from the current physical training doctrine.[8] Research has shown that tuck jumps have been associated with higher ground reaction forces and frontal plane projection angles.[287] Figure 8 shows a scatter plot of FMC composite score and peak landing force split into those who performed a tuck jump and those who did not. Figure 8 shows that the tuck jumpers were mainly clustered around the center of the graph rather than on the right side of the graph. Suggesting that the cadets performing a tuck jump were not producing high force with low vertical jump performance and FMC. A study investigating kinetic responses during landing of multiple different plyometric tasks within eight division-1 track and field athletes found that the peak landing force between tuck jumps and countermovement jumps were similar[288] which loosely supports what may be occurring in our data. Comparisons between cadets who performed a tuck jump and those who did not are difficult to assess statistically since only ~18.6% of cadets actually performed a tuck jump but the means for peak landing force and jump height were similar among the two groups were similar and can be viewed in table 7.

Table 7 Calculated means by jump style

	Tuck (n=13)	*No tuck (n=57)*
Peak Landing Force (N)	10742.210 ± 1717.839	10556.730 ± 2753.617
Vertical Jump Height (m)	0.393 ± 0.059	0.383 ± 0.111
FMC composite score	0.807 ± 7.055	-0.194 ± 12.848
Power (RSI)	0.470 ± 0.114	0.378 ± 0.115

Although the non-linear relationship between FMC and peak landing force and jump performance and peak landing force may not be able to be explained by jumping style, it is possible that landing style could explain this relationship. Stiff landing style discourages force dissipation upon landing which may explain why higher peak landing force was present with lower FMC composite score.[32,188] This is further supported because softer landing style expressed by greater trunk, hip, and knee flexion were found in those who had greater FMC composite score. Therefore, the nonlinear findings could be accounted for by landing style which may suggest that in my study those who had better jump performance and better FMC also displayed more favorable jumping mechanics than those who had lower FMC (e.g., the group with high peak landing force). Since there is a considerable amount evidence supporting that high peak landing forces can increase the risk of developing a MSKI[148,157,160,166,209,228,289,290] it is encouraging to see that those with higher FMC had preferable landing biomechanics than those with lower FMC. These findings can positively impact the Army because screening for potentially injurious biomechanics requires extensive time and training, whereas screening for FMC does not. There is potential to utilize FMC as a screening method which could indirectly inform Army leaders about how a cadet moves. Cadets with low FMC could then be placed in additional neuromuscular training to increase FMC development which in turn could indirectly train the cadets to move their bodies in a safer and more efficient manner. However, further research is needed to confirm the relationship between FMC and biomechanics in more than one task and direct connection are needed between FMC and MSKI to fully understand what FMC is able to screen for.

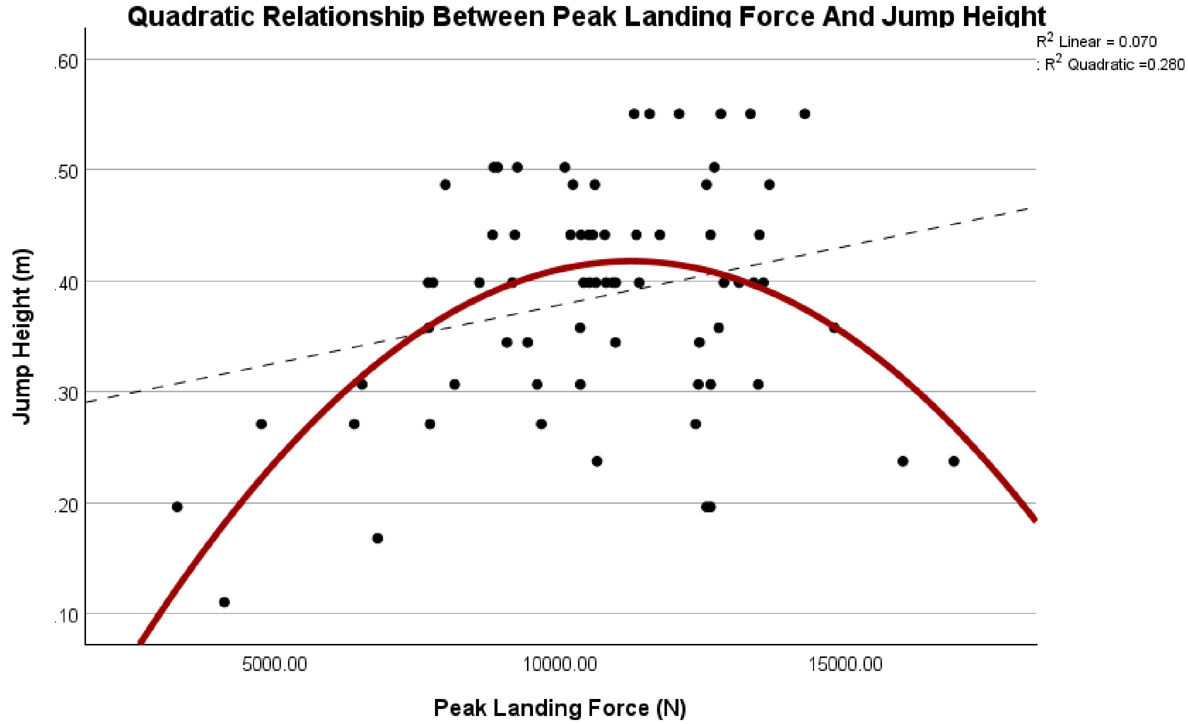

Figure 6 the red line is the best fit quadratic line, the dotted line is the linear relationship

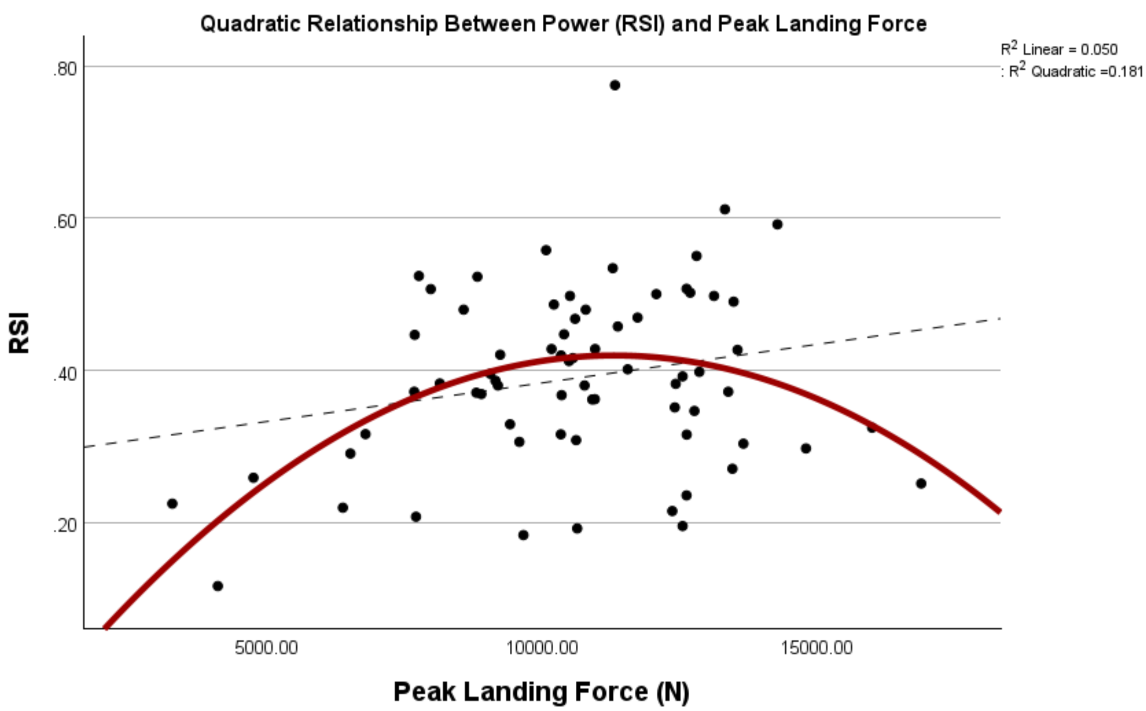

Figure 7 the red line is the best fit quadratic line, the dotted line is the linear relationship

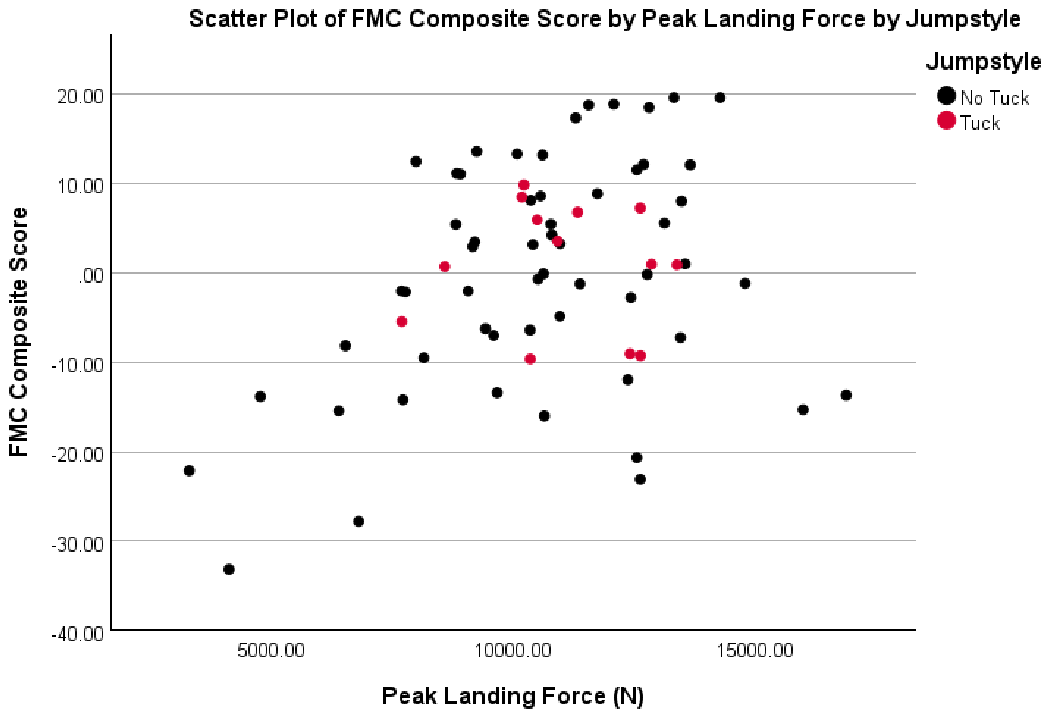

Figure 8 the red markers indicate the cadets who performed a tuck jump.

My study was the first study to provide evidence to support that FMC is related to biomechanics. Specifically, that higher FMC is related to more protective landing biomechanics. This is a major strength because it not only fills the gaps in the existing literature but also provides support for future research to be conducted on FMC in ROTC cadets. In addition to the novelty of my study there were other strengths as well. There was no missing data in my study, which could be attributed to the chosen methods. Each research team member had to sign off on the data collection sheet prior to letting the cadet leave the station. Also, the research team member at the check in/out station reviewed the data sheet for completion before dismissing the cadets. Having this set up prevented cadets leaving without finishing the questionnaires or missing a station.

My study did have some limitations, one being that I utilized 2D analysis of discrete joint angles instead of 3D analysis or multi-joint coordination analyses. The primary reason for the methods I chose was to make the most field appropriate protocol possible since this was the initial stages of exploration into this topic. An important goal when conducting initial investigations into a topic is to have a diverse and large sample, therefore having a field appropriate protocol was essential to capture all the data necessary in a short amount of time. Future research should investigate FMC and biomechanics with other methods to provide further data. Additionally, although the majority of the data collected in my study was objective, the 2D angular data could be considered subjective because the joint angles are based on the interpretation of the researcher. However, to increase the reliability of extracting the angular data, only one researcher with six years of experience in extracting 2D joint angles was assigned to that task. Additionally, in an attempt to remain as consistent as possible three visual points were established for placement of the angles. The three points included the approximate location of the greater trochanter/center of the hip joint, the center of the lateral knee, and the lateral malleolus of the ankle. These methods were how I tried to make sure the subjective 2D angular measurements maintained as objective as possible. Finally, MyoMotion utilizes proprietary algorithms to filter the data, so the exact formulae being utilized is unknown. Additionally, the signal to noise ratio were not inspected with the acceleration data due to the data being filtered and exported through the MyoMotion application. In an attempt to ensure the data was filtered properly, visual inspections of the acceleration data were performed.

Conclusion

My study supports that low FMC may be related to potentially injurious biomechanics during landing such as decreased knee flexion which was previously only a speculation. These findings are the first step in identifying if FMC is related to not only biomechanics but also potentially injurious movement patterns. Further research is necessary to identify the relationships between FMC and biomechanics in other tasks to truly identify the mechanism behind the relationship. There is potential to utilize FMC screening to identify motor skill deficits in ROTC cadets which can provide researchers and cadre valuable information about movement. Additionally, since my study only investigated one mechanism of MSKI there is a need for future research to investigate the relationship between FMC and MSKI directly either retrospectively through medical charts, or prospectively through MSKI monitoring. Physical training then could be adjusted to focus on training for general motor skill development before complex tactical skills with the overall goal of improving FMC and decreasing MSKI risk.

Chapter 5: Summary Of the Impact of the Current Work on the Existing Body of Literature

Introduction

FMC is a relatively new specific area of the traditional motor competence literature in child populations.[11,12,18,19,22,101,105,241-243,291,292] Despite FMC being based on motor competence which has a plethora of supporting evidence, the data to support FMC in adult tactical athletes was minimal with only one previous study positively relating FMC and ACFT performance.[11] Research investigating potential screening protocols and interventions utilizing FMC assessments cannot begin without understanding if FMC in adults is supported by data. Overall, it seems that FMC should support that FMC encompasses many physical and neuromuscular fitness factors[12] some of which may be measured by the ACFT[8,11,12,46,276] and that FMC may be related to biomechanics.[12] Prior to my study, there was no comprehensive evidence that indicated whether the physical and neuromuscular fitness factors of power and dynamic balance were related to FMC.

The ***expected outcomes*** of this study were that I would determine if power and dynamic balance are related to FMC which would inform us about whether FMC was able to capture the variables that it has been speculated to influence. I would identify the moderating strength of previous sport participation on FMC in an adult active population which provides insight on additional screening methods for incoming cadets. I also expected to understand the relationship among performance (ACFT), movement (biomechanics), and FMC. These results were expected to have an important positive impact because they provided strong evidence to help support FMC to be used as a screening tool for ROTC cadets. . To provide essential information to holistically approach the training of cadets and ensure there is a base level of motor development among the group before more advanced tactical training occurs.

My study contained ***highly innovative improvements*** on the status quo that have persisted for decades in epidemiological and performance studies in military populations. The ***first innovation*** was that Identified physical and neuromuscular fitness components which had only been speculated to be related to FMC but had not been supported by evidence previously. Identifying relationships among physical and neuromuscular fitness factors, sport participation, and FMC provided essential evidence to support the use of the FMC test battery to screen for deficiencies that incoming cadets may have upon entering the ROTC program. My ***second innovation*** was that I not only confirmed that a relationship between FMC and ACFT total score existed following the revisions to the ACFT scoring protocol, but I also investigated the relationships among FMC and the individual ACFT tasks. Only one previous paper examined the relationship between FMC and ACFT total score, but this was prior to the updates relating to how total score was calculated. Additionally, no previous study had explored the relationship between FMC and the individual ACFT tasks. Confirmation of the relationship between FMC and ACFT total score was the first step in understanding if FMC testing can be used as a method of screening for cadets to identify those who need additional training prior to participating in the ACFT. Investigating how individual event scores were related to FMC provided valuable information about whether one of the events required better FMC development than others which can inform future training protocols. My ***final*** innovation was that I investigated how biomechanics were related to FMC. No previous study has made direct comparisons between FMC and biomechanics.

Primary Findings by Specific Aim

Aim 1: Previous sport participation was related non-linearly to FMC which was expressed by a larger increase in slope for FMC within the first five years of participation and with participating in four sports. Prior to this study the only evidence supporting the increase in motor competence with physical activity was in youth populations most of which did not use sport participation as a measure of previous physical activity.[20,102,103,105,241,244,292-296] Although previous sport participation is not a direct surrogate for measure physical activity throughout youth since it is not able to measure many external factors associated with physical activity, it is a valuable method to gain an understanding on one's participation in structured physical activity. This study found that previous sport participation was related to higher FMC providing support to further investigate self-reported previous sport participation as an indirect method of quickly screening for FMC in large populations. Previously, power and other neuromuscular components such as dynamic balance were only speculated, not confirmed, to be incorporated with FMC.[12] This study found that power was in fact related to FMC with the cadets exhibiting higher power measured by reactive strength index also having higher FMC. This study was a first step in providing evidence to support FMC as a measurement of physical and neuromuscular fitness factors in a tactical athlete population. There is potential for previous sport participation to be utilized as a screening method during recruitment that can inform cadre about potential deficits in FMC that cadets may be entering with, particularly muscular power. Additionally, having evidence to support that power being incorporated in the FMC measurement provides support for the use of FMC testing in ROTC cadets since many functional and tactical skills require adequate power.

Aim 2: One previous study had investigated the relationship between FMC and performance on the ACFT however the study was conducted prior to major changes made to the ACFT including the adoption of sex and age adjusted scoring and the replacement of the leg tuck with the plank.[46,297] Since the ACFT is the Army's method of assessing PMR, the ACFT should measure multiple physical and neuromuscular fitness factors that should be included in measuring FMC.[8,11,12] This study supports that both the five ACFT and the ACFT and the ACFT were significant predictors of FMC. Those who performed better on the ACFT had better FMC. Additionally, a post hoc analysis provided evidence for the continued support of the goals of the original study by Terlizzi and colleagues[11] which was to understand the relationship between FMC and PMR in ROTC cadets. Since the ACFT has age and sex adjusted scoring, finding similar results with FMC being a significant predictor of ACFT performance both in ACFT total score and individual event scores strengthens the argument that FMC could be used to screen incoming cadets. Since PMR is necessary for all aspects of a career in the Army, ensuring that an individual service member's motor skills are adequate to support high level performance is essential. Currently, there is not a standardized method for screening for predicted performance on the ACFT in ROTC cadets or otherwise. The identification of FMC as a predictor of performance on the ACFT provides support for future research to investigate potential screening and intervention protocols utilizing FMC.

Aim 3: Prior to this study, the relationships between biomechanics and FMC were theoretical my study provided evidence to support that this relationship exists in ROTC populations.[12] The theoretical framework that exists to support FMC exists in child populations, and even the research in child populations is limited. Much of the research[11,12,18-20,22,101-

[103,105,240-244,280,284,292,295,298] surrounding movement and FMC investigates movements that are based on performance outcome measures as a goal of identifying a child's ability to perform a movement.[23] Whereas this study focused on FMC and its relationship with biomechanics that can be related to MSKI. Although it cannot be said that one method is better than the other since they are based on different immediate goals, both support the same long-term goals of keeping individuals healthy throughout their life. This study opens a new avenue for exploration into the potential of utilizing FMC in part of a screening protocol for MSKI in ROTC cadets. Although this study did not directly connect FMC to MSKI risk it did identify that cadets who had "softer" landings, expressed by greater trunk, hip, and knee flexion which are supported to be protective against MSKI [32,148,165,166,188,248,285,286] also had higher FMC. Those with less trunk, hip, and knee flexion had lower FMC which has been supported to increase MSKI risk especially at the knee. [32,148,165,166,188,248,285,286] Interestingly there was not a linear relationship between peak landing force and FMC, the higher the peak landing force, the lower the FMC. However, this study also found that the lower peak landing force also had lower FMC. The relationship between FMC and peak landing force was non-linear, which with a post hoc analysis, was consistent with the relationship between peak landing force and jump performance (maximal jump height and power). Cadets who performed poorly on the vertical jump task had lower FMC, whether that simply was that they did not jump high nor produce much power so therefore they had low peak landing force, or they performed more of a tuck jump where they didn't jump as high but forcefully returned their feet to the floor. This does suggest there may be ideal jumping mechanics to optimize performance along with protect against MSKI and that those with high FMC may be utilizing at least some of these mechanics.

Limitations

No study is without limitations. One limitation is that I used a product outcome measure of FMC, which simply means I only utilized the outcome of the task rather than the process of completing the task. Both of these methods are valid and often utilized in motor competence literature,[23] however, the process outcome approach may provide better insights to true FMC abilities. However, there are no known published process orientated approaches that have been utilized in adult tactical athlete populations, so this study utilized the information available based on the only published FMC and ROTC study,[11] an unpublished dissertation on FMC and ROTC,[24] and the vast literature measuring motor competence in youth.

Another limitation of my study was that previous sport participation was self-reported by the cadets which was the only way to collect the previous sport participation data. Previous research has indicated that self-reporting physical activity is reliable,[271] and the previous sport participation survey was based on previous methods used in military populations.[5,39,104,136] Additionally, there are many variables that could not be captured by the previous sport participation survey including, intensity, duration, and frequency of participation in sport. Also, in the quantification of how much previous sport participation an individual had, one year of sport participation included if a cadet participated in a sport seasonally. Additionally, previous sport participation is not a direct surrogate for physical activity throughout youth since it only captures sport participation and no other physical activities such as participation in physical education. Cadets may not have participated in extracurricular athletics but could have participated in physical education courses which could provide adequate diverse physical activity experiences to encourage motor skill development. This study was the first study attempting to collect previous sport participation since the age of five, and to quantify the data in a simple and digestible method, it was decided to include seasonal sports as a single year of participation. Despite not including the multiple external variables related to sport such as intensity and frequency, this study did find a significant relationship between previous sport participation and FMC which mirrored previous research investigating motor development. Therefore, although there is room for improvement to capture greater information about previous sport participation, the questionnaire from this study can still provide valuable information about FMC to cadre and researchers alike.

Another limitation is that my study only investigated power and dynamic balance as two physical and neuromuscular fitness factors of FMC. Although both fitness factors are needed for functional and tactical skills, there are many other components that are needed that were not included such as muscular endurance and strength, cardiorespiratory endurance, etc. However, power is brought up many times as a necessity component to perform well on the ACFT[8,12,276] which is a major reason why it was chosen for this study. Additionally, power, specifically RSI, can be measured using the vertical jump task allowing for a condensed protocol to be used which resulted in relatively time efficient data collections.[28] ROTC cadet's time is valuable, not only are they full time college students, but they also have many obligations to the Army which require a large allotment of time outside of their typical day to day schedules. Therefore, it was essential to minimize time outside of the cadets' normal schedule for data collection. Furthermore, the addition of the Y-Balance task did not add much time to the overall protocol and provided valuable data that is relative to military research.[193]

Another limitation about the method used to assess power and dynamic balance is that there are many methods of measuring power and dynamic balance directly. Both measuring RSI[28,32,174,209-213,256,299] and using the Y-Balance[29-31,191,195,197,218,219,257,300,301] are valid and reliable methods for measuring power and dynamic balance but there is room for more direct measurements. RSI is the gold standard method for measuring power indirectly by measuring the speed of the stretch shortening cycle rather than actually measuring power in watts. Despite this being a surrogate measurement for power, it is one of the most commonly used method in the sport performance literature for measuring functional power justifying the use in my study.[28,32,174,209-213,256,299] Although it is common to use the Y-Balance test as a measure of collecting data on dynamic balance in multiple populations,[29-31,191,195,197,218,219,257,300,301] using the difference between the right and left limb is typically used in MSKI risk assessment only. I chose this measure since it is a common method of assessing deficits in dynamic balance which are related to MSKI in military populations.[197,300] However, there are many different methods for assessing dynamic balance that I could have utilized such as the dynamic leap test[192,302] or measuring Y-Balance composite score which includes all of the directions rather than just the anterior reach. Utilizing different methods to collect dynamic balance data could have provided more data on one's dynamic balance capabilities outside of investigating bilateral differences.

This study utilized in-field biomechanical assessment, which although valid and reliable [158,176,177,303,304] does not provide as much data as collecting with 3D motion capture and force plates. Due to the time constraints associated with trying to collect from a large sample of cadets, it was decided to choose a field appropriate measures to capture biomechanical data. Another limitation was that I chose to use acceleration data to calculate peak landing force instead of measuring force directly with a force plate. My main reason for doing this is that I did not have access to portable force plates. Additionally, using the in-lab force plates would not have been time consuming and been a barrier to collecting from as many cadets as possible. However, the utilization of acceleration data to gather data on force is a common method for many tasks and has been found to be reliable [34,171,173,208,230,231,234,237,305] which supports the use of this method to collect peak landing force. Another limitation is that the MyoMotion IMUs utilize a proprietary algorithm to filter their data which prevented me from ensuring the data were filtered correctly. I did perform a visual inspection of the acceleration data and the data appeared to be filtered correctly. However, not being able to confirm this during processing is a major limitation. I also did not check the signal to noise ratio of the acceleration data.

The FMC tasks were all measured by members of the research team which could leave room for measurement error. However, all the FMC measurements were objective measures, and all researchers were trained on the task in which they were measuring in an attempt to decrease the risk of measurement error. Researchers were trained in the task of measuring and had adequate practice including a pilot testing day with the cadets. The cadets that volunteered for the sample were recruited from a convenience sample which may allow for some selection bias since the recruitment was not randomly from a large sample. I chose to recruit from a convenience sample because I wanted to have the largest possible sample for collection which I was able to achieve.

Impact: This study provides important information to support the initial phases of research investigating the relationship between FMC and PMR in ROTC cadets. Gaining more knowledge on the relationship between FMC and ACFT which supports the future utilization of the easily assessed FMC as a mechanism to generally understand how well a cadet may perform on the ACFT. Additionally, this study has supplied evidence to support that power is measured indirectly within FMC and that more protective landing biomechanics are visible in those with higher FMC. The relationship between FMC and biomechanics has never been investigated previously, which makes my study an essential first step in understanding this relationship. These results open avenues for exploration into FMC and its direct relationship with injurious biomechanics. Since FMC is often described as one's ability to move their body through space safely and effectively, there are opportunities to investigate what that truly means within the ROTC population.

Directions for future research

The long-term goal of the development of this study was to increase PMR and career longevity of ROTC cadets by decreasing MSKI risk and increasing physical performance. The results of this study are a first step in accomplishing this goal. Now that there is evidence that greater power production, better ACFT performance, and more preferable landing mechanics are related to higher FMC there is room for further research into the application of FMC in ROTC cadet populations. The ACFT, which can determine what career path a cadet will have, requires high performance. Additionally, many tactical skills can place large amounts of stress on the body. If a cadet does not have a solid base of physical and neuromuscular fitness factors or cannot move their bodies safely, a cadet may be placed at increased risk of developing MSKIs. Additionally, cadets entering the ROTC program may not have had the physical activity experiences that could have provided them a strong base of motor skills or physical fitness. Since it is known that sudden increases in activity levels can increase MSKI risk,[5,25,39,204,306] and that early career MSKI can lead to subsequent MSKI development later in a cadets career,[93,94] there is need to find a method to screen for potential deficits in incoming cadets. This study provides one potential method to screen for motor skill and fitness deficits in incoming cadets since previous sport participation was found to be significantly related to FMC. Previous research utilizing previous sport participation as a method to screen for injury, or as an indicator of physical fitness, may not have investigated far enough into the individual's history.[26,136] A previous study found that approximately 78% of cadets had at least one year of high school sport participation, but still displayed movement and balance issues related to increased risk of MSKI.[26] If previous sport participation since the age of five is related to MSKI then that would further support the utility for screening incoming cadets thus supporting the long-term goal of this study. Further research is needed to determine if there is an adequate time frame to collect previous sport participation to assess MSKI risk in ROTC cadets.

Although this study did find that power was related to FMC, there is still room for exploration since I only investigated one physical and neuromuscular fitness factor. Many physical and neuromuscular fitness factors are needed to perform well on the ACFT and thus reach PMR. Muscular strength and endurance, cardiorespiratory fitness, flexibility etc. are all needed not only to score highly on the ACFT but also succeed in combat. This study only investigated power and dynamic balance, leaving room to further improve the status quo by exploring multiple physical and neuromuscular fitness factors. Further exploration into dynamic balance and FMC with a more diverse population and/or with a different measurement will provide greater evidence for this relationship outside of this single study. Continuing to provide evidence to support the use and validity FMC in ROTC cadets is essential to allow adequate support for future investigations regarding screening and intervention protocols. Without confirmation that the relationships that exist in child transfer to adult populations, FMC should be explored with caution.

There is room for further exploration into how FMC is directly related to MSKI in ROTC cadet populations. Although this study provided a positive first step by investigating landing biomechanics and their relationship to FMC, MSKI was not explored. Investigating how FMC is related to MSKI risk will help support the use of FMC as a screening tool. Since it is well supported that certain biomechanics, such as still landing style[32,142,145,188,286,307] and dynamic knee valgus[168,245,307,308], are related to MKSI risk, it is necessary to further investigate how FMC effects biomechanics. Further investigating how FMC is related to movement within more traditional screening protocols, such as the LESS, will provide insight for the utility of FMC as a screening tool. Longitudinal studies investigating FMC in adults and MSKI has never been studied. Researching if FMC is related to MSKI over a period of time would support intervening early on in a cadet's career. Additionally, understanding how the current physical training methods impact FMC could inform cadre and researchers about where training can be improved to ensure the longevity of our cadets.

Overall, An important next step in this line of research would be to investigate the relationship between FMC and MSKI directly. I would Utilize a prospective study design, and measure FMC at the start of the year then monitoring for injury for over a year long period. There would be room to continue investigating FMC and performance measures over this time period, how the current training protocol affects FMC, and if low FMC is directly related to increased rate of developing MSKIs. A prospective research design could allow for many findings that would provide evidence to understand if FMC can be utilized as a screening tool in the military. Some challenges with this approach include the large amount of time and money needed to perform a prospective study. Despite these challenges, a research design like this would be the best method for collecting robust data which can best support this line of research. Regardless of the type of research design, there is opportunity and need to develop intake protocols involving screening for FMC in incoming cadets to inform cadre and research teams about potential motor skill deficits needing to be addressed early in a cadet's career. Research teams then can investigate potential training interventions that could train for FMC and increase improve performance and the longevity of the Army's ROTC cadets' careers. Additionally, there is room for investigation into FMC and injurious biomechanics which will support clinicians' and researchers' ability to investigate potential MSKI risk screening, intervention, and potential rehabilitation/training protocols based on FMC. Continuing this line of research will contribute to the long-term goal of increasing PMR in our Army and increase the longevity of our soldiers.

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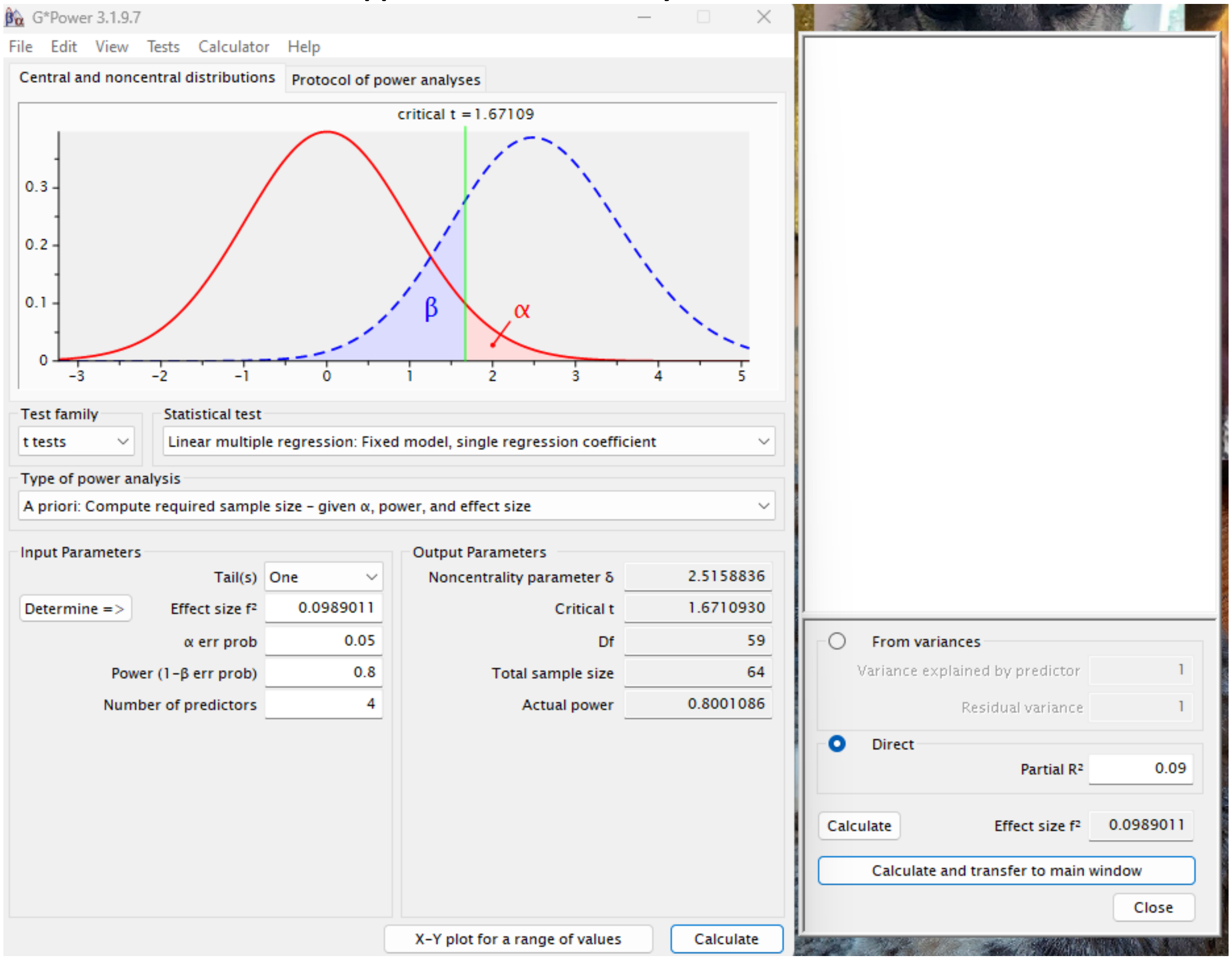
Appendices

Appendix A: Power Analysis - 4 Predictors



Appendix B: Consent

Study title	Identifying the relationship among Functional Motor Competence, the Army Combat Fitness Test, and Vertical Jump Performance in ROTC Cadets.
Researchers	Madison Mach, MS (student in the PhD Kinesiology program); Jennifer Earl-Bohem, PhD, ATC, FNATA

We are inviting you to participate in a research study. Participation is completely voluntary. If you agree to participate now, you can always change your mind later. There are no negative consequences, whatever you decide.

Overview

Purpose: We want to investigate how a motor development factor called Functional Motor Competence (FMC) can impact how you perform on the Army Combat Fitness Test (ACFT) and whether FMC impacts the way you land while jumping.

Procedures: You will be asked to fill out some paperwork focused on demographic information (age, sex assigned at birth, etc.) and previous participation in sport and military. You will also be asked to participate in four tasks (standing long jump, ball throw, ball kick and vertical jump) that will determine FMC score.

Setting: You will participate during a normal scheduled physical training session at either the University of Wisconsin Engleman Gym or Marquette University Gym. The ACFT will occur in your normally scheduled space.

Time Commitment: There will be no additional time designated to this study outside of your normally scheduled physical training session (6:30am – 7:30am). The ACFT scores will be collected from the cadre following the ACFT so no additional time will be needed to gather that information.

Primary risks: You may have some muscle soreness from the FMC tasks however, these should be minimal and similar to what you would experience from your physical training sessions. Injury from the FMC tasks is unlikely but possible, we will have certified Athletic Training staff available if injury occurs.

Benefits: Although there will not be direct immediate benefits to you from our study, the information from this study could allow for changes in physical training that could be beneficial such as increasing performance on the ACFT and decreasing injury risk in the future.

What will I do?

Location and time	What will I do?

FMC test day
 	
• Location: at either UWM or Marquette university Gyms
• Time: 1 hour
    ○ During normally scheduled physical training sessions (6:30am – 7:30am)
	• We ask you to wear your ROTC physical training clothes (black Army shirt and pants) with the shoes you would normally wear for physical training.
	• When you arrive the research team will explain the study and confirm the eligibility criteria and obtaining consent (~10 minutes) by doing the following:
	    ○ Reviewing the consent form with the researcher and signing.
	    ○ Complete a demographic form including age, height, and weight, etc.
	    ○ Assigned participant ID code under which all of your data will be saved.
	    ○ You will be provided with paperwork to work on while waiting to participate in each task.
	    ○ The paperwork will include 3 sections:
	        ▪ *Demographics:* Age, sex assigned at birth, gender identity, military science year, and dominant limb)
	        ▪ *Previous sport participation:* will inquire about the # of sports and years participated in sport for 3 age ranges (5-10 years old, 11-13 years old, and 14-18 years old)
	        ▪ *Previous military experience:* will inquire about any previous military participation you had prior to joining the ROTC.
	• 6 cadets will be in rotation at a time and after you complete the tasks and the paperwork you will send another cadet over and return to the physical training session.
	• The FMC test battery has 4 events and 3 stations:
	• Total time: ~XX
	    ○ Station 1: Standing long jump
	        ▪ You will perform a maximum standing long jump 5 times while researchers record your distance.
	    ○ Station 2: Ball throw and kick

<table>
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Throw: you will throw a tennis ball against a wall using maximum effort 5 times while researchers record the speed of the ball.
Kick: you will kick a rubber ball (dodgeball) at a wall 5 times while researchers record the speed of the ball.

Station 3: Maximum vertical jump

You will jump for maximal height 3 times while a researcher records the height reached.
The jump will also be recorded from the side with a 2D camera that will be used to measure joint angles.
You will also have a sensor attached to your shin with Velcro that will collect impact data.

After completion of all tasks and paperwork you will check out with the same member of the research team that you checked in with.

</td></tr>
<tr><td>
ACFT testing day

Time: ~ 3 hours.
Location: at either UWM or Marquette Gym.

</td><td>

ACFT testing will occur as normal with no additional research being collected for this study.
You will complete:

Height/weight
3 repetition maximal deadlift
Standing power throw
Hand release pushups
Sprint drag carry
Plank
2 mile run

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Risks

<table>
<tr><th>Possible risks</th><th>How we're minimizing these risks</th></tr>
<tr><td>Breach of confidentiality (your data being seen by someone who shouldn't have access to it)</td><td>

All identifying information is removed and replaced with a participant ID.
When all active participant data collection is complete, the code will be destroyed.
We will store all electronic data on a password-protected, encrypted computer.

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	• We will store all paper data in a locked filing cabinet in a locked office. • We will keep your identifying information separate from your research data, but we'll be able to link it to you by using a participant ID. We will destroy this link after we finish collecting and analyzing the data.
Muscle soreness as a result of testing Injury from the FMC test battery (unlikely)	• You will be allowed to practice all tasks until you feel comfortable with your ability to perform the tasks. • You will be provided a minimum of 30 seconds of rest in between each rep and 90 seconds between each task. If you need more time to rest, you will be allowed to take it. • The muscle soreness you encounter should not be more than something you would feel from a regular workout. • If you are injured during the study all study personnel are trained in CPR and first aid. We will also have athletic trainers at collection who are able to help. If you need additional care, you may seek additional care from the Norris Health Center of another provider at your own expense.

There may be risks we don't know about yet. Throughout the study, we'll tell you if we learn anything that might affect your decision to participate.

Other Study Information

Possible benefits	This study will allow for information that will help to fill knowledge gaps in research. Little is known about how FMC can impact the way someone moves and performs. The information provided by this study could inform potential changes to physical training that could better prepare ROTC cadets for combat and reduce the risk of injury.
Estimated number of participants	Approximately 82 Cadets will be recruited for this study.
How long will it take?	The total amount of time required for participation is approximately 60 minutes for active data collection (FMC test battery).
Costs	You'll pay for your own transportation and parking.
Compensation	There will be no direct compensation for your participation.
Results of the study	If you are interested in the measures taken by the researchers you may reach out to mmach@uwm.edu to receive a print out of your information (FMC measures). If you would like an additional explanation of your results you may set up a meeting to discuss your results.
Future research	De-identified (all identifying information removed) data may be shared with other researchers and may be used for further

	analysis of the data. You won't be told specific details about these future research studies
Removal from the study	You may choose to remove yourself from the study at any point and all your data will be destroyed. Failure to complete all the tasks required (demographic, previous sport, previous military surveys, FMC test battery and ACFT) will result in you being removed from the study.

What if I am harmed because I was in this study?
If you're harmed from being in this study, let us know. If it's an emergency, get help from 911 or your doctor right away and tell us afterward. We can help you find resources if you need psychological help. You or your insurance will have to pay for all costs of any treatment you need.

Confidentiality and Data Security
We'll collect the following identifying information for the research: your name, email address, phone number and signature on Consent Form. This information is necessary to contact you for the prescreening phone calls and to contact you about scheduling changes, conflicts etc. Your signature on the consent form is necessary to allow us to perform the study and have evidence that you agreed to all the risks, benefits, knowledge of the study, and participation of the study. We will keep a copy of your signed consent form and you will receive a copy of the full consent form with signatures for your referral of the study and contact information if you have any questions after the study is performed.

Where will data be stored?	Electronic data will be stored on a laboratory dedicated computer or server that are protected by password access only. Upon completion of the collection sessions, camera will be taken directly to export videos to laboratory dedicated computer. Other personal information will be kept in a locked cabinet in a locked office.
How long will it be kept?	Identifiable data will be deleted upon the completion of active data collection of the study. All other data, with your participant codes will be kept indefinitely

Who can see my data?	**Why?**	**Type of data**
The researchers	To analyze the data and conduct the study	• All participants' information on the "Data sheet" will be given an ID number that is uniquely associated with each individual participant. The ID number with the participant's name

		and email will be stored in a separate locked office in a locked filing cabinet. Identifiable: • The accelerometer electronic data will be saved by participant's ID number from the data sheet. Electronic data will be stored on a laboratory dedicated computer or server that are protected by password access only. • De-identified: • The de-identified data may be used for future research studies participants will not be given the details of these studies.
The IRB (Institutional Review Board) at UWM The Office for Human Research Protections (OHRP) or other federal agencies	To ensure we're following laws and ethical guidelines	• All participants' information on the "Data sheet" will be given an ID number that is uniquely associated with each individual participant. The ID number with the participant's name and email will be stored in a separate locked office in a locked filing cabinet. • Identifiable: • The 3D motion capture electronic data will be saved by participant's ID number from the data sheet. Electronic data will be stored on a laboratory dedicated computer or server that are protected by password access only.
Anyone (public)	If we share our findings in publications or presentations	• We may decide to present what we find to others or publish our results in scientific journals or at scientific conferences. • Information that identifies you personally will not be released without your written permission. • Deidentified information may be used in future research.

Contact information:

For questions about the research	Madison Mach, MS	mmach@uwm.edu

For questions about your rights as a research participant	IRB (Institutional Review Board; provides ethics oversight)	414-229-3173 irbinfo@uwm.edu
For complaints or problems	Jennifer Earl-Boehm, PhD, ATC, FNATA	414-229-3227 jearl@uwm.edu
	IRB	414-229-3173 irbinfo@uwm.edu

Signatures

If you have had all your questions answered and would like to participate in this study, sign on the lines below. Remember, your participation is completely voluntary, and you're free to withdraw from the study at any time.

____

Name of Participant (print)

____ __________

Signature of Participant
Date

____

Name of Researcher obtaining consent (print)

____ __________

Signature of Researcher obtaining consent

Appendix C: Participation ID Form

Participant ID #	Last name	First name
S01		
S02		
S03		
S04		
S05		
S06		
S07		
S08		
…….		
S150		

Appendix D: Full Combined Data Collection Form

FMC, ACFT, and Vertical Jump Performance in ROTC Cadets. UWM IRB 24.155
Participant Code: ___________

DATA INPUT FORM Date: _____________

TO BE COMPLETED BY PARTICIPANT

Age: _____________ **Military Science Year (please circle):** MS1 MS2 MS3 MS4 MS5 Participant

Do you compete on an ROTC team? Yes No **Have you exercised today?** Yes No
if yes which one ____________________________

Dominant Limb (Limb you would kick a ball with): Right Left

What sex was listed on your birth certificate?

A. Male
B. Female

What is your identified gender?

A. Man
B. Woman
C. Non-Binary/Other (please list ____________)
D. Prefer not to say

PREVIOUS SPORT PARTICIPATION SURVEY

Between the ages of <u>6 and 10</u> years old:
How many years did you participate in a structured sport activity (i.e., school sport program, club sport, recreational sport)?

# of years 0-5 __________________

How many separate sports did you participate in?

# of sports participated in ________________

Please indicate the sports and the years of each sport (i.e., soccer - 2 years, baseball – 3 years, etc.)

Football _____ Hockey______ Lacrosse______ Wrestling_____ Soccer______ Basketball_____
Sprint running_____ Distance Running______ Softball/baseball______
Cheerleading/dance_____

Volleyball______ Tennis_____Swimming/diving______ OTHER_____

Between the ages of 11 and 13 years old:
How many years did you participate in a structured sport activity (i.e., school sport program, club sport, recreational sport)?

# of years 0-3 __________________

How many separate sports did you participate in?

# of sports participated in ________________

Please indicate the sports and the years of each sport (i.e., soccer - 2 years, baseball – 3 years, etc.)

Football _____ Hockey______ Lacrosse______ Wrestling_____ Soccer______ Basketball_____
Sprint running_____ Distance Running______ Softball/baseball______
Cheerleading/dance_____
Volleyball______ Tennis_____Swimming/diving______ OTHER_____

Between the ages of 14 and 18 years old:
How many years did you participate in a structured sport activity (i.e., school sport program, club sport, recreational sport)?

# of years 0-5 __________________

How many separate sports did you participate in?

# of sports participated in ________________

Please indicate the sports and the years of each sport (i.e., soccer - 2 years, baseball – 3 years, etc.)

Football _____ Hockey______ Lacrosse______ Wrestling_____ Soccer______ Basketball_____
Sprint running_____ Distance Running______ Softball/baseball______
Cheerleading/dance_____
Volleyball______ Tennis_____Swimming/diving______ OTHER_____

PREVIOUS MILITARY EXPERIENCE SURVEY

Please indicate if you participated in any of the following and the time you participated (in years).

	Please indicate the age (range) you had this experience	Please indicated the number of years you had this experience
Active Duty/Regular Army		
United States Army Reserve		
Army National Guard		

Other (please list):		

TO BE COMPLETED BY RESEARCHER

Standing Long Jump Distance (cm) (write the distance for each trial in the boxes below)
initials of researcher ________

Trial 1)	Trial 2)	Trial 3)	Trial 4)	Trial 5)

Throwing Velocity (m/s) (write the speed (in mph) for each trial below)
initials of researcher ________

Trial 1)	Trial 2)	Trial 3)	Trial 4)	Trial 5)

Kicking Velocity (m/s) (write the speed (in mph) for each trial below)
initials of researcher ________

Trial 1)	Trial 2)	Trial 3)	Trial 4)	Trial 5)

Vertical Jump Height (cm) (write the vertical jump height for each trial below)
CONFIRM DOMINANT LIMB (for IMU and camera placement): RIGHT or LEFT
initials of researcher _________
(check box for completed trial)

Trial 1)	Trial 2)	Trial 3)

Y-BALANCE TEST (Record reach distance in cm, record 3 successful trials on both feet in all directions)
initials of researcher ________

Stance leg	**LEFT**				**RIGHT**			
	Trial 1	**Trial 2**	**Trial 3**		**Trial 1**	**Trial 2**	**Trial 3**	
Anterior								

■ ■

Check out: (initial in boxes to confirm all tasks are completed)

Demographics completed? Initials _______	All FMC test battery tasks completed? Initials _______	Participant ID is listed at the top? Initials _______	PSPS and Previous Military Surveys completed? Initials _______

Appendix E: Army Combat Fitness Test Description of Events

The six events that are part of the ACFT will be staffed and executed by the ROTC leadership. The testing for the ACFT will be on a separate day from the FMC testing day. Below are descriptions of each of the exercises. All information and pictures gathered from: https://www.army.mil/acft/.

Three Repetition Maximum Deadlift

Starting Position

The Soldier will step inside the hexagon/trap bar, feet generally shoulder width apart, and locate the midpoint of the hexagon/trap bar handles.

Phase 1 Preparatory Phase

On the command of "GET SET," the Soldier will bend at the knees and hips, reach down and grasp the center of the handles. Arms should be fully extended, back flat, head in line with the spinal column or slightly extended, head and eyes to the front or slightly upward, and heels in contact with the ground. All repetitions will begin from this position.

Phase 2 Upward Movement Phase

On the command of "GO," the Soldier will stand up and lift the bar by extending the hips and knees. Hips should never rise before or above the shoulders. The back should remain straight – not flexed or extended. The Soldier will continue to extend the hips and knees until reaching an upright stance. There is a slight pause at the top of this movement.

Phase 3 Downward Movement Phase

By flexing the hips and the knees slowly, the Soldier lowers the bar to the ground under control while maintaining a flat-back position. Do not drop or let go of the bar. The hexagon/trap bar weight plates must touch the ground before beginning the next repetition. Weight plates may not bounce on the ground.

Execute three continuous repetitions with the same weight. If the Soldier fails to complete three continuous repetitions under control, he or she is permitted one retest at a lower weight. If the Soldier successfully completes three continuous repetitions on the first attempt, he or she may elect an additional attempt at a higher weight. The maximum number of attempts on this event is two.

<u>Standing Power Throw</u>

Starting Position

The Soldiers will face away from the start line, grasp the medicine ball (10 pounds) with both hands at hip level and stand with both heels at (but not on or over) the start line. Grasp the ball firmly and as far around the sides of the ball as possible.

Record Throws

Soldiers are permitted several preparatory movements flexing at the trunk, knees, and hips while lowering the ball between their legs. Soldiers will have two record attempts on the Standing Power Throw. A record attempt will not count if a Soldier steps on or beyond the start line or falls to the ground.

<u>Hand Release Push-up-Arm Extension</u>

On the command of "GET SET," the Soldier will assume the prone position facing the start line with hands flat on the ground and index fingers inside the outer edges of the shoulders. The chest and front of the hips and thighs will be on the ground. Toes will touch the ground with feet together or up to a boot's width apart. The ankles will be flexed. The head does not have to be on the ground. Feet will remain generally together, no more than a boot's width apart, throughout the event. Soldiers may adjust their feet during the test event as long as they do not lift a foot off the ground.

Movement 1

On the command "GO," a Soldier will push their whole body up from the ground as a single unit to the up position by fully extending the elbows (front leaning rest).

- The Soldier will maintain a generally straight body alignment from the top of the head to the ankles. This generally straight position will be maintained for the duration of the HRP.
- Failing to maintain a generally straight alignment during a repetition will cause that repetition to not count.
- The front leaning rest is the only authorized rest position. Bending or flexing the knees, hips, trunk, or neck while in the rest position is not authorized.

Movement 2

After the elbows are fully extended and the Soldier has reached the up position, the Soldier will bend their elbows to lower the body back to the ground. The chest, hips and thighs should touch down at the same time. The head or face do not have to contact the ground.

Movement 3

Arm Extension – immediately move both arms out to the side straightening the elbows into the T position. After reaching this position, the elbows bend to move the hands back under the shoulder.

Movement 4

Soldiers must ensure their hands are flat on the ground with the index fingers inside the outer edges of the shoulders (returning to the starting position). This completes one repetition.

The Soldier will make an immediate movement to place their hands back on the ground to return to the starting position.

<u>Sprint-Drag-Carry</u>

Starting position
On the command "GET SET," the Soldier will assume the prone position with the top of the head behind the start line.
Sprint
On the command "GO," Soldiers stand and sprint 25m; touch the 25m line with foot and hand; turn and sprint back to the start line.
Drag
Soldiers will grasp each strap handle, which will be positioned and resting on the sled behind the start line; pull the sled backwards until the entire sled crosses the 25m line; turn the sled around and pull back until the entire sled crosses the start line.
Lateral
After the entire sled crosses the start line, the Soldier will perform a lateral for 25m, touch the 25m turn line with foot and hand, and perform the lateral back to the start line. The Soldier will face the same direction moving back to the 25m start line and returning to the start line so they lead with each foot.
Carry
Soldiers will grasp the handles of the two 40-pound kettlebells and run to the 25m turn line; step on or over the 25m turn line with one foot; turn and run back to the start line. If the Soldier drops the kettlebells during movement, the carry will resume from the point the kettlebells were dropped.
Sprint
After stepping on/over the start line, Soldiers will place the kettlebells on the ground; turn and sprint 25m; touch the 25m turn line with foot and hand; turn and sprint back to the start line. The time is stopped when the Soldier crosses the start line after the final sprint (250 meters).

<u>PLANK (PLK)</u>

Starting position
On the command "GET READY" hands must be on the ground, either in fists with pinky side of the hand touching the ground or lying flat with palms down, no more than the grader's fist-width apart; elbows will be bent, aligned with the shoulders, forearms flat on the ground forming a triangle; hips should be bent with one or both knees resting on the ground.

Execution
On the command "GET SET," the Soldier lifts both knees off the ground and moves the hips into a straight line with the legs, shoulders, head and eyes focused on the ground, similar to the "Front Leaning Rest." The Soldier's feet may be up to the grader's boot-width apart. Elbows are aligned with the shoulders, together with the forearms forming a triangle. Ankles are flexed with the bottom of the toes on the ground. The Soldier maintains his or her body in straight alignment from the head to the ankles. The fingers on the left hand may not be interlocked, interlaced, or touching with the fingers on the right hand, hands no more than a boot width apart. On the command "GO," the Soldier moves into the proper "plank" position.

To maintain proper plank position, the head, shoulders, back, hips, and legs must remain in a straight-line position from head to heels throughout the event. Feet, forearms, and fists/palms must remain in contact with the floor throughout the event.

As long as the hands remain in contact with the ground, Soldiers may change hand position from the fist-pinky side down to palms down during the plank.

The Plank event is terminated if the Soldier touches the ground with any part of the body other than the feet, forearms or fists/palms, raises a foot or hand off the floor, or fails to maintain a straight-line position from head to heels.

Graders will give one verbal warning to correct failure to maintain the proper plank position or if the hands/feet slide from the required position. If the Soldier is unable to correct a deficiency or maintain the proper plank position, the Soldier's performance will be terminated.

Shaking or trembling as a result of maximum exertion is permitted as long as the proper plank position is maintained.

Two-Mile Run
The two mile run can be completed on an indoor or outdoor track, or an improved surface such as a road or sidewalk. There is a programmed 10-minute rest between the leg tuck and the two-mile run.

Appendix F: FMC Test Battery

FMC event	Description
Standing Long Jump (cm)	Cadets will be instructed to complete the task with a form that is most comfortable for them but specifying that the cadets need to jump with both feet and stick the landing. The distance jumped will be taken from the back of the heels of the cadets. 5 trials will be recorded and the best of the 5 trials will be taken for analysis.
Ball Throw (m/s)	The cadets will face the wall and throw a tennis ball as fast as possible towards the wall. The trials will be measured using a radar gun (Stalker Radar, Plano TX) in miles/hour, which will then be converted to m/s. 5 trials will be recorded, and the fastest throw will be used in analysis.
Ball Kick (m/s)	The cadets will face the wall and kick a 20 cm diameter playground ball with maximal effort towards the wall. Ball speed will be recorded using a radar gun in miles/hour, which will be converted to m/s. 5 trials will be recorded, and the fastest kick will be used in analysis.
Vertical Jump (cm)	Cadets will be instructed to jump for maximal height, trying to land as close to the starting position as possible. The best of 3 jumps will be used in analysis.

Appendix G: Station Instructions For Data Collection

Station 1: Check In/Check Out

Equipment and Supplies:

- Clipboards
- Participant ID form
- Pens
- Data collection sheet

Set-up

Prepare data collection sheets on clipboards to be handed to the cadets with a pen.

Check-in:

Instruct cadets to do a warmup when they arrive (see below). Assign a participant ID number. Write the cadet's full name on participant ID sheet. Provide cadet with a clipboard and the combined data collection sheet (includes demographic questionnaire, previous sport participation survey, previous military experience survey, and the data collection sheet). Explain to the cadets that they will fill out the demographics, previous sport participation survey, and previous military survey. After providing the paperwork, send cadets to a station to control flow and ensure there is minimal backup (i.e., don't send them to all the same station, or if you see a backed-up station send them to a different station).

WARM UP:

- 2 laps around the gym, 20 jumping jacks, 15 squat jumps, and 10 burpees.

Check-out:

Collect combined data collection sheet and ensure all sections are completed and initialed by researchers (if applicable). Sign off on paperwork and thank the cadet for their participation.

Station 2: Standing Long Jump

Equipment and Supplies:

- Clipboard
- Tape measure
- Tape

Set-up

Secure tape measure at the 0cm mark with a piece of tape (cm side up). Place the starting tape line in line with the 0 mark of the tape measure so that the tape measure is on the right side of the participant perpendicular to the starting tape. Secure tape measure at far end to ensure minimal movement if a participant lands on it.

To be read to the participant:

"The goal of this task is to jump forward for maximum distance while sticking the landing. You will stand with your toes behind the taped line to start. You may use any form to complete the jump as long as you stick the landing. If you move your feet from where you initially landed the jump will not be recorded and we will ask you to redo that jump. You may have at least two practice jumps, and then we will do five recorded trials. Do you have any questions?"

Practice trials: at least 2, may have additional practice if requested.

Testing: 5 successful trials

- Successful = landed with both feet and did not move from the landing position.
- Unsuccessful = landed with one foot, moved feet from landing position, anything other than feet touched ground.

Record the distance jumped to the closest half centimeter (0.5 cm) in the designated box on the data collection sheet. You will be recording from the heel closest to the starting line.

Station 3: Ball Throw and Ball kick

<u>Equipment and Supplies:</u>

- Clipboard
- Tennis and playground ball
    - Safety Net
- Tape
- Radar Gun

<u>Set-up</u>

Place the starting tape line 7 meters away from the wall. Tape an "X" target on the wall (this will be used for aiming purposes only and cadets are not required to hit the target). Set safety net up as close to target as possible leaving about 2 feet between you and the target. The researcher will need to be as close to parallel to the ball as possible to get the most accurate velocity measurement.

All 5 throws will be completed then all 5 kicks will be completed.

To be read to the participant: (THROW)

"The goal of this task is to throw the ball as fast and as hard as you possibly can at the wall. There is a target that you don't have to hit but so that you have something to aim for. You will start in any standing position behind the taped line. You can use any form to throw the ball as long as you don't have any additional wind up, once your feet are in a comfortable position they must stay where they are. You will have at least two practice throws and then we will be collecting five trials. Do you have any questions?"

Practice trials: at least 2, may have an additional practice if requested.

Testing: 5 successful trials

- <u>Successful</u> = threw ball without moving feet.
- <u>Unsuccessful</u> = moved feet while throwing the ball

To be read to the participant: (KICK)

"The goal of this task is to kick the ball as fast and as hard as you possibly can at the wall. There is a target that you don't have to hit but so that you have something to aim for. You will start in any standing position behind the taped line. You can use any form to kick the ball as long as you don't have any additional wind up, once your feet are in a comfortable position the stance leg stay stationary while you are kicking the ball. You will have at least two practice kicks and then we will be collecting five trials. Do you have any questions?"

Practice trials: at least 2, may have additional practice if requested.

Testing: 5 successful trials

- <u>Successful</u> = kicked ball without moving stance foot.
- <u>Unsuccessful</u> = moved stance foot while kicking the ball

Record the velocity in mph in the designated box on the data collection sheet.

Station 4: Vertical Jump

Equipment and Supplies:

- Clipboard
- 1 camera and tripod
- MyoMotion IMU/setup
- Tape

Set-up

Place a tape line where participants will start their jump. Set up one camera approximately 2 meters in front of the tape line. Place 2 tape markers approximately 2 meters to the side of the tape line. Set up MyoMotion computer and IMU equipment on the cart.

To be read to the participant:

"The goal of this task is to jump for maximal height and finish the jump through the landing. We ask that you land as close to the starting position as possible and try to land securely without losing balance. If you lose balance or move your feet after you land the jump will not count and we will ask you to repeat that jump. We will be recording data with the accelerometer on your shin and lower back, and we will be recording you with one camera on the side of you. We will let you know when all the tools are ready and when you can start your jump. You may use any form that is comfortable for you as long as you land with both feet simultaneously, land as close to the starting position as possible and finish the jump through the landing. You may have at least two practice jumps and then we will collect three trials. Do you have any questions?"

Practice trials: at least 2, may have additional practice if requested.

Testing: 3 successful trials

- Successful = stuck the landing approximately where they started
- Unsuccessful = lost balance, landed with one foot before the other, was not in the center of frame during landing.

Record the successful completion of each trial on the collection sheet.

Station 5: Y-Balance Test (YBT)

Equipment and Supplies:

- YBT test kit x2
- Clipboard
- Disinfecting wipes
- Towels

Set-up

Set-up each YBT test kit (1 for practice, 1 for testing)

This YBT will utilize the anterior reach positions. All practice and testing trials are completed barefoot. Align the participant's stance limb so the toe is behind the line on the stance plate.

To be read to the participant:
"Please remove your shoes and socks while I explain the task. The goal of this task is for you to reach as far in front of you as possible with the testing foot to test your balance. You will keep your hands on your hips and keep your heel on the ground at all times. In a slow and controlled fashion, squat and reach along the line in front of you, pushing the measurement indicator as far as possible, then return to the upright starting position.
You may stand normally in between trials. Do you have any questions?"
Testing order: Right Anterior then Left anterior.

Practice: 6 trials in each direction on each leg. Practice all L then all R.

Testing: 3 trials in each direction on each leg.

- A failed trial occurs when the participant loses balance, supports body weight with reach limb, heel raises, kicks the reach indicator, and/or removes hands from hips.

Record the distance for each trial for each reach direction in centimeters on the collection sheet.
If >5 cm difference in measurement, toss out trial.

Appendix H: ACFT Scoring Sheet

ACFT GRADING SCALES

U.S. ARMY

Event	Gender	POINTS	17-21	22-26	27-31	32-36	37-41	42-46	47-51	52-56	57-61	62+
MDL (lbs.)	Female	100	210	230	230	230	210	210	190	190	170	170
		60	120	120	120	120	120	120	120	120	120	120
	Male	100	340	340	340	340	340	340	330	290	250	230
		60	140	140	140	140	140	140	140	140	140	140
SPT (meters)	Female	100	8.4	8.5	8.7	8.6	8.2	8.1	7.8	7.4	6.6	6.6
		60	3.9	4.0	4.2	4.1	4.1	3.9	3.7	3.5	3.4	3.4
	Male	100	12.6	13.0	13.1	12.9	12.8	12.3	11.6	10.6	9.9	9.0
		60	6.0	6.3	6.5	6.5	6.4	6.2	6.0	5.7	5.3	4.9
HRP (reps)	Female	100	53	50	48	47	41	36	35	30	24	24
		60	10	10	10	10	10	10	10	10	10	10
	Male	100	57	61	62	60	59	56	55	51	46	43
		60	10	10	10	10	10	10	10	10	10	10
SDC (m:ss)	Female	100	1:55	1:55	1:55	1:59	2:02	2:09	2:11	2:18	2:26	2:26
		60	3:15	3:15	3:15	3:22	3:27	3:42	3:51	4:03	4:48	4:48
	Male	100	1:29	1:30	1:30	1:33	1:36	1:40	1:45	1:52	1:58	2:09
		60	2:28	2:31	2:32	2:36	2:41	2:45	2:53	3:00	3:12	3:16
PLK (m:ss)	Female	100	3:40	3:35	3:30	3:25	3:20	3:20	3:20	3:20	3:20	3:20
		60	1:30	1:25	1:20	1:15	1:10	1:10	1:10	1:10	1:10	1:10
	Male	100	3:40	3:35	3:30	3:25	3:20	3:20	3:20	3:20	3:20	3:20
		60	1:30	1:25	1:20	1:15	1:10	1:10	1:10	1:10	1:10	1:10
2MR (mm:ss)	Female	100	15:29	15:00	15:00	15:18	15:30	15:49	15:58	16:29	17:18	17:18
		60	23:22	23:15	23:13	23:19	23:23	23:42	24:00	24:24	24:48	25:00
	Male	100	13:22	13:27	13:31	13:42	13:58	14:05	14:30	15:09	15:28	15:28
		60	22:00	22:00	22:00	22:00	22:11	22:32	22:55	23:20	23:36	23:36

*The full ACFT grading scales are available at https://www.army.mil/acft/

Appendix I: ACFT Score Card

ACFT Scorecard 2022

ARMY COMBAT FITNESS TEST SCORECARD

For use of this form, see ATP 7-22.01; the proponent agency is TRADOC.

NOTE: To convert raw scores to scaled scores, refer to the ACFT event score conversion tables posted to the Army Combat Fitness Test website at https://www.army.mil/acft.	**FOR OFFICIAL USE ONLY** NAME *(Last, First, MI)*
	GENDER ☐ MALE ☐ FEMALE
Body Composition Testing will **NOT** be conducted on the same day as the ACFT. To avoid illness and injury, height and weight should be recorded at least 7 days before or at least 7 days after the ACFT when feasible.	UNIT/LOCATION

PRIVACY ACT STATEMENT

AUTHORITY: 10 USC 7013, Department of the Army; 10 USC 671, Members not to be assigned outside United States before completing training; 10 USC 14503, Discharge of officers with less than six years of commissioned service or found not qualified for promotion to first lieutenant or lieutenant (junior grade); Army Regulation 350-1, Army Training and Leader Development.

PRINCIPAL PURPOSE: The Army Combat Fitness Test (ACFT) assesses a Soldier's combat fitness capability. Fitness test standards are adjusted for age and gender. For additional information, see the System of Records Notice 0005, Defense Training Records, https://www.federalregister.gov/documents/2020/12/28/2020-26548/privacy-act-of-1974-system-of-records.

ROUTINE USES: There is no specific routine uses anticipated for this form; however, it may be subject to a number of proper and necessary routine uses identified in the system of records notice(s) specified in the purpose statement above.

DISCLOSURE: Voluntary. However, failure to provide identifying information may prevent ability to remain in the military.

TEST ONE	TEST TWO
DATE *(YYYYMMDD)* | MOS | GRADE | AGE	DATE *(YYYYMMDD)* | MOS | GRADE | AGE
BODY COMPOSITION DATE:	BODY COMPOSITION DATE:
HEIGHT *(inches)* | WEIGHT ______ lbs. ☐ GO ☐ NOGO | BODY FAT ______ % ☐ GO ☐ NOGO	HEIGHT *(inches)* | WEIGHT ______ lbs. ☐ GO ☐ NOGO | BODY FAT ______ % ☐ GO ☐ NOGO
3 REPETITION MAXIMUM DEADLIFT *(weight lifted - check heaviest (lbs.))*	**3 REPETITION MAXIMUM DEADLIFT** *(weight lifted - check heaviest (lbs.))*
1ST ATTEMPT ☐ ______ | 2ND ATTEMPT ☐ ______ | POINTS | GRADER INITIALS	1ST ATTEMPT ☐ ______ | 2ND ATTEMPT ☐ ______ | POINTS | GRADER INITIALS
STANDING POWER THROW *(distance thrown - check longest (meters : centimeters))*	**STANDING POWER THROW** *(distance thrown - check longest (meters : centimeters))*
1ST THROW ☐ ______ | 2ND THROW ☐ ______ | POINTS | GRADER INITIALS	1ST THROW ☐ ______ | 2ND THROW ☐ ______ | POINTS | GRADER INITIALS
HAND-RELEASE PUSH-UP *(number of correctly performed repetitions)*	**HAND-RELEASE PUSH-UP** *(number of correctly performed repetitions)*
REPETITIONS | POINTS | GRADER INITIALS	REPETITIONS | POINTS | GRADER INITIALS
SPRINT - DRAG - CARRY *(overall event time (minutes : seconds))*	**SPRINT - DRAG - CARRY** *(overall event time (minutes : seconds))*
TIME | POINTS | GRADER INITIALS	TIME | POINTS | GRADER INITIALS
PLANK *(maintain proper straight line position (minutes : seconds))*	**PLANK** *(maintain proper straight line position (minutes : seconds))*
TIME | POINTS | GRADER INITIALS	TIME | POINTS | GRADER INITIALS
2 - MILE RUN *(overall event time (minutes : seconds))*	**2 - MILE RUN** *(overall event time (minutes : seconds))*
TIME | POINTS | GRADER INITIALS	TIME | POINTS | GRADER INITIALS
5K ROW / 1K SWIM / 12K BIKE / 2.5MI WALK *[(circle or use the drop down list) (overall time to reach required distance (minutes : seconds))]*	**5K ROW / 1K SWIM / 12K BIKE / 2.5MI WALK** *[(circle or use the drop down list) (overall time to reach required distance (minutes : seconds))]*
TIME | ☐ GO ☐ NOGO | POINTS (60/0) | GRADER INITIALS	TIME | ☐ GO ☐ NOGO | POINTS (60/0) | GRADER INITIALS
SOLDIER SIGNATURE | DATE | TOTAL POINTS	SOLDIER SIGNATURE | DATE | TOTAL POINTS
OIC/NCOIC NAME *(Last, First, MI)* | RANK | ☐ GO ☐ NOGO	OIC/NCOIC NAME *(Last, First, MI)* | RANK | ☐ GO ☐ NOGO
OIC/NCOIC SIGNATURE | DATE	OIC/NCOIC SIGNATURE | DATE

DA FORM 705-TEST, APR 2022 PREVIOUS EDITIONS ARE OBSOLETE. APD AEM v1.01ES **PAGE 1 OF 2**