Movement description of male and female Marine Officer Candidates during a 14-km Ruck

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Ruck marches are a common military training activity important for traveling in units together safely and can be implemented as a field-based assessments with portable technology to measure demand on the Marines. **PURPOSE:** to measure biomechanical gait factors during a 14-km ruck march as descriptive changes in movement. An additional study aim is to investigate if output from the isometric mid-thigh pull (IMTP) and counter movement jump (CMJ) will provide additional insight into biomechanical changes onset during ruck marches and performance predictors. **METHODS:** 46 Officer candidates (34 male, 12 female) participated in a ruck march as part of their training during which an inertial measurement unit (IMU) was worn at the ankle over subjects' boots. The first two kilometers (km) were compared to the last 2-km for analysis. At the start of military training, subjects also completed pretesting counter movement jumps and IMTP on dual plated force plates. Paired t-tests were utilized to analyze changes from the first 2-km and last 2-km step count, impact load, and average intensity. Two-way mixed measures analysis of variance (ANOVA) was used to assess the effect of sex and time on the dependent variables. IMTP, CMJ, and symmetry angle (SA) assessed for correlations from the performance measures on effects of biomechanical performance in the 14-km ruck march. **RESULTS:** There was significant increase in the impact load of the left leg, right leg and total from the first 2-km (6613.99 ± 1824.27; 6731.48±1780.18; 13345.48±3544.09) to the last 2-km of the ruck march (7130.92 ± 1856.15; 7190.92±1791.72; 14321.33 ± 3547.52; $p < 0.001$). There was significant increase in the impact load of the average intensity on left leg at first 2-km (8.85 ± 1.47 g; 8.97±1.48 g; 8.90±1.40 g) and last 2-km of the ruck march (9.58 ± 1.76 g; 9.59±1.67 g; 9.58±1.61 g; $p < 0.001$). Step count increased for men from first 2-km compared to last 2-km of ruck march; women step count decreased.

CONCLUSION: The first 2-km are lower in impact load, average intensity compared to the last 2-km of a ruck march for Marines. Marines will change parameters of gait which vary depending on individual characteristics to be able to maintain pace with the group.

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1.0 Introduction

Military, law enforcement, and rescue personnel are commonly referred to as "tactical athletes" which is a term frequently used by the tactical strength and conditioning community (Scofield & Kardouni, 2015). A tactical athlete requires physical training strategies aimed at optimizing occupational performance. For tactical athletes, call to duty/response can happen at any moment with no defined start or end time. Therefore, tactical athletes must always be able to perform any task in response, especially since there is no offseason, and need to show continual preparedness for all physically and psychologically stressful events (Scofield & Kardouni, 2015). One training activity that is commonly performed in training and in tactical athletes is a loaded march, which is generally completed under strenuous conditions that lead to many injuries. Factors routinely associated with injuries are load, excessive fatigue, terrain, footwear, and distance traveled during marching (Knapik et al., 1997).

The ability to predict and monitor fatigue is an advantageous topic to carry over to many areas of performance and injury prevention. The ability to predict an individual's health and performance from adjusting training variables, especially in real time, would allow better individualized recommendations for training prescriptions. General motor coordination tests can differentiate athletes in different sports and levels of participation and enable prediction of future performance (Vandorpe et al., 2012). Assessment of movement patterns and ground reaction forces may predict future injury status, allowing preventative measures such as gait retraining, rest or other interventions to reduce loss of military readiness (Friedl, 2018). Military environments require atypical amounts of high training volumes and intensities in conjunction with suboptimal conditions, which are often associated with high occurrences of musculoskeletal injury. Overuse injuries are consistently attributed to excessive amounts of neuromuscular fatigue (Kaufman, Brodine, & Shaffer, 2000). These injury risk factors have come to be more accurately monitored with modern technologies and strategies have been developed to decrease their negative impact. Individuals may change stride length, stride frequency, double and single support time, ankle and knee joint motion, joint moments, and vertical and horizontal ground reaction forces in an effort to counter the variations in backpack load (Kinoshita, 1985) (Harman, Han, & Frykman, 2001) (Quesada, Mengelkoch, Hale, & Simon, 2000) (Simpson, Munro, & Steele, 2012). In previous research, lower limb kinematic and kinetic changes have been assessed after the prolonged load carriage and are believed to be due to fatigue of the quadriceps muscle, ensuing in the knee lacking in the ability to function effectively to absorb impact forces (Frykman, Harman, Knapik, & Han, 1994) (Quesada et al., 2000) (Simpson et al., 2012).

1.1 Fatigue

Neuromuscular fatigue is defined as an acute reduction in task performance, via increased perceived effort, as well as an inability to produce force (Wan, Qin, Wang, Sun, & Liu, 2017) The capacity to effectively monitor fatigue provides military commanders with a greater understanding of training levels and performance through the application of resistance and conditioning programs, allowing for more efficient monitoring and responses to training for better performance. Muscular fatigue causes decreased production of force capacity in muscles (Farina, Fattorini, Felici, & Filligoi, 2002) & (Gandevia, 2001).

While research has been conducted on fatigue, the rule is that no single performance marker will be definitive in all situations. Fatigue could be due to multiple factors such as lack of sleep, inadequate nutrition, mental focus or more, leading to the belief that no one marker is able to truly reflect the status of general or neuromuscular fatigue (Hughes, Jones, Starbuck, Sergeant, & Callaghan, 2019). Additionally, neuromuscular fatigue has been associated with overuse injuries with a frequent prevalence in military personnel (Kaufman et al., 2000). With multi-joint movements, individuals may alter movements to complete a task by repeated use in range of motion of minimal effort to accomplish task even if not the most biomechanically correct to resist fatigue, and repeated movements may require alteration of muscle activation patterns or inter-joint and inter-muscular coordination (Srinivasan & Mathiassen, 2012) (Madeleine & Farina, 2008) (Holtermann, Grönlund, Ingebrigtsen, Karlsson, & Roeleveld, 2010) (Gorelick, Brown, & Groeller, 2003) (Côté, Feldman, Mathieu, & Levin, 2008). Local fatigue can result in greater muscle imbalances comparing two opposing muscle groups and greater changes in neuromuscular coordination compared to non-specific global fatigue (Alizadehkhaiyat, Fisher, Kemp, Vishwanathan, & Frostick, 2007) (Gorelick et al., 2003). Selen et al. found that fatigue can increase force variability meaning a wider range of outputs produced, which fatigue state requires increase in corrective action to produce right amount of force, when in fatigue states lead to decrease in performance or increase in injury risk (Selen, Beek, & van Dieen, 2007). Cowley et al. found wide variability in inter-subject fatigue-recover rates after fatiguing protocol. Also, localized fatigue in subjects lead to shorter and slower movements, altering kinematics focusing on control of movement (Cowley, Dingwell, & Gates, 2014).

1.1.1 Fatigue on gait

The effect of fatigue on gait parameters has been studied in running. Peak tibial acceleration and peak sacral acceleration are recurring parameters with fatigue (Marotta, Buurke, van Beijnum, & Reenalda, 2021). In similar metrics, vertical load and tibial shock are repeatedly reported to increase fatigue (Clansey, Hanlon, Wallace, & Lake, 2012); (Verbitsky, Mizrahi, Voloshin, Treiger, & Isakov, 1998) (Derrick, Dereu, & McLean, 2002) (Mizrahi, Verbitsky, & Isakov, 2000b). In a study by (Schütte, Seerden, Venter, & Vanwanseele, 2018), shock attenuation was shown as a significant effect for fatigue as a possible indicator in dynamic loading variables. Shock attenuation of impact phase magnitude (12-20 Hz) showed a decrease of 10.71 bD in the final lap; this was not different by running speed at different speeds. Ruder et al. (2019) found an actual decrease in tibial shock (TS) with coinciding decrease in speed of the runners. When TS was adjusted with speed (TS/speed), no significant difference. Also, Ruder et al. (2019) showed a significant difference in foot strike pattern with TS of forefoot strikers compared to midfoot and rearfoot strikers (Ruder, Jamison, Tenforde, Mulloy, & Davis, 2019).

Strohrmann et al. (2012) found a relationship between fatigue status and lengthened foot contact duration. Decreased heel lift during running is a strong indicator of fatigue. An increased forward trunk lean and decreased heel lift is an indicator of fatigue in both treadmill and outdoor running. Runners with different levels of running experience showed differences in running kinematics with advanced and expert runners showing less kinematic changes compared to beginner and intermediate runners such as increased foot contact time and increased oscillation on the treadmill (Strohrmann, Harms, Kappeler-Setz, & Troster, 2012).

Although significant changes in biomechanics have been frequently found when assessing biomechanics with IMUs, no clear association sufficiently detected fatigue over time in the real-world (Marotta & Reenalda, 2021). Impact loading on the lower extremities has measured the vertical load rates using force plates. Accelerometers have shown strong correlations to force plate, skin mounted accelerometers studies have reported correlations of r=0.70 (Stackhouse, Davis, & Hamill, 2004).

1.1.1.1 Peak Tibial Accelerations (PTA)

Peak Tibial Acceleration is affected by lower limb movement speed or any factor that alters position and velocity prior to impact (Winslow & Shorten, 1989). PTA has been used repeatedly as a proxy measure for load (impact) on tibia during running (Clansey (Clansey et al., 2012) et al., 2012). PTA correlates with three parameters of running: spatiotemporal, kinematic, and kinetic. Kinematic data collected during running can quantify joint angles, and kinetics data collection involves the forces occurring such as ground reaction and loading rates (Winslow & Shorten, 1989) (Lafortune, Lake, & Hennig, 1995). Reenalda et al. (2019) found an increase in PTA due to fatigue status. Performing intense, prolonged running was observed to impact kinematics resulting in higher PTA and lower shock attenuation compared to the start of the run (Mizrahi, Verbitsky, & Isakov, 2000a) & (Mizrahi et al., 2000b). Tibial acceleration is affected by velocity of movement, higher velocity associate with higher PTA with repeated findings of faster running speed (3.5 and 4.7 m/s) (Sheerin, Reid, & Besier, 2019). Typical tibial acceleration for walking is between 2.7-3.7g (Lafortune et al., 1995).

1.1.1.1.1 Ruck effects

The greater load carried by the Marines, the greater the energy cost of standing and moving (Charteris, Scott, & Nottrodt, 1989) (Pedersen, Stokke, & Mamen, 2007) (Robertson et al., 1982). The load placed on the Marines' backs carries extra physiological cost, which may be increased, on average, to those of male Marines (Bhambhani & Maikala, 2000) (Bartlett & Mitchell, 2015) (Harper, Knapik, & de Pontbriand, 1997) (Holewijn, Heus, & Wammes, 1992). Not only is energy cost important but excluding differences in sex, cardiovascular fitness and muscular strength important aspects of fitness for load carriage ability (Robinson, Roberts, Irving, & Orr, 2018) (Scott & Ramabhai, 2000). In a generalization, female subjects compared to male subjects have lower mean aerobic and anaerobic capacity and lower strength in both groups from the general population (Harper et al., 1997) and samples in military service (Allison et al., 2015). Load carriage induces strain on the body due to the increased mass needed to be supported and carried by the musculoskeletal system. (Harman et al., 2001) & (Polcyn, Bessel, Harman, & Obusek, 2001). Various injuries have been associated with load carriage in military personnel, such as musculoskeletal pain, stress fractures, and neuropathies (Knapik, 2014; Knapik, Reynolds, Orr, & Pope, 2016) (Knapik, Reynolds, Orr, & Pope, 2017) (Orr & Pope, 2016) (Orr, Pope, Johnston, & Coyle, 2014). Lower back injuries are especially common during or after load carriage events and are a probable reason for failure to complete a load carriage event. Load carriage injuries by sex found similar rates of lower back injuries (incidence rate ratio [IRR] - 1.26; 95% confidence interval [CI], 0.67–2.37), but female Marines were subjected to more severe injuries (IRR 5 2.40; 95% CI, 0.98–5.88) (Orr & Pope, 2016).

Most of the research on isometric mid-thigh pull (IMTP) has been done by looking at the metrics for performance. Few studies look at IMTP before and after a fatiguing protocol and show no decrements in performance after fatigue protocol was completed. (Simpson et al., 2012) found that female recreational hikers made significant changes to ground reaction force (GRF) and spatio-temporal parameters as load carriage increased (20% Body Weight (BW), 30% BW, & 40% BW) but changes were small and taken with caution for functional relevance. The statistically significant changes were that GRFs varied by less than 0.06 BW, stride length differed by only three centimeters, and cadence differed by of only two steps.min^{-1}. These changes, with emphasis on movement distance and rate of steps, can have major effects on longer events with greater difference, especially in mixed gender groups which can slow both groups down causing greater time under load to slower pace leading to unwanted extra stress However, Sessoms et al. article on effect of load distribution using various military load configurations on mobility and performance during hiking under load in simulated and field conditions found no difference in the various loadouts of gear configurations with no alteration in gait or on marksmanship (Sessoms et al., 2020). Loadouts is the term to describe the set of objects to be carried into battle. Simulated conditions were done through a mountain pass scenario within a computer assisted rehabilitation environment on a integrated treadmill with six-degree of freedom platform for 1.61-km for each of the loadouts. Field testing performed a 24.14-km training hike switching at halfway (12.07-km of the ruck march between two loadout options. Changes to load placement on subjects made no difference in effects to performance (Sessoms et al., 2020).

1.2 Bilateral Asymmetry

Used as a monitoring tool on athletes during training and work in the field of exceeding the commonly used asymmetry threshold (greater than 15% difference) and allowance of corrective strategies to reduce imbalance and attempt to mitigate injury risk (Soligard et al., 2016). Clinical significance in asymmetry is >10% (Glassbrook, Fuller, Alderson, & Doyle, 2020). Higher accelerations were associated with clinically significant asymmetry for all but one participant of professional rugby players during the competitive season. Asymmetry was significant in %time which was highest seen in negative accelerations and very high accelerations in the same participants. Majority of the gameplay is in low acceleration intensities. Asymmetries greater than 10% have been associated with performance decrements measured by slower change of direction speed and jump height. Asymmetry testing has been seen to be quantifiable using CMJ and IMTP. In a study by Glassbrook et al., the strongest participant had no measure of asymmetry across strength measures, with one of the tests being IMTP. Decreased absolute strength can influence asymmetry, as research has demonstrated that athletes with greater lower body strength tend to exhibit less asymmetry (Bailey, Sato, Burnett, & Stone, 2015). Female athletes may be more susceptible to asymmetrically producing forces than male athletes during jumping and weight distribution tasks.

Di Paolo et al. (2021) found significant asymmetries in poor coordinated groups. Poor coordination elicited altered hip and knee biomechanics during sport specific movements in this study focusing on soccer (Di Paolo, Zaffagnini, Pizza, Grassi, & Bragonzoni, 2021). The identification of lower body asymmetries can aid in training or prehabilitation in order to strengthen and stabilize deficient limb segments and joints aiding coordination improvement.

1.2.1 Symmetry angle

Symmetry is expected within the uniformity of extremity movements in bilateral tasks. Biomechanical movements and forces during tasks can be analyzed to improve movement quality and performance and reduce injury. This is an area of focus for research to provide improvement in clinical knowledge or to know when it is a cause of concern (Zifchock, Davis, Higginson, & Royer, 2008).

Symmetry angle is a relationship between discrete values acquired from left and right sides. There is no need for a reference value when calculating this variable, which is important when baseline information or movement is not discriminatory.

1.3 Inertial measurement Unit

Inertial measurement units (IMU) are devices that measure angular velocity orientation and acceleration of an object. Assessment of IMUs is done using three components, which are accelerometer, gyroscope, and magnetometer. Continued development and evolution of IMUs have allowed for more field-based studies on 3D movement analysis, such as running and throwing, providing continuous and simultaneous measurements. Tibial acceleration by segment mounted accelerometers is typically used for proxy measurement (Mathie, Coster, Lovell, & Celler, 2004). Extensive literature has supported the use of IMUs to measure movements in sport-specific tasks and quantification of the sport movements unable to be achieved previously in lab-based settings (Reenalda, Maartens, Homan, & Buurke, 2016). IMUs have become a popular tool for monitoring activity profiles during training. Benefits imploring the use of IMUs are that they are light, portable, inexpensive, easy to set up, and allow for quick assessment of many subjects (Picerno, Camomilla, & Capranica, 2011). A Burland et al. study found validation of IMeasureU™ against gold standard Vicon 3D motion capture cameras, allowing for more field-based assessment to see effects of bone impact and lower leg symmetry data (Burland, Outerleys, Lattermann, & Davis, 2021). IMU has primarily and predominantly been used to evaluate impact load metrics during soccer-specific moving tasks. Lower limb mounted IMUs validated onto the foot in sport match-play of Rugby for detecting inter limb asymmetries (Glassbrook et al., 2020). Also, Stevens et al., (2014) found good to excellent reliability for measurement of training magnitudes during soccer sport specific movements of acceleration-deceleration, “plant and cut” and change of direction tasks(Stevens et al., 2014).

IMUs use accelerometer and gyroscope synchronization during collection with autocorrelation method, with high accuracy identifies gait stride duration while walking with approximation of roughly less than a hundredth of a second. Concurrently with extremely high between-sensor validity (correlation coefficient =0.999) (Scalera, Ferrarin, & Rabuffetti, 2020).

1.3.1 Gait analysis with IMU

Quantifying gait with IMUs provides both spatiotemporal parameters and kinematic parameters. Previous studies have shown IMUs are an acceptable tool for measuring PTA at various speeds of running(Brayne, Barnes, Heller, & Wheat, 2018).

1.4 Isometric Mid-Thigh Pull

IMTP measures have been reported by Lum et al. to be good indicators of endurance runners' performance(Lum, Chua, & Rashid Aziz, 2020). IMTP measurements access information related to force generating capability of runners. The study showed higher IMTP force output resulted in favorable running outcomes due to less metabolic demand and lower intensity relative force output for the individual to be more easily maintained. This was evident with variables of max aerobic speed and running economy efficiency being improved. In higher detail the findings were inverse correlations of large to very large across differing points in 50ms increments on IMTP PF and IMTP Net PF to 2.4 kmTT. Also, $Force_{100ms}$ and all RFD measures showed moderate to large correlation with running economy and moderate to large correlation between maximum aerobic speed and all IMTP measures except $Force_{150ms}$. Performance testing such as IMTP can be used for prediction for performance in aerobic running events and not just anaerobic tasks. There is also more evidence to correlation to sprinting agility tests used in testing of team sports, such as rugby, basketball, and track. Also, in another study by Lum et al., IMTP was related to time trial performance, max aerobic speed, and running economy. There was also carry over translation of IMTP relative peak force (PF) increase which showed an increase in countermovement jump height. Also, isometric training has been done in other ways; single joint (plantar flexion) isometric strength training has been shown to be beneficial for running performance in highly trained runners (Lum, Barbosa, Aziz, & Balasekaran, 2023).

IMTP has been used as a performance metric test, but very few studies used IMTP as a performance metric test after fatigue inducement. No studies have seen decrements in IMTP performance after acute fatigued state. This lack of effect of fatigue on IMTP may be due to the possibility of multiple motor control mechanisms working to produce near maximal force for the short contraction bout. IMTP testing are simple to administer, time efficient, reduce injury risk compared to some other forms of maximum testing, and maintain high degrees of reliability under correct testing environment compared to other forms of testing such as one rep maximum (Brady, Harrison, Flanagan, Haff, & Comyns, 2019) (Comfort, Jones, McMahon, & Newton, 2014) (Merrigan, Stone, Hornsby, & Hagen, 2020) (Buckner et al., 2017). Testing parameters of IMTP such as PF and rate of force development (RFD) are associated with performance in dynamic movements of powerlifting, weightlifting (Beckham et al., 2013), sprinting (Slawinski et al., 2010), and jumping (Haff et al., 1997).

Max force has shown limited sensitivity to fatigue, only showing gross decreases when accumulation of fatigue is severe (Hornsby et al., 2013) (Painter et al., 2018). RFD has been shown in literature to be very sensitive to fatigue (Aagaard, Simonsen, Andersen, Magnusson, & Dyhre-Poulsen, 2002; Andersen & Aagaard, 2006). Multi-joint measures contribute greater ecological validity for sports, especially explosive sports like weightlifting (Hornsby et al., 2013) (Giles, Lutton, & Martin, 2022) (Roe et al., 2016).

1.5 Counter Movement Jump

The counter-movement jump (CMJ) test is a commonly used test to assess an athlete's maximal power output. CMJ performance is linked to maximal strength, rate of force developed relatedly termed explosive strength, and neuromuscular coordination.

Plyometric training such as performing CMJs and the rapid force output required for CMJ is important and has been shown to be related to running. In a study by Lum et al., plyometric training led to improvements in time trial time and maximum aerobic speed. Plyometric training is known to increase muscle strength via musculotendinous stiffness (Paavolainen, Hakkinen, Hamalainen, Nummela, & Rusko, 1999) (Spurrs, Murphy, & Watsford, 2003).

Production of large amounts of force over a short amount of time consistently during competition have a positive influence on performance for most sports (Suchomel, Nimphius, & Stone, 2016). PF and RFD are consistently measured to assess training adaptations and neuromuscular fatigue. Acute fatigue can lead to changes in metabolic activity, and metabolic activity changes may cause decrease in performance due to changes in muscle contraction. Gustavo et al., 2014 saw a noticeable decrease in the descending phase under fatigued conditions. There was no effect for max force in use of determining fatigue (Gustavo & Gabriel, 2014).

Trivial changes for flight time during CMJs in trained groups have been observed during force plate testing. The possibility of flight time change results are indicated if there is a negative sign of fatigue or positive increase in performance (Lombard, Reid, Pearson, & Lambert, 2017). An acute fatigue protocol leads to increased force exertion and increase in the takeoff duration of the jump (Truppa, Guaitolini, Garofalo, Castagna, & Mannini, 2020).

1.5.1 Dynamic strength index

Dynamic strength index (DSI) is an equation often used to measure current training status and the identification of performance deficits of maximal strength vs ballistic strength training (Sheppard, Chapman, & Taylor, 2011) (Thomas, Dos'Santos, & Jones, 2017). DSI is calculated by taking a ballistic PF dividing dynamic or isometric PF, IMTP being the maximal force test to provide PF and CMJ being the ballistic test to express PF in a fast movement.

1.6 Research Problem

Currently, there is a lack of literature investigating wearable technology, especially IMUs, in describing movements during tactical training events. Research is needed to determine which factors are most predictive of performance in military events.

1.7 Study Purpose

The purpose of the study is to measure biomechanical gait factors during a 14-km ruck march as descriptive changes in movement. We will also test if output from the IMTP and CMJ can provide additional insight into biomechanical changes during ruck marches and performance predictors.

1.8 Specific Aims/Hypothesis

1. To assess changes in biomechanical gait factors from the beginning 2-km of the loaded ruck march compared to the last 2-km of the loaded ruck march. We hypothesize that:

1a: There will be greater peak tibial accelerations during the first 2-km of the loaded ruck march to the last 2-km of the loaded ruck march.

1b: There will be greater step frequency during the first 2-km of the loaded ruck march than the last 2-km of the loaded ruck march.

1c: There will be greater peak tibial acceleration magnitude frequency when comparing the first 2-km of the loaded ruck march to the last 2-km of the loaded ruck march.

1d. There will be lower step intensity during the first 2-km of the loaded ruck march than the last 2-km of the loaded ruck march.

1e. There will be greater impact asymmetry discrepancy from the first 2-km of the loaded ruck march than the last 2-km of the loaded ruck march.

1f: There will be an increase in impact load during the first 2-km of the loaded ruck march to the last 2-km of the loaded ruck march.

2. To assess if sex differences appear in beginning 2-km of the loaded ruck march to the last 2-km of the loaded ruck march.

2a: There will be an increase in peak tibial acceleration from the first 2-km of the loaded ruck march to the last 2-km of the loaded ruck march in female participants compared to male participants.

2b: There will be an increase in impact asymmetry discrepancy from the first 2-km of the loaded ruck march to the last 2-km of the loaded ruck march in female participants compared to male participants.

2c: There will be an increase in impact load from the first 2-km of the loaded ruck march to the last 2-km of the loaded ruck march in female participants compared to male participants.

2d: There will be an increase in step frequency from the first 2-km of the loaded ruck march to the last 2-km of the loaded ruck march in female participants compared to male participants.

3. Determine if IMTP performance is related to biomechanical changes during the ruck march . We hypothesize that:

3a: Production of higher IMTP max force will be associated with less peak tibial acceleration in final 2-km of the loaded ruck march to the first 2-km of the loaded ruck march.

3b: Production of lower RFD will be associated with less peak tibial acceleration in final 2-km of the loaded ruck march to the first 2-km of the loaded ruck march.

3c: Production of higher IMTP (force/kg) will be associated with less peak tibial acceleration in final 2-km of the loaded ruck march to the first 2-km of the loaded ruck march.

3d: Higher jump height (cm) will be associated with less peak tibial acceleration in the first 2-km of the loaded ruck march to the last 2-km of the loaded ruck march.

3e: Production of higher CMJ PF will be associated with less peak tibial acceleration in final 2-km of the loaded ruck march to the first 2-km of the loaded ruck march.

3f: Production in higher flight time will be associated with less peak tibial acceleration in final 2-km of the loaded ruck march to the first 2-km of the loaded ruck march.

3g: Production of high DSI (>0.80) will be associated with more peak tibial acceleration in the final 2-km of the loaded ruck march to the first 2-km of the loaded ruck march.

4. Determine if bilateral symmetry is present across tests for both 14.5-km ruck march and performance test of the IMTP and CMJ. We hypothesize that:

4a: Lower symmetry angle difference in ruck march will associate in less peak tibial acceleration in the final 2-km of the loaded ruck march to the first 2-km of the loaded ruck march.

4b: Lower symmetry angle difference in IMTP will associate in less peak tibial acceleration in the final 2-km of the loaded ruck march to the first 2-km of the loaded ruck march.

4c: Lower symmetry angle difference in CMJ will associate in less peak tibial acceleration in the final 2-km of the loaded ruck march to the first 2-km of the loaded ruck march.

1.9 Study Significance

The outcome of this study will provide insight on ways to use portable technology to monitor tactical athletes in real-world training events. Notably, this study will contribute information to the current research on military training and ruck marches. Identifying relationships between gait metrics and performance test to monitor performance by biomechangical changes in onset, to improve decisions on performance and combat readiness. Identifying a relationship between IMTP and CMJ for biomechanical changes can establish signs of performance and readiness on ruck marches. Therefore, significant relationships are noted, training monitoring can be implemented to improve tactical athletes.

2.0 Methods

2.1 Design

This study is part of another study through the NRML titled developing a warfighter mobility signature and predictive algorithm for Musculoskeletal Injury Risk During Marine Corps Officer Candidate School (OCS) in the United States Marine Corps (USMC). The study received Institutional Review Board approval from the University of Pittsburgh.

2.2 Subjects

Subject recruitment was performed by members of the OCS research team from the Neuromuscular Research Laboratory at the University of Pittsburgh by providing a talk to the incoming USMC OCS class before the start of training. Individuals interested in the study were asked to fill out informed consent forms and any questions were answered by researchers. Researchers informed subjects of inclusion and exclusion criteria that would involve exclusion from the study.

2.3 Power analysis

The sample for this thesis was extracted from a larger study with the OCS study of the USMC as convenience sampling. Conduct of the current study required fitting study participants with IMUs. Based on feasibility, all available participants from one iteration of the larger study were fitted with IMUs for the current study. A total of 46 participants were included in this study.

2.3.1 Inclusion Criteria

Inclusion criteria included the following: USMC Officer Candidate 18-40 years old, consisting of both men and women. Inclusion criteria involved passing USMC health standards and physical fitness standards for OCS.

2.3.2 Exclusion Criteria

Exclusion criteria was being dropped from Officer Candidate School due to any reasons.

2.4 Independent and Dependent Variables

2.4.1 Specific Aim 1: Descriptive measures of gait

The independent variable for specific aim one is time points of the ruck march. The dependent variables looked at in gait are listed below.

- Impact load (step count*g)
- Step count
- Average Intensity (g)
- Impact Asymmetry

2.4.2 Specific Aim 2: Sex Differences

The independent variable is sex. The dependent variables looked at in gait are listed below.

Impact load (step count*g)

- Step count

- Average Intensity (g)
- Impact Asymmetry

2.4.3 Specific Aim 3: Prediction of Biomechanical changes

The dependent variable is biomechanical changes in this aim, which looked at different performance measurements that predict occurrence of change for performance. The independent variables looked at through IMTP and CMJ testing are listed below.

- Max force (N)
- Rate of force development (at various ms; unit of measure N/s)
- Force relative to bodyweight (/kg)
- Jump Height (cm)

2.4.4 Specific Aim 4: Bilateral comparison of symmetry

The independent variable is output of each extremity during each test, 14.5 km ruck, IMTP, and CMJ. The dependent variable is the measure of difference between limbs.

2.5 Instrumentation

2.5.1 Inertial Measurement Unit

All subjects were provided with a Blue Trident IMU (Vicon, Denver, USA) which was worn during for the ruck march. The Blue Trident IMU is tri-axial with accelerometer low and high, gyroscope and magnetometer. Low and high accelerometer means the Blue Trident Imu just uses 2 different accelerometers with low being more sensitive to detect lower changes and high to detect bigger impact changes. Blue Trident IMU can collect data of low g and high g with ability to capture accelerations up to +/-200g. Blue Trident IMU capture rate is high g up to 1600 Hz 200 g within high accelerometer, low g up to 1125 Hz and up to 16g accelerometer. Magnetometer up to 112 Hz, and global angles 225 Hz.

Reliability for IMUs was reported to have agreement levels between IMU and Motion Capture (MoCap). The results show high (from 0.71 to 1) agreement for distance and time extracted from IMU and MoCap at different speeds for both legs of all subjects.

Average accuracy of the distance travelled is 97.99% (95% CI ±1.41), the average accuracy of time shows 99.01% (95% CI ±0.26), the average accuracy of speed 97.39% (95% CI ±1.44). The estimated speed on average is 1.53 $ms^{-1}$and this agrees with expected human walking speed averaging 1.5-2.5 ms^{-1} [33]. There is no significant difference between IMU estimated distance (μ =7.49, σ =0.39) and MoCap distance (μ =7.67, σ =0.26); t-test p=0.94 there is a strong correlation between the two; Pearson correlation coefficient (r=0.81)

Reliability, measured by an intraclass coefficient (ICC), was good-to-excellent. These results suggest that fatigue-related changes in biomechanics derived from a CoM-mounted IMU are reliable day-to-day when participants ran at or around Maximal Steady State and are not significantly affected by slight deviations in speed.

Inter-unit reliability was excellent ($0.90 \leq ICC \leq 0.98$) for most metrics (21 out of 26), including all step count, Low Intensity Step, High Intensity Step and bone stimulus metrics. Inter-unit reliability was good ($0.83 \leq ICC \leq 0.86$) for all other metrics except for Yo-Yo impact load (ICC = 0.79; CI: 0.40, 0.93) which was acceptable. TE (CV%) was good ($0.7\% \leq TE \leq 9.7\%$) for all metrics assessed except for impact load during the overall session, Yo-Yo, sprint and Zig-Zag tasks which were questionable (10.8 – 14.5 %)

Present findings are comparable to previous research which reported reliability (0.89 – 0.96 ICC, excellent) for step peak resultant acceleration during treadmill running in a laboratory using earlier model IMeasreU Blue Thunder units (Sheerin et al., 2017)

Figure 1 Blue Trident IMU

2.5.2 Isometric Mid-Thigh Pull

Force plates used in IMTP testing were the VALD FD Lite (VALD, Newstead, NZ). The VALD force plates were dual-platform setup collecting data at 1000 Hz. Comfort et. al. (2015) & Brady et. al. 2018) found high reliability of the IMTP compared to maximum rep testing under standard conditions.

2.5.3 Counter movement jump

Hawkins Dynamics force plate (Hawkins Dynamics Inc, Westbrook, ME) was conducted through a dual-platform setup collecting data at 1000 Hz. The CMJ data was collected during the performance of a movement screen. Lombard et al. found high reliability for CMJ metrics across training levels of participants (Lombard et al., 2017). CMJ most commonly and practical used metric is jump height, jump in previous research findings deemed reliable (0.97) and may be used to detect change (Merrigan et al., 2020).

2.6 Testing Procedures

2.6.1 IMU

Blue Trident IMU was utilized to collect data during the ruck march. IMUs were placed approximately 1 inch above medial malleolus on both legs on top of the standard issue military boot, pointing toward the toes with the widest part of the IMU parallel with the floor. Subjects were seated on the ground during the placement process of the IMUs by the researchers.

The IMUs were placed in the blue trident straps with a piece of double-sided tape on the back of the IMU. The IMU was further secured with wrapping Coban 4-5 fully around. With Pro Kinesiology Tape (SB Box, Irving, Texas) tape 3 times around the Coban (3M, Maplewood, Minnesota). These steps were repeated on the opposite leg.

Participants were dressed in military fatigues with standard issue military combat boots as footwear. Full ruck packs were carried which is around 35 kg. Pace was set by leaders up front and ended up equating to about 13.5 mins as a whole. No warm-up was performed. The ruck started at 0300 and went until around 0710 this included three breaks lasting 15, 10, and 5 mins respectively. First break 1 hour (hr) 15 mins in 2^{nd} break hr from then and then 3^{rd} around 45 mins to an hour for the last one. The majority of the ruck march was under low light conditions. Terrain overall was not terribly uneven or treacherous with it being on a path ranging from dirt with roots and rocks, to gravel and pavement overall did not seem to be overall to much in elevation changes unlike if it took place in parts of Pittsburgh. While I do remember maybe a few short fairly intense inclines in the beginning where definitely in the second half it was not as steep but longer duration elevation changes where it seemed to be a little more of decline towards the end. After completion of the ruck march IMUs were collected from all subjects data was stored on the device until offloading of data post-test back at the NMRL.

2.6.2 IMTP

Isometric midthigh pull was tested as part of baseline testing, before ruck march about eight weeks. Prior to IMTP testing, subjects completed a standardized dynamic warm-up. Subjects stood on dual force plates with bar perpendicular, then subjects were asked to grab the bar with weightlifting hooks, instructed to grab the bar with a clean grip (thumb distance from thigh) with bar in contact with mid-thigh. Barbell height was adjusted so participants were standardized to a knee angle of 125-145 degrees and 140–150 degrees hip angle were achieved, through joint angles handheld goniometer. The bar height was recorded to speed up transitions in the notes section per subject. Three familiarization pulls were done at subjects self-perceived 50%, 75%, and 90% intensity for three seconds. With two more maximum effort trials to pull as hard as possible to reach maximum in a five second pull duration (two-minute rest period between trials). If between the two max attempts was a greater than 250 N difference a third trial was performed. After successful completion of all trials, “stop” button was selected.

2.6.3 Counter Movement Jump

CMJ bilateral testing was conducted as a part of baseline testing, before ruck march about eight weeks. Prior to testing, subjects were instructed to jump “as high and as fast as possible.” The force plate was zeroed and then patient was instructed to step on. The subject was asked to stand still on the force plate. Then, subjects were instructed to place “arms up’ and “jump” when instructed. A minimum of three jumps were performed for each subject, with each time repeating instructions of arms up followed by a jump call. The CMJ was within a screening of movements with others taking place around the sequence such as overhead squat, lunge, box step and drop jump.

These same steps and verbal clues were repeated for single leg CMJ jumps which were done for one trial unless the subject did not land on force plate and was repeated. This testing allowed for greater assessment of extremities.

2.7 Data Reduction

All data was downloaded offsite at Quantico and assessed back at the Neuromuscular Research Laboratory. Then data was copied for each subject that participated in the ruck march, placed in a separate direct. For example, a file will be named subject_001F.

2.7.1 IMU data reduction

Data from each IMU was collected for the entire ruck march, but only the data from the first ruck march portion (defined as the start of the ruck march 2-km) and the last ruck march portion (last full 2-km from last break until end) was used in the study. The breaks were pre planned spots instructors from a set distance in variations apart first being 4.94-km, second being

4.26-km and 3.18-km. Data has footnotes describing what is going on and separated into two parts: first ruck march and last ruck march to exclude numbers in the middle of the ruck march. Data from the 14-km ruck was be extracted using proprietary software (IMU_Step, Version 2.5.1, iMeasureU, Auckland, New Zealand).

Threshold for asymmetrical values between extremities for defining clinical significance of 10%(Kvist, 2004; Schmitt, Paterno, & Hewett, 2012).

2.7.2 IMTP data reduction

IMTP was visually inspected to make sure measures with limit error on trial attempts. Was only inspected in real time if a third attempt was needed due to testing error or force output not being within 250 N of the first two attempts. In depth visual inspection occurred back at the NMRL through data reduction was started by analyzing entries for pre-start countermovement or unsteady weighing period or pretension pull, PF at the end of trial and drastic changes in force. When comparing the max attempts, if there was a between-trial difference of greater than 250 N, a third trial was performed. In scaling PF to body weight, the PF obtained was divided by bodyweight in (kg).

2.7.3 Counter Movement Jump

In scaling PF into bodyweight, the PF obtained was divided by bodyweight in (kg).

2.7.4 Dynamic Strength Index

DSI calculated by taking a ballistic PF dividing dynamic or isometric PF. In this study DSI= CMJ PF/ IMTP Peak Vertical Force.

2.7.5 Symmetry Angle

Symmetry Angle equation is defined as follows: (Zifchock et al., 2008)

$SA = (45° - \arctan(X_{left}/X_{right}))/ 90° \times 100\%$

If angle for arctan is greater than 90° then the following equation will be used so the set of values are not on the wrong line of symmetry.

$SA = (45° - \arctan(X_{left}/X_{right}) - 180°)/ 90° \times 100\%$

In comparison between the numbers comparing within trial differences versus other tests, the smallest worthwhile change will be used by calculating individual between subject standard deviation and multiplying by 0.2 (Turner, et al., 2015).

All measures from IMUs, IMTP, and CMJ of unilateral and bilateral that could be compared were assessed for symmetry angle.

2.8 Data Analysis

Descriptive statistics (mean, standard deviation, median, interquartile range, and proportion, as appropriate) were calculated for all variables.

Specific aim 1- changes in dependent variables pre to post were analyzed using paired samples T-test or Wilcoxon signed rank test, as appropriate.

Specific aim 2- a 2-way mixed measures analysis of variance (ANOVA) was conducted to analyze the effect of sex (men, women), time (first 2-km, last 2-km), and the effect of interaction between sex and time on the dependent variable. If assumptions for ANOVA were not met, data transformations or corresponding non-parametric tests were conducted.

Specific aim 3- the associations between IMTP strength/power variables measured at baseline and the changes in biomechanical variables, were analyzed using Pearson or Spearman correlation coefficient, as appropriate.

Specific aim 4- the associations between symmetry angle scores across tests of IMU during 14-km ruck, IMTP, and CMJ, compared to PTA were analyzed using Pearson or Spearman correlation coefficient, as appropriate.

Statistical significance was set a priori at alpha = 0.05, two sided. Statistical analyses were conducted using SPSS Statistics Version 28 (IBM Corporation; Armonk, NY).

3.0 Results

Forty-five subjects included in the IMU data for ruck march analysis. Forty-two subjects were analyzed in the final analysis for IMTP, and forty subjects were analyzed in the final analysis for CMJ. Five subjects were missing CMJ data because they did not have time due to training requirements. Two subjects were missing from IMTP due to technological error.

3.1 Descriptive Data

The ruck march in totality was 14.5 km with the study analyzing the first 2-km compared to the last 2-km. Pace of the USMC Officer Candidates for the 14.5 km ruck march was about thirteen and half mins per km.

3.1.1 Demographic Data

Table 1 includes descriptive data for the USMC Officer candidates who participated in the study.

Table 1 Descriptive Data on Subjects

Descriptive Statistics					
	N	Minimum	Maximum	Mean	Std. Deviation
Height (cm)	45	154	189.8	174.54	8.30
Weight (kg)	45	54.4	96.2	76.54	9.75
Age	32	19	35	24.06	3.72

13 subjects were missing data on age.

3.2 Aim 1

Results of statistical analysis for biomechanical variables in 14-km ruck march are presented in Table 2.

Table 2 Biomechanical Measures during the First and Last 2-km of the Ruck March

		First 2-km			Last 2-km			
	n	Mean	Std. Deviation	Median	Mean	Std. Deviation	Median	P-value for change over time
Impact Load Left	45	6613.99	1824.27	6187.98	7130.92	1856.15	6692.37	<0.001
Impact Load Right	45	6731.49	1780.18	6142.70	7190.41	1791.72	6821.01	<0.001
Impact Load Total	45	13345.48	3544.09	12350.07	14321.33	3547.52	13492.32	<0.001
Step Count Left	45	1490.96	306.23	1424.00	1489.31	296.26	1412.00	0.798
Step Count Right	45	1499.58	304.21	1422.00	1503.80	303.25	1425.00	0.623
Step Count Total (L+R)	45	2990.53	606.16	2853.00	2993.11	595.63	2848.00	0.835
Average Intensity Left (g)	45	8.85	1.47	8.66	9.58	1.76	9.46	<0.001
Average Intensity Right (g)	45	8.97	1.48	8.86	9.59	1.67	9.25	0.000
Average Intensity (L and R; g)	45	8.90	1.40	8.68	9.58	1.61	9.36	<0.001
Impact Asymmetry (%)	45	1.31	10.69	0.87	0.03	11.77	1.08	0.199

There was significant increase in the impact load of the left leg from the first 2-km (6613.99 ± 1824.27) to the last 2-km of the ruck march (7130.92 ± 1856.15; p <0.001) and a significant increase in the impact load of the right leg from the first 2-km (6731.48 ± 1780.18) to the last 2-km of the ruck march (7190.92 ± 1791.72; p <0.001). Also, there was a significant increase in the impact load of total with left and right leg combined from the first 2-km (13345.48 ± 3544.09) to the last 2-km of the ruck march (14321.33 ± 3547.52; $p < 0.001$).

A significant increase was demonstrated in the average intensity on left leg from the first 2-km (8.85 ± 1.47g) to the last 2-km of the ruck march (9.58 ± 1.76g; $p < 0.001$). There was a significant change in the of the average intensity on right leg from the first 2-km (8.97 ± 1.48g) to the last 2-km of the ruck march (9.59 ± 1.67g; $p < 0.001$). Also, a significant increase was demonstrated in the average intensity on both left and right leg combined at first 2-km 8.90 ± 1.40g to last 2-km of the ruck march 9.58 ± 1.61g; $p < 0.001$. There was no significant difference in the measures of step count of left, right and total (left+right) and the impact asymmetry.

3.3 Aim 2

Table 3 shows descriptive data of the USMC Officer Candidates on 14-km ruck march.

Table 3 Descriptive Data split by sex

	Sex	N	First 2-km		Last 2-km	
			Mean ± SD	**Median**	**Mean ± SD**	**Median**
Impact Load L (Steps x g)	Males	33	6058.66±1060.68	5852.23	6666.66±1289.92	6569.27
	Females	12	8141.16±2563.11	7309.27	8407.63±2552.66	7723.07
Impact Load R (Steps x g)	Males	33	6271.64±1132.70	6055.12	6852.14±1333.74	6533.42
	Females	12	7996.07±2563.02	7148.31	8120.68±2525.65	7637.6
Impact Load T (Steps x g)	Males	33	12330.31±2112.71	11826.86	13518.80±2483.70	12689.50
	Females	12	16137.23±5065.89	15055.1	16528.30±5014.2	15505.12
Step Count L	Males	33	1409.27±90.54	1402.00	1417.30±67.34	1405.00
	Females	12	1715.58±525.54	1492.00	1687.33±528.72	1472.50
Step Count R	Males	33	1418.18±90.54	1400.00	1434.91±67.43	1408.00
	Females	12	1723.42±529.28	1493.50	1693.25±534.37	1475.00
Step Count T	Males	33	2827.45±141.21	2821.00	2852.21±150.34	2820.00
	Females	12	3439.00±1054.76	2985.50	3380.58±1063.03	2947.50
Avg. Intensity of L (g)	Males	33	8.60±1.38	8.27	9.41±1.83	9.27
	Females	12	9.54±1.56	9.27	10.03±1.52	10.13
Average Intensity of R (g)	Males	33	8.85±1.51	8.61	9.57±1.82	9.17
	Females	12	9.30±1.42	9.08	9.63±1.22	9.81
Average Intensity T (g)	Males	33	8.72±1.36	8.51	9.49±1.72	9.15
	Females	12	9.42±1.42	9.10	9.83±1.31	9.86
Impact Asymmetry	Males	33	2.65±11.01	4.59	1.43±12.56	1.92
	Females	12	-2.37±9.17	-2.11	-3.82±8.57	-3.85

Reciprocal transformation of Impact Load L was used in the analysis since the raw data and other transformations were not successful in meeting the assumptions for the ANOVA. Results from the reciprocally transformed data showed a significant interaction effect (p=0.005, partial η^2 = 0.169). The significant interaction was followed up by analysis of the simple main effect of time at each level of sex there was a significant simple main effect of time (p< 0.001, η^2= 0.674 for men. Among women, there was no significant simple main effect of time (p=0.103, η^2=0.223). Estimated marginal means for Inversed Impact Load Left in 14-km ruck march are presented in Figure 2.

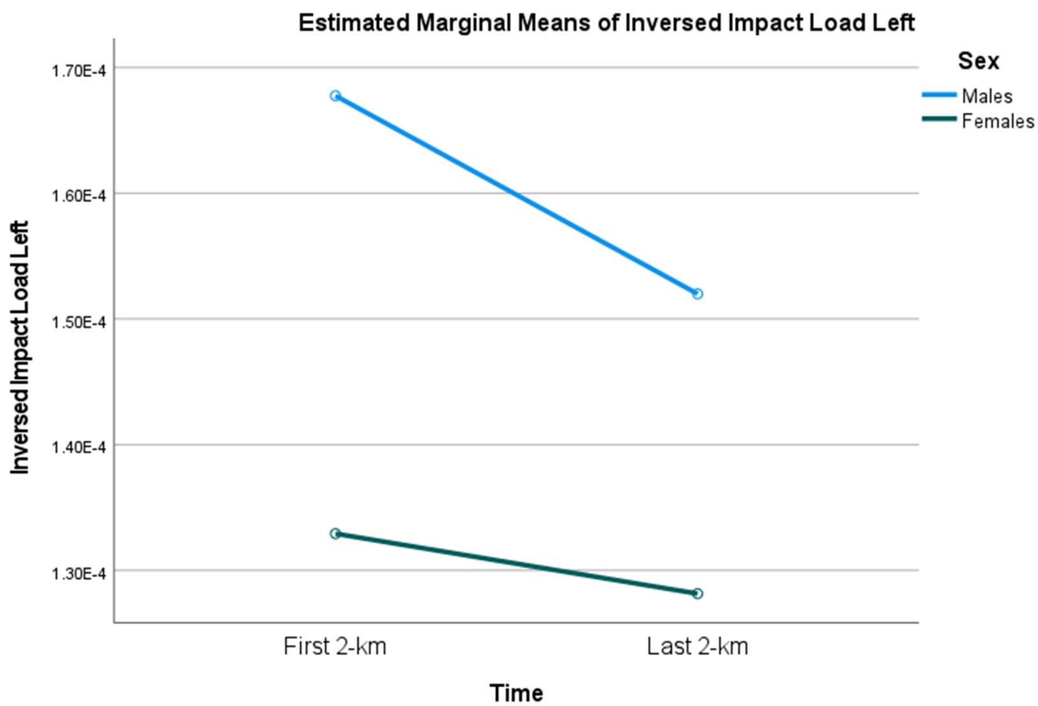

Figure 2 Impact Load Left

Results from the impact load right showed a significant interaction effect (p=0.010, partial η^2 = 0.142). The significant interaction was followed up by analysis of the simple main effect of time at each level of sex. There was a significant simple main effect of time (p< 0.001, η^2= 0.573) for men. Among women there was no significant simple main effects of time (p=0.413, η^2= 0.062).

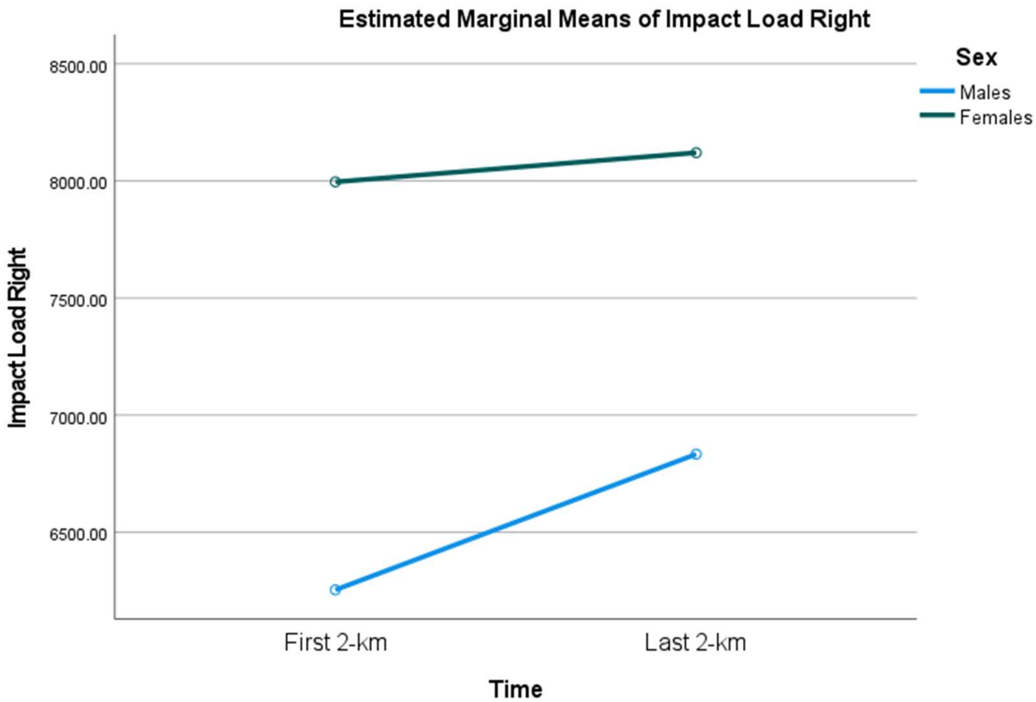

Figure 3 Impact Load Right

Results from the impact load total showed a significant interaction effect ($p=0.013$, partial $\eta^2 = 0.136$). The significant interaction was followed up by analysis of the simple main effect of time at each level of sex. There was a significant simple main effect of time ($p< 0.001$, $\eta^2= 0.634$) for men. Among women there was no significant simple main effects of time ($p=0.152$, $\eta^2= 0.178$).

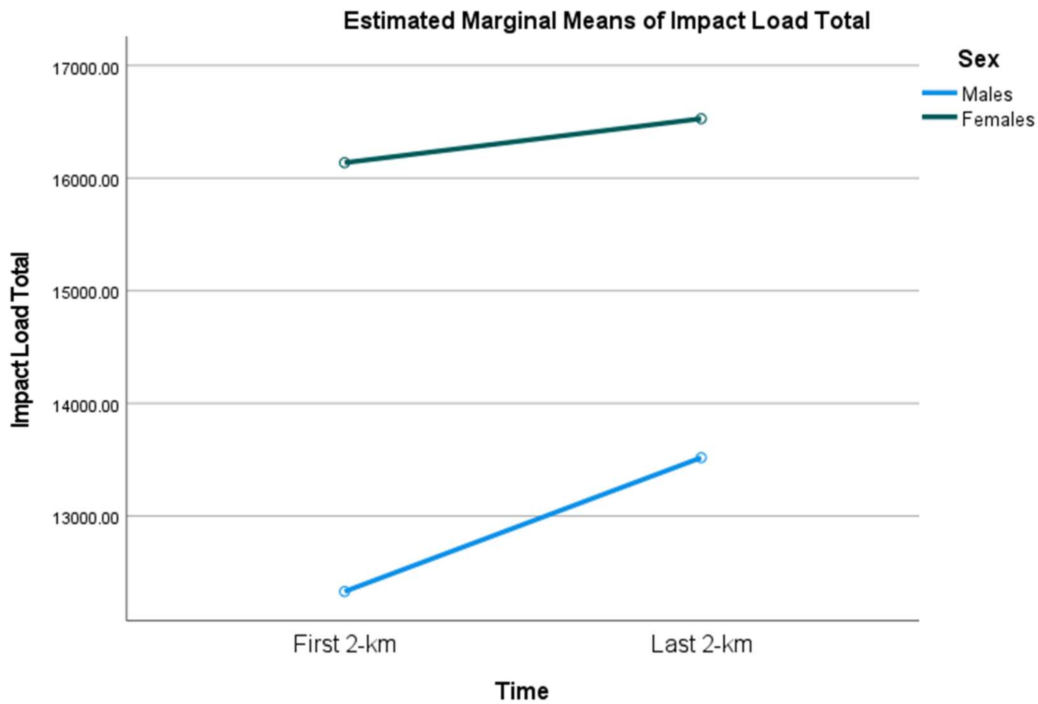

Figure 4 Impact Load Total

None of the data transformations for the variable step count left resulted in a normal distribution. The results of simpler tests (Wilcoxon signed ranks tests) showed that among men, there was no significant change in step count left over the duration of the march (pre median: 1402.00, post median 1405.00, p=0.066). Among women there was significant reduction in step count left over the duration of the march (pre median 1492.00, post median 1472.50, p=0.016).

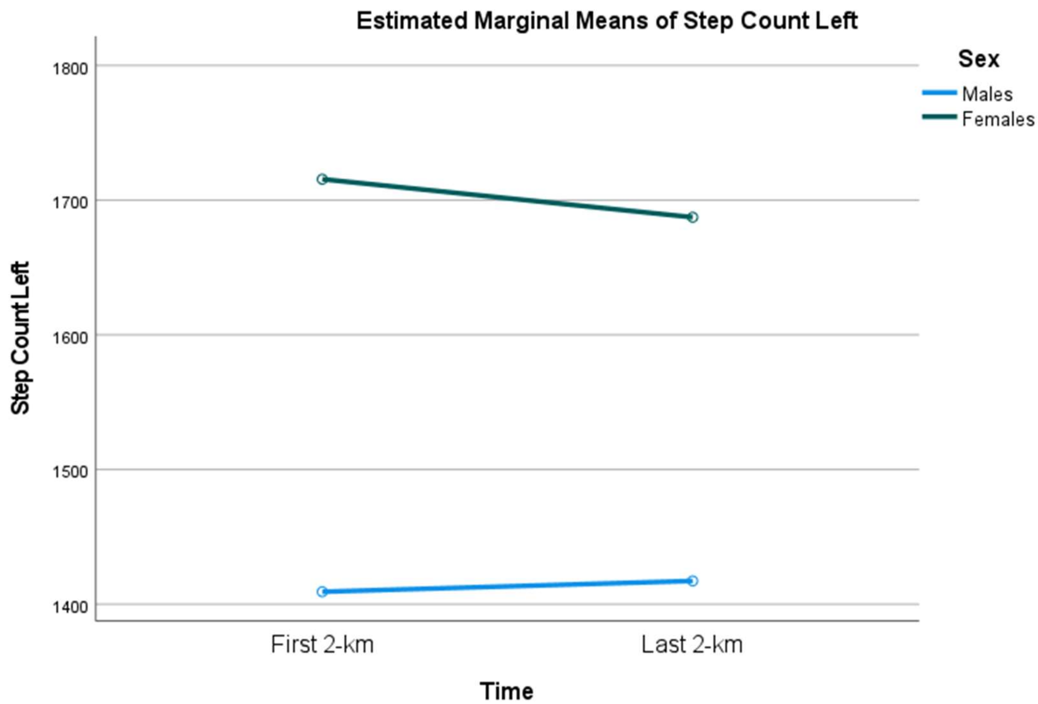

Figure 5 Step Count Left

None of the data transformations for the variable step count left resulted in a normal distribution. The results of simpler tests (Wilcoxon signed ranks tests) showed that among men there was significant increase in step count right over the duration of the march (pre median: 1400.00, post median 1408.00, p=0.043). Among women there was significant reduction in step count right over the duration of the march (pre median 1493.50, post median 1475.00, p=0.011).

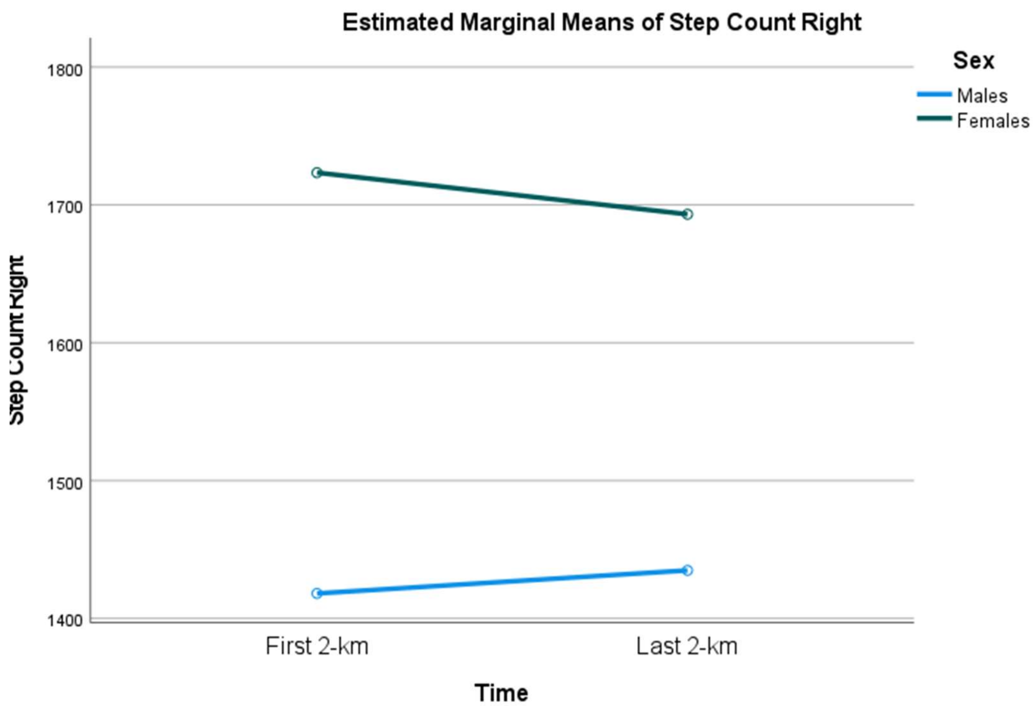

Figure 6 Step Count Right

None of the data transformations for the variable step count left resulted in a normal distribution. the results of simpler tests (Wilcoxon signed ranks tests) showed that among men there was significant change in step count total over the duration of the march (pre median: 2821.00, post median 2820.00, p=0.024). Among women there was significant reduction in step count total over the duration of the march (pre median 2985.50, post median 2947.50, p=0.011).

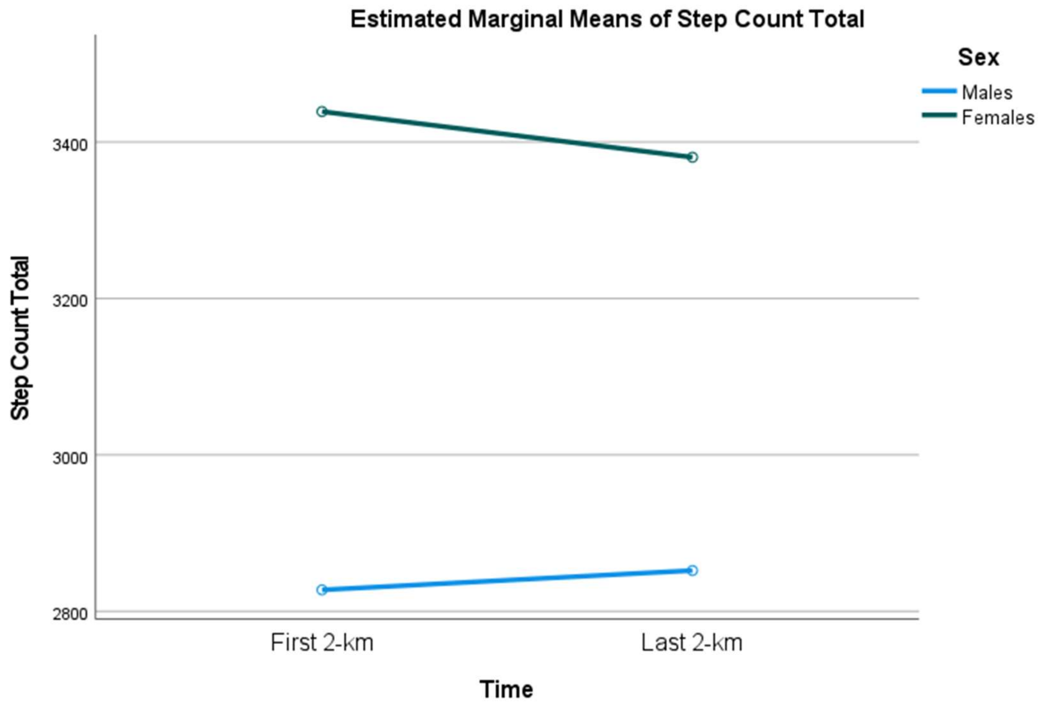

Figure 7 Step Count Total

There was no significant interaction effect for average intensity left extremity ($p=0.209$, partial $\eta^2=0.036$). There was a significant main effect of time ($p<0.001$, partial $\eta^2=0.397$), but no significant main effect of sex ($p=0.146$, partial $\eta^2=0.048$). Average Intensity Left was significantly higher during the last 2-km of the march (mean 9.72, std. error 0.30) as compared to during the first 2-km (9.07, 0.24).

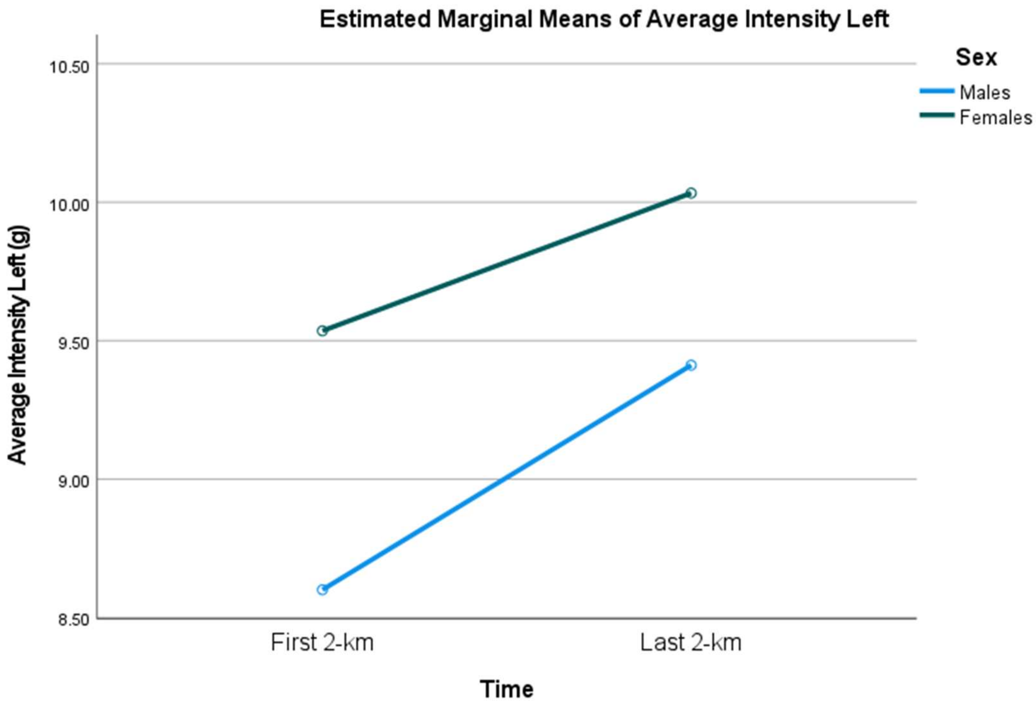

Figure 8 Average Intensity Left

There was no significant interaction for average intensity right extremity ($p=0.133$, partial $\eta^2=0.052$). There was a significant main effect of time ($p<0.001$, partial $\eta^2=0.295$), but no significant main effect of sex ($p=0.628$, partial $\eta^2=0.006$). Average Intensity Right was significantly higher during the last 2-km of the march (mean 9.60, std. error 0.28) as compared to during the first 2-km (9.07, 0.25).

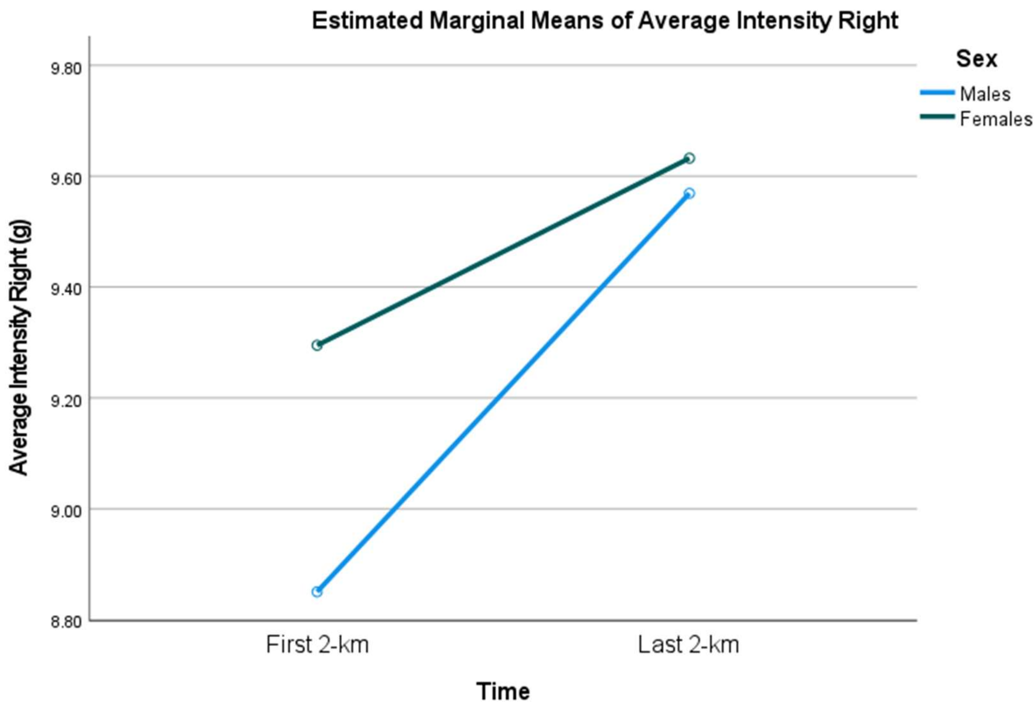

Figure 9 Average Intensity Right

There was no significant interaction for average intensity total extremity ($p=0.114$, partial $\eta^2=0.057$). There was a significant main effect of time ($p<0.001$, partial $\eta^2=0.407$), but no significant main effect of sex ($p=0.299$, partial $\eta^2=0.025$). Average Intensity Total was significantly higher during the last 2-km of the march (mean 9.66, std. error 0.27) as compared to during the first 2-km (9.07, 0.23).

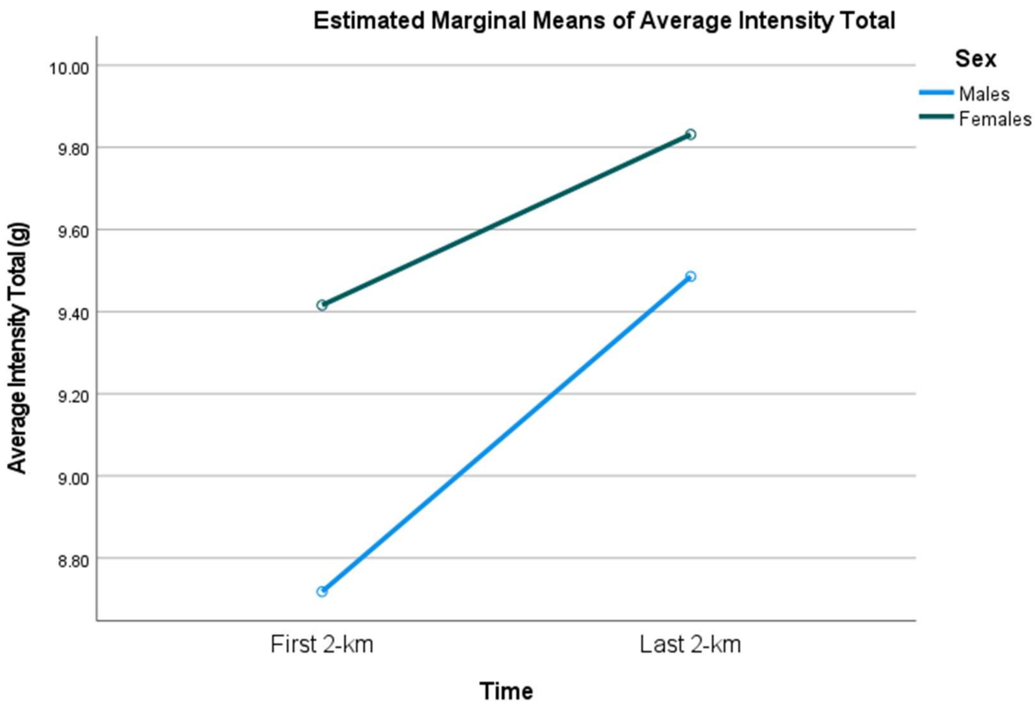

Figure 10 Average Intensity Total

There was no significant interaction for impact asymmetry ($p=0.918$, partial $\eta^2<0.001$). There was a significant main effect of time ($p=0.241$, partial $\eta^2=0.032$), but no significant main effect of sex ($p=0.412$, partial $\eta^2=0.020$). Impact asymmetry was significantly higher during the last 2-km of the march (mean -1.19, std. error 1.97) as compared to during the first 2-km (0.14, 1.78).

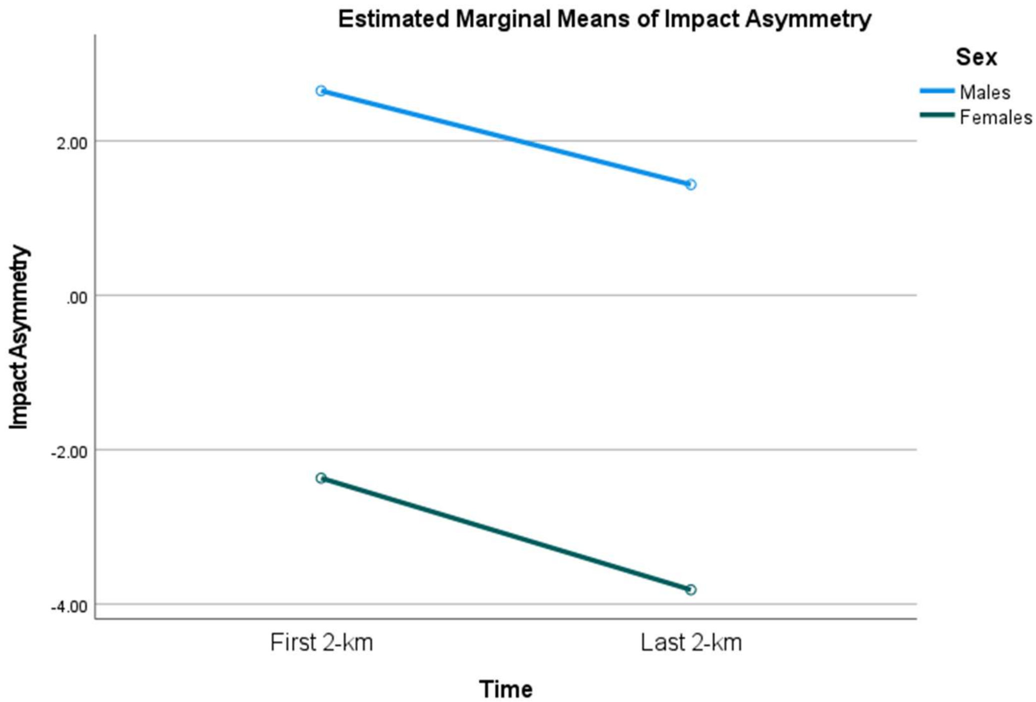

Figure 11 Impact Asymmetry

3.4 Aim 3

Biomechanical variables during the 14-km ruck march were correlated with peak vertical forces collected during the IMTP. Table 4 shows the correlation coefficients determined between IMU variables of impact load, step count, average intensity, and impact asymmetry and peak vertical force and peak vertical force relative to mass (kg).

Table 4 IMTP Peak Vertical Force

	Peak Vertical Force			Peak Vertical Force relative to kg	
	n	Correlation Coefficient	p value	Correlation Coefficient	p value
Diff_Impact Load Left	41	0.244	0.124	0.244	0.124
Diff_Impact Load Right	41	0.080	0.617	0.080	0.617
Diff_Impact Load Total	41	0.184	0.249	0.184	0.249
Diff_Step Count Left	41	0.362*	0.020*	0.295	0.061
Diff_Step Count Right	41	0.148	0.355	0.148	0.355
Diff_Step Count Total	41	0.343*	0.028*	0.343*	0.028*
Diff_Avg Intensity Left	41	0.205	0.199	0.205	0.198
Diff_Avg Intensity Right	41	0.035	0.827	0.035	0.827
Diff_Avg Intensity Total	41	0.14	0.382	0.140	0.382
Diff_Impact Asymmetry	41	-0.185	0.248	-0.185	0.248
*Spearman's correlation coefficient					

There was a significant positive correlation between peak vertical force and step count left (0.362, p =0.020). There was a significant positive correlation between peak vertical force and step count total (left + right combined) (0.343, p =0.028). There was a significant positive correlation between peak vertical force relative to mass and step count total (left + right combined) (0.343, p =0.028).

Biomechanical variables during the 14-km ruck march were correlated with RFD data collected during the IMTP. Table 5 shows the correlation coefficients determined between IMU variables of impact load, step count, average intensity, and impact asymmetry and rate of force development at five different time points.

Table 5 IMTP RFD

RFD at various time points in IMTP							
		50ms		100ms			
	n	Pearson	p value	Pearson	p value		
Diff_Impact Load Left	41	0.103	0.522	0.040	0.806		
Diff_Impact Load Right	41	0.040	0.804	-0.011	0.945		
Diff_Impact Load Total	41	0.081	0.614	0.016	0.920		
Diff_Step Count Left	41	0.042	0.795	0.040	0.805		
Diff_Step Count Right	41	0.071	0.657	0.016	0.920		
Diff_Step Count Total	41	0.069	0.668	0.029	0.858		
Diff_Avg Intensity Left	41	0.104	0.517	0.041	0.798		
Diff_Avg Intensity Right	41	0.010	0.948	-0.020	0.901		
Diff_Avg Intensity Total	41	0.068	0.674	0.016	0.920		
Diff_Impact Asymmetry	41	-0.158	0.325	-0.112	0.488		
150ms				200ms		250ms	
	n	Pearson	p value	Pearson	p value	Pearson	p value
Diff_Impact Load Left	41	0.041	0.801	0.020	0.904	0.025	0.878
Diff_Impact Load Right	41	0.035	0.827	0.056	0.726	0.039	0.810
Diff_Impact Load Total	41	0.043	0.789	0.043	0.789	0.036	0.823
Diff_Step Count Left	41	0.042	0.796	0.144	0.368	0.179	0.263
Diff_Step Count Right	41	0.007	0.966	0.169	0.291	0.194	0.223
Diff_Step Count Total	41	0.023	0.886	0.183	0.252	0.216	0.174
Diff_Avg Intensity Left	41	0.043	0.790	-0.001	0.994	0.002	0.992
Diff_Avg Intensity Right	41	0.037	0.819	0.001	0.996	-0.021	0.898
Diff_Avg Intensity Total	41	0.048	0.764	0.001	0.996	-0.010	0.952
Diff_Impact Asymmetry	41	-0.047	0.769	-0.033	0.840	-0.059	0.714

There was no significant correlation between the first 2-km and the last 2-km of the 14-km ruck march variables and the IMTP RFD data.

Biomechanical variables during the first 2-km and the last 2-km ruck march were correlated with jump height assessed during the CMJ. Table 6 shows the correlation coefficients determined between IMU variables of impact load, step count, average intensity, and impact asymmetry and bilateral and unilateral jump height in CMJ.

Table 6 Jump Height

Bilateral Jump Height CMJ				Unilateral Jump Height Left leg		Unilateral Jump Height Right leg	
	n	Pearson	p value	Pearson	p value	Pearson	p value
Diff_Impact Load Left	40	0.249	0.121	0.241	0.134	0.336	0.034
Diff_Impact Load Right	40	0.193	0.234	0.212	0.190	0.402	0.010
Diff_Impact Load Total	40	0.248	0.123	0.254	0.114	0.413	0.008
Diff_Step Count Left	40	0.176	0.277	0.178	0.273	0.210	0.193
Diff_Step Count Right	40	0.141	0.384	0.105	0.520	0.019	0.907
Diff_Step Count Total	40	0.189	0.242	0.165	0.310	0.121	0.457
Diff_Avg Intensity Left	40	0.226	0.160	0.209	0.195	0.369*	0.019*
Diff_Avg Intensity Right	40	0.134	0.410	0.170	0.295	0.398	0.011
Diff_Avg Intensity Total	40	0.204	0.206	0.214	0.184	0.388	0.013
Diff_Impact Asymmetry	40	-0.118	0.467	-0.041	0.802	0.117	0.471
*=spearman correlation coefficient							

There was a significant positive correlation between unilateral jump height in right leg and ILL (0.336 p =0.034). There was a significant positive correlation between unilateral jump height in right leg and ILR (0.402, p =0.010). There was a significant positive correlation between unilateral jump height in right leg and ILT (0.413, p =0.008). There was a significant positive correlation between unilateral jump height in right leg and average intensity on left leg (0.0369, p =0.019). There was a significant positive correlation between unilateral jump height in right leg and AvIR (0.0398, p =0.011). There was a significant positive correlation between unilateral jump height in right leg and AvIT (0.388, p =0.013).

Biomechanical variables during the first 2-km and the last 2-km ruck march were correlated with peak propulsive force assessed during the CMJ. Table 7 shows the correlation coefficients determined between IMU variables of impact load, step count, average intensity, and impact asymmetry and bilateral and unilateral peak propulsive force in CMJ.

Table 7 Peak Propulsive Force

Biomechanical Variables		Bilateral Peak Propulsive Force		Unilateral Peak Propulsive Force Left		Unilateral Peak Propulsive Force Right	
	n	Correlation Coefficient	p value	Correlation Coefficient	p value	Correlation Coefficient	p value
Diff_Impact Load Left	40	0.202	0.212	0.286	0.073	0.328	0.039
Diff_Impact Load Right	40	0.223	0.166	0.172	0.287	0.278	0.083
Diff_Impact Load Total	40	0.238	0.139	0.258	0.108	0.340	0.032
Diff_Step Count Left	40	0.276	0.085	0.259	0.107	0.200	0.216
Diff_Step Count Right	40	0.155	0.339	0.049	0.765	0.005	0.977
Diff_Step Count Total	40	0.250	0.120	0.167	0.304	0.106	0.517
Diff_Avg Intensity Left	40	0.157	0.334	0.262	0.102	0.274	0.088
Diff_Avg Intensity Right	40	0.184	0.257	0.180	0.267	0.310	0.051
Diff_Avg Intensity Total	40	0.191	0.239	0.25	0.119	0.353	0.025
Diff_Impact Asymmetry	40	0.064	0.695	-0.031	0.850	0.032	0.845
*=spearman correlation coefficient							

There was a significant positive correlation between unilateral peak propulsive force right and ILL (0.0328, p =0.039). There was a significant positive correlation between unilateral peak propulsive force right and ILT (0.0340, p =0.032). There was a significant positive correlation between unilateral peak propulsive force right and AvIT (0.0353, p =0.025).

Biomechanical variables during the first 2-km and the last 2-km ruck march were correlated with flight time assessed during the CMJ. Table 8 shows the correlation coefficients determined between IMU variables of impact load, step count, average intensity, and impact asymmetry and bilateral and unilateral flight time in CMJ.

Table 8 Flight Time

Biomechanical Variables		Bilateral Flight Time		Unilateral Flight Time Left		Unilateral Flight Time Right	
	n	Correlation Coefficient	p value	Correlation Coefficient	p value	Correlation Coefficient	p value
Diff_Impact Load Left	40	0.253	0.115	0.308	0.054	0.336	0.034
Diff_Impact Load Right	40	0.163	0.315	0.225	0.163	0.340	0.032
Diff_Impact Load Total	40	0.234	0.146	0.299	0.061	0.379	0.016
Diff_Step Count Left	40	0.187	0.248	0.133	0.412	0.192	0.234
Diff_Step Count Right	40	0.155	0.339	0.059	0.719	0.033	0.842
Diff_Step Count Total	40	0.205	0.206	0.110	0.501	0.121	0.456
Diff_Avg Intensity Left	40	0.221	0.170	0.331*	0.037*	0.361*	0.022*
Diff_Avg Intensity Right	40	0.095	0.559	0.194	0.229	0.318	0.045
Diff_Avg Intensity Total	40	0.179	0.268	0.274	0.088	0.344	0.030
Diff_Impact Asymmetry	40	-0.165	0.309	-0.107	0.509	0.032	0.846

*=spearman correlation coefficient

There was a significant positive correlation between unilateral flight time left and AvIL (0.331, p =0.037). There was a significant positive correlation between unilateral flight time right and ILL (0.336, p =0.034). There was a significant positive correlation between unilateral flight time right and ILR (0.340, p =0.032). There was a significant positive correlation between unilateral flight time right and ILT (0.379, p =0.016). There was a significant positive correlation between unilateral flight time right and AvIL (0.361, p =0.022). There was a significant positive correlation between unilateral flight time right and AvIR (0.381, p =0.045). There was a significant positive correlation between unilateral flight time right and AvIT (0.344, p =0.030).

Biomechanical variables during the first 2-km and the last 2-km ruck march were correlated with DSI values. Table 9 shows the correlation coefficients determined between IMU variables of impact load, step count, average intensity, and impact asymmetry and DSI which depicts ratio of force between the CMJ and the IMTP

Table 9 Dynamic Strength Index

Dynamic Strength Index			
	n	Pearson	p value
Diff_Impact Load Left	40	-0.140	0.417
Diff_Impact Load Right	40	0.123	0.477
Diff_Impact Load Total	40	-0.011	0.950
Diff_Step Count Left	40	-0.178	0.298
Diff_Step Count Right	40	-0.054	0.755
Diff_Step Count Total	40	-0.114	0.506
Diff_Avg Intensity Left	40	-0.102	0.553
Diff_Avg Intensity Right	40	0.146	0.394
Diff_Avg Intensity Total	40	0.020	0.906
Diff_Impact Asymmetry	40	0.301	0.074

No tests showed significant correlation between the 9mile ruck march variables and the test outputs.

3.5 Aim 4

Table 10. displays the descriptive statistics for symmetry angle in first 2-km and the last 2-km ruck march and performance tests.

Table 10 Descriptive Statistics of Symmetry Angle

Variables	N	Minimum	Maximum	Mean	Std. Deviation
SA Pre Impact Load	45	-6.355	7.430	0.613	3.084
SA Post Impact Load	45	-5.736	7.193	0.306	3.541
SA Pre Step Count	45	-4.794	6.150	0.196	1.491
SA Post Step Count	45	-1.070	7.469	0.286	1.360
SA Pre Average Intensity	45	-6.836	7.668	0.413	3.398
SA Post Average Intensity	45	-6.021	7.424	0.026	3.728
SA Jump Height	40	-10.462	9.380	-2.023	4.242
SA Bilateral Peak Propulsive Force	40	-2.381	6.780	0.856	2.133
SA Unilateral Peak Propulsive Force	40	-6.350	4.017	-0.397	2.437
SA Peak Propulsive Relative Force	40	-6.309	4.067	-0.412	2.457
SA Flight Time	40	-5.585	3.213	-0.757	1.833
SA Peak Vertical Force	42	-8.592	10.674	.495	5.393
SA RFD 50ms	42	-34.054	144.424	3.673	26.786
SA RFD 75ms	42	-26.917	143.820	3.690	24.954
SA RFD 100ms	42	-47.253	27.494	-1.137	12.908
SA RFD 150ms	42	-37.627	20.549	-0.991	12.036
SA 200 RFD	42	-28.610	15.503	-1.503	10.028
SA RFD 250ms	42	-24.337	15.546	-0.642	8.793
All variables presented as %					

Table 11 shows correlation between symmetry angle and to peak tibial acceleration of left leg measured during the first 2-km and the last 2-km ruck march.

Table 11. Symmetry Angle Correlation with Left Peak Tibial Acceleration

Peak Tibial Acceleration of Left (AvIL Difference)			
	n	Correlation Coefficient	p value
First 2-km Impact Load	45	0.041	0.787
Last 2-km Impact Load	45	-0.252	0.095
First 2-km Step Count	45	0.111	0.468
Last 2-km Step count	45	-0.038	0.803
First 2-km Average Intensity	45	-0.012	0.935
Last 2-km Average Intensity	45	-0.226	0.135
Jump Height Unilateral CMJ	40	0.136	0.402
PPF Bilateral CMJ	40	-0.113	0.487
PPF Unilateral CMJ	40	0.063	0.701
PPRF Unilateral CMJ	40	0.076	0.640
Flight time Unilateral CMJ	40	-0.018	0.912
IMTP Peak Vertical Force	42	-0.102	0.522
IMTP RFD 50ms	42	-0.291	0.062
IMTP RFD 75ms	42	-0.229	0.145
IMTP RFD 100ms	42	0.008	0.959
IMTP RFD 150ms	42	0.004	0.981
IMTP RFD 200ms	42	0.080	0.613
IMTP RFD 250ms	42	0.082	0.606
CMJ= Counter movement jump PPF = Peak propulsive force PPRF= Peak propulsive relative force IMTP = Isometric mid-thigh pull RFD= Rate of Force Development			

No significant correlation was made between symmetry angle and any other variables.

Table 12 shows correlation between symmetry angle and to peak tibial acceleration of right leg measured during the first 2-km and the last 2-km ruck march.

Table 12 Symmetry Angle Correlation with Right Peak Tibial Acceleration

PTA of Right (AvI R Difference)			
	n	Correlation Coefficient	p value
First 2-km Impact Load	45	0.071	0.644
Last 2-km Impact Load	45	0.267	0.076
First 2-km Step Count	45	0.169	0.266
Last 2-km Step count	45	-0.045	0.767
First 2-km Average Intensity	45	-0.012	0.938
Last 2-km Average Intensity	45	0.269	0.074
Jump Height Unilateral CMJ	40	0.458	0.003
PPF Bilateral CMJ	40	0.044	0.786
PPF Unilateral CMJ	40	0.230	0.153
PPRF Unilateral CMJ	40	0.240	0.135
Flight time Unilateral CMJ	40	0.287	0.072
IMTP Peak Vertical Force	42	-0.168	0.286
IMTP RFD 50ms	42	-0.138	0.382
IMTP RFD 75ms	42	-0.109	0.493
IMTP RFD 100ms	42	-0.108	0.496
IMTP RFD 150ms	42	-0.045	0.775
IMTP RFD 200ms	42	0.028	0.858
IMTP RFD 250ms	42	-0.007	0.964
CMJ= Counter movement jump PPF = Peak propulsive force PPRF= Peak propulsive relative force IMTP = Isometric mid-thigh pull RFD= Rate of Force Development			

There was a significant positive correlation between peak tibial acceleration of right leg and jump height of unilateral counter movement jumps (0.458, p =0.003).

Table 13 shows the correlation between symmetry angle and total peak tibial acceleration.

Table 13 Symmetry Angle Correlation with Total Peak Tibial Acceleration

Peak Tibial Acceleration of Total (AvI T Difference)			
	n	Correlation Coefficient	p value
First 2-km Impact Load	45	0.123	0.419
Last 2-km Impact Load	45	0.095	0.535
First 2-km Step Count	45	0.113	0.459
Last 2-km Step count	45	0.043	0.780
First 2-km Average Intensity	45	0.067	0.664
Last 2-km Average Intensity	45	0.075	0.622
Jump Height Unilateral CMJ	40	0.174	0.283
PPF Bilateral CMJ	40	-0.083	0.611
PPF Unilateral CMJ	40	0.165	0.309
PPRF Unilateral CMJ	40	0.166	0.305
Flight time Unilateral CMJ	40	0.122	0.452
IMTP Peak Vertical Force	42	-0.063	0.693
IMTP RFD 50ms	42	-0.081	0.610
IMTP RFD 75ms	42	-0.043	0.785
IMTP RFD 100ms	42	0.468	0.002
IMTP RFD 150ms	42	0.485	0.001
IMTP RFD 200ms	42	0.311	0.045
IMTP RFD 250ms	42	0.237	0.131
CMJ= Counter movement jump PPF = Peak propulsive force PPRF= Peak propulsive relative force IMTP = Isometric mid-thigh pull RFD= Rate of Force Development			

There was a significant positive correlation between peak tibial acceleration of total and rate of force of development 100ms during IMTP (0.468, p =0.002).

There was a significant positive correlation between peak tibial acceleration of total and rate of force 150ms of development during IMTP (0.485, p =0.001).

There was a significant positive correlation between peak tibial acceleration of total and rate of force 200ms development during IMTP (0.311, p =0.045).

4.0 Discussion

The purpose of the study was to measure biomechanical gait factors of the first 2-km and the last 2-km during a 14-km ruck march as descriptive changes in movement. We also tested output from the IMTP and CMJ to provide additional insight into biomechanical changes that may occur during ruck marches in order to determine predictors of performance. Specifically, the ruck march was evaluated through impact load, step count, average intensity and impact asymmetry through IMU. Monitoring of these military movement tasks allow for more detailed assessment of factors to complete and maintain military readiness and improve operational effectiveness. Before the ability to implore changes for testing effects of improvement baseline measures need to be taken to understand the effects the changes had/will have. To the best of the author's knowledge, this is the first time that these portable devices have been utilized to quantify biomechanical variables during a ruck march.

4.1 Aim 1

Impact Load for Left, Right and Total were significant increase from first 2-km to the last 2-km of the ruck march. Average intensity for left right and total were significant less in first 2-km compared to last 2-km of the ruck march. This has been seen previously in studies sometimes under tibial acceleration (Shorten et al., (Winslow & Shorten, 1989) (Clansey et al., 2012) (Reenalda et al., 2016).

The average step count for the group was 2,990 for 2-km. According to Alemany et al., an Army basic combat training (BCT) study determined the average step count was about 13,500 steps per day (Alemany et al., 2022). In the current study, just the 4-km of the total 14-km were assessed determined the step count was around 44% of daily average in comparison to the Army BCT. Step count split by sex determined that men had a lower step count average of 2827.45±141.21 in first 2-km compared to women had 3439.00±1054.76. Compared to last 2-km of the march, inverse changes occurred; men's last 2-km was 2852.21±150.34 which was an increase from the first 2-km, while women decreased their step count during the last 2-km (3380.58±1063.03). An explanation for this is when starting pace, men are using long strides to cover the distance while women instead of matching stride length due to greater portion of height increased cadence of steps resulting in higher counts. Near the end of the ruck march, it is proposed that men were taking shorter strides leading to increases in step count, while this allowed the female subjects to have a slower cadence keeping up with the group, which may have allowed for their longer strides. For this group, men had an average height difference being 10 cm taller than female counterparts (177.13±7.55; 167.65±6.11). This explanation would need further research to find the true reason for these changes.

4.2 Aim 2

The analysis of between-sex differences in biomechanical measures showed a significant change in impact loads and step count between sexes. Male Officer Candidates showed a significant difference between impact load left, right and total, average intensity left, right, total and step count right and total in first 2-km to last 2-km, while women showed significance in step count left, right, and total and average intensity left and total first 2-km to last 2-km. Impact load had greater increases in female subjects compared to male subjects. Average intensity for the female subjects increased at a more rapid rate of change compared to the men, which is expected because women generally carry a higher percentage of overall body weight as body fat, requiring more work to move across space. In addition, women generally produce less force compared to male counterparts, due to less lean body mass leading to the tendency of bigger effects of load on the smaller body structure typically. A study by Simpson et al., investigated changes with ground reaction force and spatio-temporal parameters for women during ruck marches which showed small change in parameters of GRFs varied by less than 0.06 BW, stride length differed by only three centimeters, and cadence differed by of only two steps.min^{-1} (Simpson et al., 2012). These small changes can lead to a very different picture about how the Marine is moving. The study differed since the load carried in this study remained consistent while in the Simpson study, they assessed changes over different loads.

Differences in stride and mechanism theorize reason between the sexes has led to higher prevalence of female fractures in the pubic rami compared to men when training condition are similar in any activities (Krappinger, Struve, Schmid, Kroesslhuber, & Blauth, 2009) (Hulkko & Orava, 1987). Site of injury for athletes and younger individuals usually occur at inferior pubic ramus near pubic symphysis (Pavlov, Nelson, Warren, Torg, & Burstein, 1982). In military training it has prevailing situation female recruits suffer pubic rami fractures higher rate compared to male recruits, especially during mixed training for men and women (Hill, Chatterji, Chambers, & Keeling, 1996) The rate has been reported for pubic rami fractures in females to males in two studies to be 11:1 and 67:3 respectively (Hill et al., 1996) (Ozburn & Nichols, 1981). Integrated gender training has consistently been associated with higher rates of pubic rami fractures.

Following the discovery of the association, training sessions were segregated by gender again, rates of the pubic rami fracturs consequently decreased (Pavlov et al., 1982) (Ozburn & Nichols, 1981) (Jones, Bovee, Harris, & Cowan, 1993). Three theories have been proposed to why with first on the integration of training with differences due to overstriding to keep up leading to abnormal gait pattern with support army decreased standard stride length from 30 inches to 27 inches for all marching, with no reports of pubic rami fractures in the reporting timeframe of the study. Also, women bone structure comparison to men, is more slender, pubic symphysis shallower, ischiopubic rami less inverted and obturator foramina more triangular than oval. Third is proposed with more emphasis during running mechanics that high amounts of tensile force from the leg/hip going to extension which can lead to a single fracture at the pubic rami (Pavlov et al., 1982) (Hill et al., 1996) (Ozburn & Nichols, 1981). Female runners rely on hip-extension force more than male runners, leading to greater tensile stress and more susceptible to injury of the pubic ramus (Pavlov et al., 1982). Recommendations have been suggested to allow recruits to stride according to their own physical metrics for their body to reduce prevalence of pubic ramus fractures. Also, recommendations have been made about the high impact activity volume in intervals, which in the study stress fractures in female recruits was reduced 7.3% per year rate (Pester & Smith, 1992).

4.3 Aim 3

There was one difference in results in this study for correlation in PF significant with two pairings to PF relative to mass one pairing. Both variables demonstrated significant correlations with total step count, but only PF was shown to be significant correlated for step count left and not when relative to bodyweight. This oddity and the oddity of not being significant for step count right needs further exploration. The greater the PF able to be produced allows less percentage of one's force capacity to be utilized, which can allow for more comfort (less mentally daunting) to be supported by a single leg. While in other research showed positive correlations and effects from high force output for long distancing performance (Lum et al., 2020)

In this study, there were no significant correlations between biomechanical factors of impact load, step count, average intensity and impact asymmetry and RFD measured during first 2-km & last 2-km, unlike in other studies looking at RFD and performance in running, especially endurance runners. These findings may be due to differences in parameters from specific running metrics compared to a ruck march at group pace, especially because a ruck march is a walking movement which has a longer time frame to apply the force in the ground in the stance leg during stride cycle where weight is always transferred in contact with the ground through at least one limb. as needed to propel yourself while in running force is needed to be applied much more quickly in time frames due to having a flight phase where no limb is in contact with the ground and when is at a much faster rate that more align with the RFD testing. Other research showed correlations to RFD with performance in sports task (Lum et al., 2020) (Suchomel et al., 2016).

Jump height from the counter movement jump only showed weak correlation from the unilateral CMJ of the right leg in impact load left, right, and total and average intensity left, right, and total. Since jump height has not been investigated looking at these parameters before. Force requires to be applied for jump height which could be reason associate of impact load and average intensity. Right leg may be the one associated due to the more common limb choice for kicking leading to higher perception of motor control. Flight time from the counter movement jump only showed a significant but weak correlation with the unilateral CMJ of the right leg in impact load left, right, and total, and average intensity left, right and total. Only average intensity level left paired a weak correlation to unilateral CMJ left leg. Flight time is associated with increase jump height due to higher amount of force allowing longer flight time and leads to higher force impact of landing after a jump or after every strike of the foot. Jump height and flight time in the case of CMJ may be redundant in analyzing due to the calculation when using force plates uses flight time to compute jump height. CMJ has been used in other research especially in using jump height as a performance metric. Jump height associated with higher performance in explosive movements sprinting, jumping and change of direction, which led to disagreement of non-equal comparison of movement types.

Peak propulsive force from the counter movement jump only showed weak correlation from the unilateral CMJ of the right leg in Impact load left and total and average intensity left and total. Peak propulsive force was needed to use repeatedly in gait covering the uneven terrain and to continuing to propel the Marines forward. Other literature has shown increases in performance from increased peak propulsive force through higher levels and effects of training in aspects of running (Lum et al., 2023).

In this study, no significant correlations were demonstrated between biomechanical factors of impact load, step count, average intensity, and impact asymmetry and the DSI. This could be due to the lack of correlation with RFD with the 14-km ruck march being “slow” movement. The ruck march relies on endurance and strength endurance aspects of performance being able to handle the ruck load over the terrain.

4.4 Aim 4

Two out of three biomechanical measures (Impact load, step count and Average intensity) showed SA for biomechanical measures from the IMU showed minimal differences. This finding agrees with other research done on running and effect of velocity changes with tempo spatial parameters, which were less than 2% difference in asymmetry from limbs ing gait patterns (Girard, Morin, Ryu, Read, & Townsend, 2019). While performance test metrics (Peak Vertical force, RFD, Peak Propulsive force, jump height, and flight time) from IMTP and CMJ showed greater differences in symmetry angle compared to ruck march measurements between limbs in testing especially in RFD production from IMTP. The change in right leg peak tibial acceleration was weakly correlated with unilateral CMJ jump height symmetry angle. Change in total (both legs) peak tibial acceleration was weakly correlated RFD at 100ms, 150ms, and 200ms. These findings are in mixed agreement with other research where no correlation to CMJ performance, but this study used asymmetry through strength measures (kaçoğlu, 2019). In this study many of the variables had no correlation while some variables showed positively weak correlation.

4.5 Limitations

Since there were greater than eight weeks from pretesting of IMTP and CMJ prior to the ruck mark, this could result in different levels of performance compared to performance on these tests closer to the ruck march due to fatigue of Officer Candidate School. Pretesting took place before the start of the Officer Candidate School where subjects participated in physical training and schoolwork.

Another limitation there was no subjective measure to gain perspective of how the subjects were feeling going into the ruck, or during or post ruck. This doesn't allow for the mental perspective of performance/energy compared to physical performance, which did not allow researchers to investigate if changes in the subjects' mental perception.

4.6 Future Research

This study was one of the first to measure changes of biomechanical characteristics during a 14-km ruck march. The findings of this study may build the foundation for further research to investigate these characteristics during ruck marches of various distances, including rucks of variable distances. Also, a more specific breakdown of changes per each km throughout the whole ruck can be assessed in future research, leading to better understanding of when the physical and physiological stress of the ruck march may result in increased injury risk.

This study was successful in evaluating biomechanical characteristics in a military population while in the field, which is especially relevant in military populations where ruck marches are performed as regular training exercises. Due to originality of this study, this research provides important foundational data in describing the biomechanical load that a 14-km ruck march requires. Also, this research can provide baseline data for injury prevention and machine learning recommendations for training to make it easier to make better decisions in training.

As military research continues to evolve, training methods or performance outcomes on the outcome of changes to performance on the 14-km ruck marches may be investigated relative to biomechanical characteristics assessed during the ruck march.

5.0 Conclusion

The purpose of the study was to measure biomechanical gait factors during a 14-km ruck march as descriptive changes in movement. Intensity was the most influential in ruck march to of first 2-km to last 2-km, while step count variations in change between sex of Marine Officer Candidates in first 2-km to last 2-km. Limited associations could be made between performance tests and intensity of steps and step count of first 2-km to last 2-km.

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