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Mechanical and Physical Characteristics of Knee Flexors and Extensors Following Different Warm up Protocols in Collegiate Male Soccer Athletes

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MECHANICAL AND PHYSICAL CHARACTERISTICS OF KNEE FLEXORS AND EXTENSORS FOLLOWING DIFFERENT WARM UP PROTOCOLS IN COLLEGIATE MALE SOCCER ATHLETES

by

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ABSTRACT

PURPOSE: To compare potential differences in mechanical and physical characteristics of knee flexors and extensors in collegiate male soccer players following different warm up protocols.

METHODS: Sixteen collegiate male soccer players (20.33 ± 1.33 years, 176.97 ± 6.72 cm, and 78.43 ± 7.42 kg) participated in this study. A small sided games warm up (SSG), a dynamic warm up (DYN), and a plyometric warm up (PLY) were completed using a randomized crossover design. Tensiomyography (TMG) was used to assess contraction time (Tc), delay time (Td) and maximal displacement (Dm) of the rectus femoris (RF) and biceps femoris (BF) of both legs before (PRE) and after (POST) each warm up. POST assessment included: TMG of the RF and BF, countermovement jump height (CMJ-h), CMJ flight time (CMJ-ft), 20m sprint time (20m), T-test time, and sit and reach (SR) distance. All TMG measures were analyzed using a three-way [condition × time x leg] analysis of variance (ANOVA). All performance variable data were analyzed with a repeated measures ANOVA**.**

RESULTS: There was no difference between warm up protocols for T-test, CMJ-h, or CMJ-ft. 20m significantly improved following SSG ($p=0.020$) compared to DYN and PLY. SR was significantly greater following PLY ($p=0.022$). Three-way ANOVA did not reveal a significant interaction for any of the measured TMG variables. However, main effects of time were seen PRE to POST for BF-Tc ($p=0.035$), RF-Td ($p<0.001$) and BF-Td, ($p=0.008$) and a main effect of condition was seen for RF-Tc ($p=0.038$).

CONCLUSION: Warm-up specific improvements were demonstrated in sprint speed and flexibility measures following SSG and PLY, respectively. While no differences were shown between the examined protocols, the present study revealed PRE to POST changes in certain

TMG measures (RF-Td, BF-Td, and BF-Tc) following a warm up in male collegiate soccer athletes.

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CHAPTER ONE: INTRODUCTION

Soccer is a sport comprised of a number of intermittent high intensity bouts of exercise inclusive of maximum sprints, jumping and multiple changes of direction (Gabbett, Sheppard, Pritchard-Peschek, Leveritt, & Aldred, 2008; los Arcos, Mendiguchia, & Yanci, 2017). The sport specific physiological requirements for competing in soccer at a high competitive level have been identified in a number of studies (Bangsbo, 1994; Reilly, Bangsbo, & Franks, 2000; Mohr, Krustrup, & Bangsbo, 2003; di Salvo et al., 2007). More specifically high-level soccer players have been shown to commit 1000-1400 changes in activity in a match (Bloomfield, Polman, & O'Donoghue, 2007; di Salvo et al., 2007; Vigne, Gaudino, Rogowski, Alloatti, & Hautier, 2010; los Arcos, Mendiguchia, & Yanci, 2017) with varied high intensity actions and multiple sprints at near maximal intensities (Stølen, Chamari, Castagna, & Wisløff, 2005; Vigne et al., 2010). Recent advances in technology have helped create a better picture of the demands placed on today's soccer athlete (Carling, Bloomfield, Nelson, & Reilly, 2008; Portas, Harley, Barnes, & Rush, 2010). The benefits of this are two-fold, these improvements in technology have allowed coaches and sport scientists to analyze position specific demand in match play, but also allow for better assessment of athlete activity during training sessions as well (Aughey, 2011).

The preparation of soccer players for training sessions is critical for attaining maximal performance in match play, and the demands of the training session should closely mimic the competitive demands associated with games (Kelly & Drust, 2009). Sport coaches and strength coaches alike have sought to optimize a player's performance through design and administration of a variety of training sessions. One of the key components to any training program or individual training session is application of an appropriate warm up designed to enhance performance (Shellock & Prentice, 1985; Bishop, 2003a; Fradkin, Zazryn, & Smoliga, 2010).

Warm ups are typically designed to slowly raise muscle temperature and heart rate increasing blood flow to working muscles and also increase joint viscosity (Haff & Triplett, 2015). However, the true underlying reason for a warm up is to improve performance in the tasks associated with the day's training session. Warm up exercises typically fall within in one of two classifications, either passive or active warm up. Active warm up routines have been shown to improve performance in activities related to soccer such as sprinting, dribbling, and striking a soccer ball (Gelen, 2010). The physiological benefits associated with active warm ups include thermogenic, metabolic and neurological effects induced by the warm up (Bishop, 2003a). Thermogenic effects elicited following an active warm up include: decreased viscous resistance of joints (Bishop, 2003a), increase in blood flow to working muscles (Barcroft & Edholm, 1943; Gray & Nimmo, 2001), increased anaerobic metabolism (Febbraio, Carey, Snow, Stathis, & Hargreaves, 1996), and improved central nervous system functioning (Karvonen, 1992).

Soccer teams use a variety of warm up modalities at the start of training sessions such as a series of dynamic movements, reactive work with the ball during small-sided games, or warm ups that include explosive plyometric movements. There have been a number of studies examining how different warm ups have shown improvements in strength and power components of athletes, such as sprint speed and jump height (Fletcher & Jones, 2004; Little & Williams, 2006; Gabbett & Mulvey, 2008; Holt & Lambourne, 2008; Gelen, 2010). The findings of such studies showing a relationship between warm ups and sport performance have gained the attention of coaches and sport scientists alike. The goal then becomes determining what warm up protocols will best prepare their athletes to meet sport specific demands and improve performance most efficiently and effectively.

While a number of studies have been conducted on the sport specific performance benefits from different warm up protocols, few have examined the contractile properties of the muscle following a warm up session. Contractile history has been shown to affect the performance of skeletal muscle (Sale, 2002). Tensiomyography (TMG) is a non-invasive indirect measure of superficial skeletal muscles contractile properties (Wiewelhove et al., 2017). TMG measures are obtained by stimulating the individual muscle with a small electrical current and then recording a number of variables related to the mechanical properties of muscle contraction such as: delay time (Td), contraction time (Tc), sustain time (Ts), relaxation time (Tr), and maximal displacement (Dm) (Jones, Harrison, Francis, & Wilson, 2017). TMG provides a valid and reliable means (Martin-Rodriguez, 2017) of immediate feedback (Martín-Rodríguez, Loturco, Hunter, Rodríguez-Ruiz, & Munguia-Izquierdo, 2017) with the sensitivity to measure small changes in muscle contractile properties (Rey, Lago-Peñas, & Lago-Ballesteros, 2012). Subsequent, this method of evaluation has been used to detect neuromuscular status and muscle fatigue (Piqueras-Sanchiz, Rodríguez, González-Hernández, & García-García, 2017) which directly impact on muscle activity and performance. In a study by Loturco et al. (2015), correlations were found between decreased Td, Tc, and Dm, as measured by TMG, and greater scores on performance assessments. Furthermore, TMG can be used to assess muscular fatigue as well by identifying parameters of muscle contraction such as Tc and Dm (García-Manso et al., 2011; Gil et al., 2015). The changes in TMG following various training and rehabilitation have also been assessed in a number of different athletic populations (Rey et al., 2012; Lohr, Braumann, Reer, Schroeder, & Schmidt, 2018).

Therefore, the purpose of this study was to compare the potential differences in mechanical and physical characteristics of knee flexors and extensors in collegiate male soccer players following different warm up protocols. It is hypothesized that TMG analysis will reveal that the warm ups with a more explosive component will have the greatest impact on decreasing Tc and Dm of the muscles and that the more continuous movement warm ups may actually show increased signs of muscular fatigue.

Purpose

1. Is there a difference in performance assessments following different warm up protocols (Dynamic, Small Sided Games, Plyometric) in collegiate male soccer players?
2. Are there differences in the contractile properties of the muscles assessed between PRE and POST following different warm up protocols in collegiate male soccer players?

Hypotheses

1. The small sided games warm up will have the greatest impact on improvement in the performance assessments.
2. The warm ups with a greater plyometric component will have the greatest impact on TMG assessment of muscle contractile properties.

Operational Definitions

1. Dynamic Warm up – A warm up protocol consisting of sport specific movements performed in a safe and controlled fashion over a distance of 12 yards.
2. Small Sided Games – A warm up consisting of open field passing patterns with a soccer ball, involving anywhere from 4-6 players.
3. Plyometric Warm up – A warm up consisting of some dynamic movements and a number of explosive plyometric movements (or jumping) with one or both legs.
4. Tensiomyography – A method for assessing a muscle's mechanical response based on muscle belly displacement induced by a single electrical stimulus.

5. Delay Time – The time between the electrical impulse and 10% of the muscle contraction.
6. Contraction Time – The time between the 10% and 90% of the muscle contraction.
7. Maximal Displacement – Maximal displacement of the muscle belly during contraction.
8. Collegiate Level of Play – NCAA Division I level athletes.

CHAPTER TWO: REVIEW OF LITERATURE

Physiological Demands of Soccer

Stølen, Chamari, Castagna, & Wisløff (2005)

Physiology of Soccer: An Update

This was a review article providing an update on the physiology of soccer players and the physiological demands associated with the sport. The distances covered during competitive matches in high level soccer are approximately 10-12 km for field players and about 4 km for goalkeepers. During a typical match a sprint bout occurs roughly every 90 seconds and can last anywhere from 2-4 seconds, this will constitute up to 11% of the total distance covered in a match, corresponding to up to 3% of total play time. Each player was found to perform up to 1400 different short duration activities, such as sprinting, tackling, jogging, walking, changing direction, heading, striking, receiving, and passing the ball. Due to the length of the matches, soccer could be considered highly dependent on aerobic metabolism; however, the most decisive activities are dependent on anaerobic metabolism of players. The ability to sprint, jump or kick utilizes the anaerobic pathways, and may have a greater impact on the match outcome. This review study also revealed that the VO_{2max} in male field players ranges from 50-75 mL/kg/min, while anaerobic threshold is between 76-90% of HRmax. These numbers are representative of an increase from data that was collected in previous decades, indicating the physiological demands for high level performance are increasing.

di Salvo et al. (2007)

Performance Characteristics According to Playing Position in Elite Soccer

This study evaluated the movement characteristics of high level soccer players during match play to establish distances covered and running intensities based on playing position. This investigation utilized a video match analysis system and monitored 300 players during 20 Spanish Premiere League matches as well as 10 Champions League matches. The mean distance covered regardless of position was 11.4 km ± 1km. The distance covered by position were as follows: central defender 10.6 km ± .9 km; external defender 11.4 km ± .7 km; central midfielder 12.0 km ± .6 km; external midfielder 11.9 km ± .8 km; forward 11.2 km ± .9 km. The distance covered with player in possession of the ball was 1.2-2.4% of the total distance, with external midfielders covering the greatest distance with a ball and central defenders covering the least distance. There was no significance difference in halves on total distance covered; however, there was a significant difference in distance covered based on intensity of runs. The second half had greater distance covered at lower intensities (0-11 km/h) than the first half, the first half had greater distances at middle intensities (11.1-19 km/h and there was no difference between halves for submaximal (19.1-23 km/h) and maximal intensities (>23 km/h). Analysis revealed that during a 90-minute match, players performed bursts of maximal intensity runs ranging in distance from 10 - 32 m, and were comparable across player positions. This study showed the high work rate associated with top level male soccer, and that, independent of player position, the distances covered and intensities were similar.

Bloomfield, Polman, & O'Donoghue (2007)

Physical demands of different positions in FA Premier League soccer

This study evaluated the demands placed on elite level soccer players based on field playing position, specifically; defender, midfielder and striker. Subjects included 55 players (18 defenders, 18 midfielders and 19 strikers) from the English Premier League. Time-motion video analysis was used to identify purposeful movement (PM), this is defined as movements performed with deliberate intention to influence the performance, via Bloomfield Movement

Classification procedure. This analysis revealed that players spent 41% of the match performing what was considered PM. There was a significant difference on specific activity performed, running, sprinting, shuffling or standing still. However, playing position had no impact on the %PM time spent at low, medium, high or very high intensities. Players spent 50% of the time in forward movement, 30% moving either backwards, lateral, or diagonal direction and the remainder of time was spent not moving. During this PM, players completed ~725 turns and ~ 112 touches on the ball, regardless of playing activity. This study suggests that high level soccer players perform a variety of movements at different intensities throughout the match regardless of playing position.

Osgnach, Poser, Bernardini, Rinaldo, & di Prampero (2010)

Energy cost and metabolic power in elite soccer – a new match analysis approach

The purpose of this study was to assess match performance of elite soccer players by using video analysis to determine instantaneous metabolic power. The investigators accomplished this by applying a theory developed by Di Prampero (2005) that determines metabolic power based on multiplying energy cost of running by running speed. Therefore, if the investigators know the speed and acceleration of the athlete, they can determine metabolic power for any given moment. The subject data analyzed for this study were from 399 players over 56 matches of Serie A in the 2007-2008 season. The performance of each player was assessed by examining three variables including: speed, acceleration, and estimated metabolic power. The following six speed zones were established: walking (0 to 8 km/h), jogging (8 to 13 km/h), low-speed running (13 to 16 km/h), intermediate-speed running (16 to 19 km/h), high-speed running (19 to 22 km/h), and maximal speed running (922 km/h). The acceleration categories were as follows: low acceleration (0 to 1 m/s^2), intermediate acceleration (1 to 2 m/s^2), high acceleration

(2 to 3 m/s^2), and maximal acceleration (>3 m/s^2). The following five power categories were used: low power (0 to 10 W/kg), intermediate power (10 to 20 W/kg), high power (20 to 35 W/kg), elevated power (35 to 55 W/kg), and maximal power (955 W/kg). Energy expenditure was calculated for each of the previous categories. The investigation revealed that in all of the players, the increase of total energy expenditure was due to increase in anaerobic performance, such as high intensity runs. Mean match distance values were 10,950 m, total distance covered at high power (920 W/kg) amounted to 26% of total distance covered and corresponding energy expenditure to approximately 42% of the total energy expenditure calculated, based on mean play time of 95 minutes per match. This study identified "High" intensities expressed as high-power output based on actual metabolic power and produced results 2-3 times larger than values based only on running speed. These results, utilizing a new formula for determining intensity, may provide a clearer picture on the high metabolic demands of soccer, and identify what portion is related to anaerobic activities during match play.

<u>Physiological Response to Different Warm up Protocols</u>

Chimera, Swanik, Swanik, & Straub (2004)

Effects of Plyometric Training on Muscle-Activation Strategies and Performance in Female Athletes

The aim of this study was to evaluate how plyometric training effects muscle-activation strategies and lower extremity performance during jumping exercises. This was a pretest posttest control-group design study, the independent variables were: time (pretest, posttest) and group (Control and Plyometrics) the dependent variables measured included EMG measures (area, mean, peak, coactivation, pattern) and performance measures (vertical jump height and sprint speed). The subjects examined in this study were 20 female NCAA division I collegiate field hockey and soccer athletes (18-20 yrs.). Subjects were randomly assigned to either the control group (CG, *n* = 9, 7 soccer players, 2 field hockey players) or the plyometrics group (PG, n = 9, 7 soccer players, 2 field hockey players). All subjects in the CG were asked to refrain from any type of plyometric-type activities. The EMG data were collected from 6 muscles: vastus medialis, vastus lateralis, medial hamstrings, lateral hamstrings, hip abductors, and hip adductors electrodes were placed at 50% of the contractile length for the respective muscles. The test used for sprint speed analysis was a 40-yard shuttle run assessed with an infrared timing device. A drop jump was used in which subjects were instructed that they would drop from a height of 18 inches then immediately jump as high and fast as possible and reach the highest point possible on a Vertec device. On the first day of testing (PRE), following a warm up, subjects were asked to perform a 40-yard shuttle run as a practice test. Following the practice run subjects completed 3 tests of the 40-yard shuttle run with 1-minute rest in between attempts. The fastest of the three trials was recorded for data analysis. Following the shuttle run, EMG electrodes were applied to right leg and subjects completed the drop jump procedure. Subjects were allowed 3 practice jumps followed by 3 jumps for testing purposes, with the best of the three test jumps recorded for data analysis. Subjects were then randomly assigned to either the CG or the PG. The PG was given detailed instruction on the exercises to be performed in the following 6-week period. At the conclusion of the 6-weeks, both groups completed a second day of testing (POST) in the same manner that was used at PRE. Although not significant, it was noted that the PG had increases of 5.8% in jump height. Results of the study demonstrated a significant (p = .037) increase in preparatory adductor-to-abductor muscle coactivation, as well as a trend (p = .053) toward reactive quadriceps-to hamstring muscle coactivation in the PG following the 6-week plyometric exercise protocol. The significant changes in muscle coactivation following plyometrics suggest that preactivation greater in the PG compared to the CG.

Relationship between Warm ups and Sport Performance

Fletcher & Jones (2004)

The Effect of Different Warm up Stretch Protocols on 20M Sprint Performance in Trained Rugby Union Players

This study looked to examine the effect of different warm up stretching protocols on 20 m sprint performance. The subjects for this study were 97 amateur male rugby union players who had at least 1 year of regular training and participation in rugby union. The athletes were randomly assigned to one of four groups: passive static stretch (PSS), active dynamic stretch (ADS), active static stretch (ASST) or static dynamic stretch (SDS). The athletes all performed a 10-minute jog, after which they performed two 20 m sprints. The two 20 m sprints were then repeated after the athletes performed the warm up stretch protocol of their assigned group. The PSS protocol consisted of athletes performing a static stretch, which was held at point of mild discomfort for 20 seconds, for muscles of the lower body. The ADS group performed a series of lower body stretches with a controlled movement through the active range of motion at each joint, this was done at a jogging pace. The ASST group performed an active contraction of the agonist muscle to its full inner range, stretching against the antagonist's outer range. The stretches were done on the same muscle groups as the PSS and were held for 20 seconds. The SDS protocol performed stretching on the same muscle as the ADS group but were held for 20 seconds opposed to being completed at a jogging pace. There was significant increase in sprint time in both the PSS and ASST groups, indicating static stretching may decrease sport performance. There was a significant decrease in sprint time in the ADS group and a non-significant decrease in sprint time in the SDS group. This would indicate that an active dynamic stretching routine may increase sprint performance. The potential mechanisms related to these findings attribute the increase in sprint speed following static stretching to be related to the decreased ability of the musculotendinous unit to store elastic energy. The investigators attribute the significant improvement in the ADS group to the incorporation of jogging while performing the movements. It was hypothesized that these specific movement patterns could also benefit coordination in the 20 m sprint test following the warm up. The results of this study suggest that coaches and athletes should consider incorporating warm ups that contain an active dynamic series of exercise that mimic aspects of a sprint.

Fletcher & Monte-Colombo (2010)

An Investigation into The Effects of Different Warm up Modalities on Specific Motor Skills Related to Soccer Performance

The goal of this study was to determine the effect of different warm up protocols on specific high-speed motor capabilities associated with soccer performance. The subjects for this study were 27 college-age male soccer players with at least 8 years of experience who completed at least 90-120 minutes of soccer specific training a minimum of three times per week. All of the subjects completed each of the three different warm up protocols in random order. The warm up (WU) protocol involved the subjects completing a 5-minute jog at a self-selected pace. The warm up with static stretching (SPS) protocol required subjects to complete a 5-minute jog before completing a series of static stretches for muscles of the lower body (hamstrings, quadriceps, abductors, adductors, gluteus maximus, hip flexors, gastrocnemius, and solei). The stretches were held at a point of mild discomfort for 15 seconds per muscle and repeated twice for the larger muscle groups, for a total of 3 minutes of stretching per leg. The ADS warm up protocol consisted of the same 5-minute jog followed by a series of dynamic stretches (heel flicks, high knees, hip rolls, walking on toes, straight leg skipping, and walking lunges) for muscles of the lower body. These movements were performed for two sets of twelve for each movement. Following the assigned warm up protocol subjects were given a 1-miute recovery before performing 2 countermovement vertical jumps (CMJ) on a jump mat. CMJ were performed with hands on hips, and subjects were instructed to jump as high as possible. One-minute of rest was given between CMJ attempts. Following jump assessment, subjects performed three 20-m sprints with 2 minutes of rest between each sprint. Following the sprints, the subjects performed the Balsom agility run. The results were as follows: vertical jump heights were significantly greater ($p < 0.01$) following the WU and ADS protocols compared to those of the SPS. Following the SPS protocol, the 20-m sprint and agility times were significantly slower ($p < 0.01$) than the WU and ADS protocols, the ADS trial was revealed to be significantly faster ($p < 0.05$) than the WU protocol. These findings would suggest that warm ups containing a dynamic stretching protocol should be considered for increasing performance in motor skills and movement patterns related to soccer.

<u>Relationship between Sport Performance and Performance Testing</u>

López-Segovia, Marques, van den Tillaar, & González-Badillo (2011)

Relationships between Vertical Jump and Full Squat Power Outputs with Sprint Times in U21 Soccer Players

The aim of this investigation was to examine the relationship between vertical jump and full squat with the sprint performance of college age soccer players. The subjects for this study were 14 male soccer players (age 20.14 ± 0.4 yrs., body mass 75.5 ± 7.7 kg, body height 1.79 ± 0.10 m). All the soccer players were well conditioned and had familiarity with the testing exercises), which had been part of their regular training (1-2 x week). The testing consisted of two sessions separated by 7 days. On the first day of testing, subjects completed 3 CMJ on a jump mat, with the average of 3 jumps being recorded, subjects also completed a series of progressive load CMJs on a Smith machine. The loaded CMJ began with 20 kg load and increased 10 kg for each subsequent jump until the loaded CMJ was less than 20cm (as outlined in a previous study). Four minutes of rest was given in between loaded CMJ attempts. Following the loaded CMJ, subjects completed a progressive test of the full squat on a smith machine. Full squat was considered to be at correct depth when the top of each player's thigh was below parallel with the floor. The number of full squats was determined by the velocity of the first repetition. Three repetitions were performed when the velocity was > 1 m/s and 2 repetitions were performed when the velocity was < 1 m/s. The load was increased in 10 kg increments until the average velocity was < 0.7 m/s. Power was calculated for both the loaded CMJ and full squat by a linear transducer attached to the bar of the smith machine. On the second day of testing subjects performed three maximum effort sprints of 30 m. times were recorded for the following distances of the 30 m sprint: 0-10m (T10), 0-20m (T20), 0-30 (T30), 10-20m (T10- 20), 10-30m (T10-30), and 20-30m (T20-30). Subjects were given three minutes rest between sprint testing trials. Results of the study revealed significant correlation between the CMJ height and the sprint times at 20m and 30 m, which suggests that CMJ may be a useful measure to explain short sprint distance times in soccer athletes.

Cronin & Hansen (2005)

Strength and Speed Predictors of Sports Speed

The aim of this study was to assess and identify any relationship between strength and power and measures of first step quickness (5 m time), acceleration (10 m time), and maximal speed (30 m time). The subjects involved in this study were 26 professional adult male rugby players (23.2 ± 3.3 years, 97.8 ± 11.8 kg, 183.1 ± 5.9 cm). While other measures were also assessed in this investigation, for the purpose of this review we will examine the results pertaining to the CMJ in regard to power assessment. Subjects completed the CMJ on a jump mat and were instructed to stand with their hands on their hips and jump as high as possible following a bend in the knees to approximately a 120º knee angle. The sprint testing and CMJ testing measures were performed on the same day of testing. Results revealed a significant negative correlation between CMJ jump height and the 3 speed measures (5 m, 10 m, and 30 m). These findings are in agreement with other studies showing that CMJ is significantly related to an athlete's quickness, as well as speed over short distances (< 40 m).

<u>Relationship between Muscle Mechanical Properties in Sport Performance</u>

Burgess, Connick, Graham-Smith, & Pearson (2007)

Plyometric vs. Isometric Training Influences on Tendon Properties and Muscle Output

The aim of this investigation was to determine the effect of plyometric and isometric training on tendon stiffness and characteristics of muscle output. The subjects in this study were 13 college-aged men who were randomly assigned to either a plyometric training group (PG) or an isometric training group (IG). The study was a pretest-posttest design, the independent variables consisted of the training groups (PG or IG) and the dependent variables examined were tendon stiffness (K) of the medial gastrocnemius, jump height and rate of force development (RFD). The IG followed a protocol that consisted of repeated maximal one-leg explosive isometric plantar flexion, the PG followed a training protocol that consisted of repeated maximal one-leg straight-leg drop jumps. The volume of the training was progressively increased over a 6-week period, from 2 sessions per week with 3 sets of 15 repetitions during week 1, to 3 sessions per week with 4 sets of 20 repetitions for week 6. Prior to training all subjects warmed up by performing several submaximal effort repetitions of their training program. Subjects were tested prior to the start of the intervention (PRE) and at the end of the 6-week period (POST). Testing consisted of a maximal straight leg concentric jump, an explosive maximal isometric plantar flexion and a graded isometric plantar flexion used to determine K. Subjects were asked to develop force as rapidly as possible for both of the maximal tests. The tests were administered at random to each participant however, the same order was used in the PRE and POST testing sessions. To assess K the subject stood on a force plate and under the bar of a modified Smith machine, which essentially held the subject in place and did not allow the heel to raise during the explosive maximal plantar flexion. The same portable force plate was used to assess jump height and RFD for the maximal jump assessments. The results of this study showed an increase in K for both PG and IG. However, while the IG group showed a trend toward significance ($p < 0.059$) for jump height, the PG showed a significant increase ($p < 0.05$) for jump height. This study shows similar increase in tendon stiffness and muscle output from both isometric and plyometric training, and suggests that explosive isometric training may be used in place of plyometric training to increase tendon stiffness, greater force transmission, for sports that require explosive movements such as jump height.

Turner, Bellhouse, Kilduff, & Russell (2015)

Postactivation potentiation of sprint acceleration Performance Using Plyometric Exercises

The purpose of this study was to examine the influence of plyometric exercise on postactivation potentiation (PAP) and subsequent sprint performance. The subjects for this study were 23 college-aged men (22 ± 1 years) who were healthy, free from injury and had regularly performed plyometric training for at least 2 years prior to the start of the study. The study consisted of three experimental trials and followed a randomized-crossover design where subjects were assigned to one of three groups; a walking control (C) plyometric (P) or a weighted plyometric (WP) group. Prior to the experimental trials subjects attended a familiarization session to learn the plyometric bounding techniques and a sprint performance test was practiced. During the experimental trials subjects performed a standardized warm up of jogging, dynamic movements and progressively increasing intensity (to near maximal speeds) on a 20 m sprint. An active 2-minute recovery was performed then subjects completed a baseline 20 m sprint followed by another 2-minute active recovery before beginning the experimental condition for the day (C, P, or WP). After performing 1 of the 3 conditions, 20 m sprints were retested at: 15 s and 2, 4, 8, 12, and 16 minutes to profile both transient fatigue and potentiation effects, as outlined in previous studies examining PAP. Both the P and WP groups performed 3 sets of 10 alternate leg bounds with (body mass plus 10%) or without (body mass only) a weighted vest. The C group performed a continuous walk to minimize losses in body temperature relative to P and WP. All 3 interventions were similar in duration.

The results of this study revealed that at baseline mean sprint velocities of 10 and 20 m were similar between groups. WP impaired 20-m sprint velocity at 15 seconds when compared with C. However, 10 and 20 m sprint velocities improved in WP at 4 minutes and 8 minutes compared with C. P showed improved 10m sprint acceleration performance at 4 minutes compared to C. Therefore, these findings suggest that plyometric exercise enhances sprint acceleration performance if adequate recovery is given between plyometrics and sprinting.

Gil et al. (2015)

Tensiomyography parameters and jumping and sprinting performance in Brazilian elite soccer players

The aim of this study was to examine the association between tensiomyography (TMG) parameters (of rectus femoris and biceps femoris) and jumping and sprinting abilities in elite soccer players**.** The subjects for this study were 20 elite Brazilian soccer players (23.3 ± 4.8 years); who had no history of lower limb musculoskeletal injuries or neuromuscular disorders. Prior to testing the athlete's completed two familiarization sessions with all testing procedures. Athletes were then required to attend three separate, randomized testing sessions consisting of (1) TMG assessment of the rectus femoris (RF) and biceps femoris (BF) muscles; (2) CMJ and drop jump testing; and (3) sprint testing, recording times for distances of 5, 10, 15, 20, and 25 m. TMG measures included radial displacement of the muscle belly (Dm) and contraction time (Tc) for the rectus and biceps femoris of both legs. CMJ and drop jump were measured on a contact mat that records flight time in milliseconds which is used to calculate jump height. For both tests, the athletes were instructed to place their hands on their hips. During the CMJ test, athletes were instructed to perform a bend in the knees to make a downward movement and then jump as high and fast as possible. During the drop jump test, the athletes dropped from a 45cm tall box, landed with both feet at the same time and jumped as high and fast as possible. Each jump was attempted 5 times with a 15 second rest period, and the best of the 5 jumps was recorded for analysis. For the drop jump, contact time was also measured to calculate reactive strength index. Thirty minutes following the jump tests, athletes completed the sprint test. This test allowed the athlete two submaximal sprints as a warm up, and then the athlete completed three 25 m maximal effort sprints. Photocells were used for timing purposes and were set to record split times at distances of 0, 5, 10, 15, 20 and 25 m, the best sprint time was recorded for analysis. The results showed a moderate negative association between Dm of both the RF and BF muscles and contact time. Furthermore, a moderate association seen between the Dm of the BF and reactive strength index was found. Dm response is thought to inversely reflect muscle stiffness and shown to be directly related to strength and power performance. Lower Dm values would reflect higher muscle stiffness and imply higher performance stretch-shortening cycle involved motor skills. While in this study TMG did not appear sensitive enough to predict jumping performance, it did reveal a significant moderate association with jumping kinematics. The results of this study did not show TMG to have a predictive ability in performance of power related tasks.

Schroeder, Renk, Braumann, & Hollander (2017)

Acute Foam Rolling Effects on Contractile Properties of the M. Biceps Femoris

The purpose of this study was to investigate the effects of foam rolling, stretching and resistance training on the contractile properties of the Biceps Femoris (BF). The participants examined were six males and six females (26.8 ± 5.7 years). This was a crossover design inclusive of three sessions in randomized order separate by one week. PRE and POST treatment the contractile properties of the BF were recorded using TMG, specifically maximal displacement (Dm), Contraction time (Tc) were measured. The three different sessions included: stretching, foam rolling and weight training for muscles of the lower back, glutes and hamstrings. Single Pre-post comparisons were calculated using paired t-tests and a 3-way ANOVA was conducted to reveal main effects for [body-side' (left–right) × 'treatment' (FR–stretching–strengthening) × 'time' (pre–post)]. Results revealed that Dm was significantly decreased following the weight training sessions while changes after foam rolling and stretching were nonsignificant. Tc measures demonstrated no significant changes by treatment or time. The results of this study show a decreased muscle tone in the BF following weight training, however no changes in contraction time. Further research is warranted to evaluate changes following different exercise techniques or conditions and the acute impact on muscle contractile properties.

Rey, Lago-Peñas, & Lago-Ballesteros (2012)

Tensiomyography of Selected Lower-Limb Muscles In Professional Soccer Players

The purpose of this study was to gather normative data for TMG variables in the RF and BF for male soccer players according to playing position, and also to establish intra-session reliability for measured variables. 78 professional male soccer players participated in this study age (26.6 ± 4.4 years) and had 4 – 15 years of professional soccer playing experience. TMG measures of maximal displacement (Dm), contraction time (Tc), sustain time (Ts), delay time (Td), and half-relaxation time (Tr) were recorded for the RF and BF. Intra-session reliability of the TMG measured variables, was conducted using 15 players randomly selected to participate in two testing session separated by a rest period of 10 minutes. Players were classified into six position groups; goalkeepers, center backs, outside backs, center midfielders, outside midfielders and forwards. Each testing session was done following a mandatory 48 hour period with no strenuous exercise and no energy drinks or supplements containing caffeine. This study revealed no significant differences of the BF for any of the five measures. However, RF-Tc, RF-Tr, and RF-Ts showed significant differences between playing positions. Furthermore good to excellent intra-session reliability was seen for all recorded measures.

CHAPTER THREE: METHODOLOGY

Participants

Sixteen participants were recruited for this study. Participants were all active members of the 2017-2018 UCF men's college soccer program (n= 16, 20.33 ± 1.33 years, 176.97 ± 6.72 cm, and 78.43 ± 7.42 kg) (See Table 1.). All participants were familiar with all the warm up protocols performed and the physical assessment tests used for this investigation. The protocols and testing were comprised of warm ups and physical assessments typically performed by the UCF men's soccer team over the course of the competitive season. All athletes were free from injury and volunteered to participate in this investigation. In an attempt to eliminate the potential of fatigue-related performance decrements, participants were asked to refrain from any strenuous physical activity during the duration of the protocol. The study was approved by the University's Institutional Review Board. All components of the testing procedures were explained to each participant, and informed consent was received before the initial testing session.

Experimental Design

This study utilized a randomized crossover design to examine the effect of different warm up protocols on performance and the physical and mechanical characteristics of knee flexors and extensors. The experimental design involved three different warm up protocols: small sided games (SSG), dynamic warm up (DYN), or plyometric warm up (PLY). The subjects completed each individual protocol and associated testing sessions at the same time of day for all sessions, each individual session was followed by a 24-hour off day before completing the next protocol. This schedule of one day on one day off design (presented in Figure 1) was followed until all subjects had completed each protocol (3 in total).

Variables

The independent variables included in the study were the different warm up protocols: (1) small sided games, (2) dynamic warm up, and (3) plyometric warm up. The dependent variables measured include: average heart rate, player load, total distance covered, recorded TMG values of the rectus femoris, and biceps femoris muscles, countermovement jump, 20m sprint time, T-test time, and sit and reach scores.

Anthropometric and Physiological Assessments

Height and Weight

Each subject's height was measured with a portable stadiometer (Seca 213;Seca Corp., Chino, CA) and body mass was measured with a calibrated standard medical scale (439 Physician Scale; Detecto, Webb City, MO, USA).

Tensiomyography Measurements

The following procedures were used, as described by Jones and colleagues (2017), for assessment of the musculature of the leg and lumbo-pelvic region of the spine utilizing Tensiomyography (TMG) (TMG Measurement System, TMG-BMC Ltd., Ljubljana, Slovenia). [Delay Time (Td), Contraction Time (Tc) and Maximal Displacement (Dm)] For each muscle examined the TMG sensor tip was to be placed at a location to measure maximal radial displacement of the selected muscle. All subjects were free from soft tissue or muscular injury at time of examination. Measurements were performed under static and relaxed conditions, with the subject in the supine position and the knee joint fixed at a 120-degree angle (with 180 degrees corresponding to full extension of the knee). The leg measured was positioned on a triangular wedge foam cushion to maintain a fixed knee angle. A digital displacement transducer, which incorporates a spring of 0.17 N m-1 was set perpendicular to the muscle belly to acquire radial displacement of the selected muscle. The site for measurement of the radial displacement of the rectus femoris (RF) was determined by placing a transversal mark with a dermatological pen at 50% of the total length between the greater trochanter and the lateral condoyle of the distal end of the femur. The subject was then instructed to contract the quadriceps muscle of the leg being examined to palpate the rectus femoris and place a line longitudinally across the transversal line creating an “x” landmark for sensor tip placement. Two square (5x5 cm) 2 mm thick self-adhesive electrodes were placed symmetrically 5 cm (±5 cm) or 3 cm (±3 cm) distal and proximal to the sensor tip. This procedure was completed for both the right and left RF before the subject was repositioned in a prone position to examine posterior muscles of the leg. The site for measurement of the radial displacement of the biceps femoris (BF) was determined by measuring the distance between the ischial tuberosity and the lateral condoyle of the distal end of the femur and placing a transversal mark at 50% of the total length. The subject was then instructed to flex their knee against resistance, placed by the hand of the assessor at the ankle, to palpate the BF, a longitudinal line was drawn across the transversal line creating an “x” landmark for sensor tip placement. This procedure was then repeated for both the right and left leg. Regarding electrical stimulation procedures, the pulse duration was 1 ms and the initial current amplitude was set at 50 mA. For each test (4 total per muscle), current amplitude was progressively increased by 10 mA increments until there was no difference in muscle displacement (Dm) or maximal stimulator output 100 mA was reached. For each subject two consecutive measurements were recorded and averaged for analysis. Reliability of TMG has been established in a review conducted by Martin-Rodriguez and colleagues (2017) who reported high to excellent intraclass correlation coefficient (ICC) values for Dm (0.82-0.99); good to excellent ICC values for Tc (0.70-0.99), and low to excellent ICC values for Td (0.60-0.98).

Bioelectrical Impedance Analysis

Body composition was determined using a bioelectrical impedance analysis (BIA) device (Inbody 770, Biospace Co., Ltd., Seoul, Korea) that determined total fat and fat-free body mass by segmental multifrequency analysis. Subjects were asked to report for body composition testing adequately hydrated and having fasted and abstained for exercise for at least 4 hours. Subjects were instructed to remove any jewelry, footwear, including socks, and stand on the BIA platform. Using the BIA device, a minute electrical current was conducted through the body to determine body composition. While standing on the platform the subjects held two handles, one in each hand, with arms extended from the side laterally and held that position for the duration of the 45 second analysis. Whole body fat-free mass, and fat mass were estimated while total body water, intracellular water, extracellular water, resistance, and reactance values were also recorded for possible further analysis.

<u>Warm up Protocols</u>

Global positioning system units (Polar Team Sport System, Polar Electro Oy, Finland) were used during all the warm up protocols to acquire the following data: heart rate, distance covered and player load. Subjects performed all warm ups on the same natural grass playing surface at the same time of day, under similar environmental conditions in athletic apparel, consisting of shorts, a tee shirt and their usual soccer cleats for all testing sessions.

Dynamic

The dynamic (DYN) warm up began with a 5-minute jog around the testing field. The next component was 9 minutes in duration and completed on the field at a distance of 12 yards, identified by 2 cones (A and B) placed at start and finish. The participant completed a series of DYN patterns from cone A to B, then a jog from B to A with no rest between the DYN movement and jogging. Subjects were allowed a 5-second rest after the jog and before the next dynamic movement pattern began. This alternation between DYN pattern and jogging continued for the entire series of DYN patterns The DYN patterns included: small skips, open the gate, close the gate, tall shuffle, lunge walk, side lunge walk, hamstring walk, knee hug, heel kicks, A-skip, B-skip, C-skip, low shuffle, carioca, lean-fall-sprint. The DYN warm up progressed from simple movements to a series of dynamic stretches and finally to more complex movements in multiple planes. The total activity time of the DYN warm up was 15-minutes. This DYN is a warm up protocol that is currently used by the UCF men's soccer team, and the athletes have familiarity with it.

Small Sided Games

The small sided games warm up (SSG) began with a 5-minute jog around testing field. The next phase of the SSG began with a series of dynamic movement patterns over a distance of 12 yards from cone A to cone B, similar to that of the DYN. However, this dynamic series was from cones A to B and back to A, not interspersed with a jog, and duration was approximately 5 minutes. The final component of the SSG warm up included players performing "rondo" drills that include an individual player defending, or trying to win the ball from, a set of 4 offensive players positioned in a square approximately 7m × 7m in dimension. Players rotated positions in this drill spending 1 minute as a defender and 4 minutes as an offensive player, lasting a total of 5 minutes in duration. The total activity time of the SSG warm up was 15-minutes. This SSG is a warm up protocol that is currently used by the UCF men's soccer team, and the athletes have familiarity with it.

Plyometric

The plyometric (PLY) warm up began with a 5-minute jog around the testing field. The next component was 4 minutes in duration and be completed on the field at a distance of 12 yards, identified by 2 cones (A and B) placed at start and finish. This component of the PLY began with the following dynamic movements: small skips, open the gate, close the gate, tall shuffle, lunge walk, side lunge walk, and hamstring walk. Again, unlike the DYN detailed above, these dynamic movements were completed from cone A to cone B, with no jogging between movement patterns. The subject would do dynamic movement from Cone A to B and then back to cone A, and get a 5-second rest in between before the next dynamic movement. For the final phase of the PLY the subject completed a series of plyometric movements utilizing the same 12 yards distance from cane A to cone B and jog back to cone B. Subjects were allowed a 5-second rest after the jog and before the next dynamic movement pattern began. The PLY component included: double leg hops, single leg hops, lateral hops, double leg forward jump for distance, double leg explosive jump for height, single leg bounds, power skips, tuck jumps. The total activity time of the PLY warm up was 15-minutes. This PLY is a warm up protocol that is currently used by the UCF men's soccer team, and the athletes have familiarity with it.

Performance Testing

Jump Assessments

Countermovement jump (CMJ) tests were conducted using a validated optical timing system (*MyJump* V2.1) which recorded video on a tablet computer (iPad, Apple Inc., USA) (Balsalobre-Fernandez, 2015). During the CMJ test, the subject was instructed to begin by standing with their hands at their waist, and then told to listen for audible signal, which would alert him to bend his knees and maximally jump upward using arms for momentum. This CMJ was performed three times with 1-minute of rest between each jump attempt. Flight time was calculated for each jump after the take-off and landing was identified in frames of the recorded video. The following equation: $h=t^2 x\ 1.22625$ (h= jump height in meters, t= time in seconds) was used, as outlined by Bosco and colleagues (1983), to determine jump height. Jump height from the application was found to have excellent reliability (ICC) =0.997, p<0.001) and excellent agreement with countermovement jump height (CMJ-h) measured using a force platform (ICC=0.997, p<0.001) (Stanton, 2015).

Sprint Speed

Participants were asked to perform 2 x 20-meter maximal sprints on a natural grass surface with 1-minute of rest between each sprint trial. Peak Sprint speed was assessed by recording video of each sprint using a tablet computer (iPad, Apple Inc., USA) and a mobile application (*MySprint* Apple Inc., USA). The mobile application was specifically designed to use video analysis to determine the start time and finish time of each sprint using a frame-by-frame method. The tablet computer was mounted to a tripod and set at the 20m point of the sprint, 18m from the course, to ensure capturing the start and finish portions of the sprint. The sprint course was marked at 0, 5, 10, 15 and 20m by vertical poles that were set to account for possible video parallax. That is, the poles were set not exactly at the specific distances (0, 5, 10, 15 and 20m), but at the point where the subjects were viewed with the tablet computer to have crossed the maker with their hips and were at the target distance (see figure #). Players were instructed to wear their normal soccer cleats for this test. Players also wore a global positioning system chest strap unit (Polar Team Sport System, Polar Electro Oy, Finland) to provide greater accuracy on acceleration. Synced global positioning system units were worn on a chest strap and worn over the center of the thoracic cavity just below the sternum. The better of the two sprint trials time were recorded and used for further analyses. Peak velocity was acquired via the global positioning system units from both trials and the best score was used to calculate velocity threshold calculations.

T-Test

The T-test course is set up with four cones A, B, C, and D, set up as identified in figure # .The subject began the T-test with both of his feet behind starting point A. The test started with the athlete being given the verbal command “Go”. On this command, he sprinted 9.14m forward to point B and touched the cone. Then, he shuffled 4.57m to the left and touched cone C. After that, he shuffled 9.14m to the right and touched cone D and then shuffled 4.57m to the left, back to point B. Then, the subject ran backward passing the finish line at point A. The time started on the player’s first movement from point A, and stopped when he crossed the finish line. Time was measured using a hand held stopwatch and all T-tests trials were timed by the same assessor (Hetzler, 2008). Each athlete performed this test two times and the faster time was recoded for further analysis.

Sit and Reach

The subject was instructed to sit on the ground with knees straight, legs separated just enough to be comfortable, with the feet placed firmly against the sit and reach box. The arms were extended forward with the hands placed palms down on the upper surface of the box which has a scale for distance printed on horizontal surface (top side) of box. In this position the subject reached forward to the position of maximum reach. The score is the most distant point reached and held. The test administrator stood close beside the scale and recorded the most distant line touched by the fingertips of both hands of the subject. If the hands reached unevenly, the hand reaching the shorter distance was used to determine the score. The score was recorded to the nearest half inch. If the reach appeared to be exactly half-way between two lines the score was based on the last line actually touched.

Statistical Analysis

All data are reported as mean ± standard deviation. All TMG measures data were analyzed using a three-way [condition (DYN vs. SSG vs. PLY) × time (pre-testing vs. post-testing) x leg (left vs right)] analysis of variance (ANOVA) with post-hoc analyses performed when appropriate. All performance variable data were analyzed with a repeated measures ANOVA with post-hoc analyses performed when appropriate. Effect sizes will be interpreted using Cohen's *d*, in which *d* values of .8, .5, and .2 are representative of large, medium, and small effect sizes, respectively (Cohen, 1988). Statistical software (SPSS; V. 20.0; SPSS, Inc, Chicago, IL, USA) was used for data analysis. Results were considered significant at an alpha level of $p \leq 0.05$.

CHAPTER FOUR: RESULTS

Training Stress

Individual subjects were equipped with a telemetric device (Polar Team Sport System, Polar Electro Oy, Finland) which recorded variables related to player training stress variables such as; average heart rate percent (AVG HR%), player training load (PL), and total distance (DIST). Means and standard deviations for the training stress variables are presented in Table 2. Repeated measures ANOVAs were used to detect any overall differences in the mean scores of these training variables. The results of these analyses revealed that there was a significant effect of condition on DIST, (F=8.75, p=0.011, η^2=0.442) where PLY was significantly greater than DYN, and SSG (p=0.002 and p=0.010, respectively) and a significant difference was evident between DYN and SSG (p=0.043) with SSG having lesser DIST. Analysis of AVG HR% revealed a significant main effect of condition (F=6.717, p=0.379, η^2=0.379) where PLY was significantly greater than DYN and SSG (p=0.009 and p=0.023 respectively). No significant effect of condition was observed in PL (F=0.570, p=0.574, η^2=0.049).

Environmental Factors

Environmental factors including temperature (TEMP) and relative humidity (HUM) were recorded for each testing session. Repeated measures ANOVAs were used to detect any significant differences in environmental factors on the days of the different protocol conditions. There was no significant difference in TEMP for any of the protocol conditions (F=0.020, p=0.980, η^2=0.007) or HUM (F=).845, p=0.475, η^2=0.220). The average temperature on testing days was recorded as follows: DYN (72.5 ± 2.51), PLY (71.75 ± 7.5), and SSG (72.00 ± 5.41); while humidity on test days was: DYN (74.5 ± 8.81), PLY (65.5 ± 19.46), and SSG (63.50 ± 13.60).

Performance Testing

The results for the performance test assessments are presented in Table 3. Potential differences in all the performance tests were analyzed using repeated measures ANOVA analysis.

In assessing 20m sprint time of the subjects following the warm up protocols, there was a main effect of condition (F=4.858, p=0.040, η^2= 0.258). Following SSG, there was a significant reduction in sprint time (p=0.020, d=0.61 “medium“) compared to DYN. No significant differences in 20m sprint time were observed between SSG and PLY (p=0.133, d=0.35 “small”); however, a trend was noted for PLY and DYN (p=0.086, d=0.43 “medium”).

Analysis of the subjects’ T-Test times, following completion of the prescribed warm up protocols, revealed no main effect of condition (F=0.527, p=0.596, η^2= 0.036).

In assessing sit and reach scores of the subjects after completion of the warm up protocol, there was a main effect of condition (F= 4.394, p=0.043, η^2 = 0.239). Sit and reach scores following PLY were revealed to be significantly greater (p=0.022, d=0.51 “medium“) than DYN. Furthermore, a trend was noted for differences between PLY and SSG (p=0.060, d=0.33 “small”). No significant difference was observed between DYN and SSG (p=0.136, d= 0.16 “small”),

Results for the variables measured during the CMJ are presented in Table 4. Variables analyzed during the CMJ included; jump height (CMJ-h), flight time (CMJ-ft) and, velocity (CMJ-v), . Analysis of subject CMJ performance revealed no main effect of condition on CMJ-h (F= 0.372, p=0.693, η^2= 0.026), CMJ-ft (F=0.406, p=0.670, η^2= 0.028) or CMJ-v (F= 0.430, p=0.654, η^2= 0.030).

Tensiomyography

The TMG measurements performed pre- (PRE) and post-intervention (POST) are represented in Table 5. The TMG measures included in analysis were: contraction time (Tc), delay time (Td) and maximal displacement (Dm) of the RF and BF of both left (L) and right (R) legs.

Three-way ANOVA did not reveal a significant condition × leg × time interaction for RF-Tc measures (F=0.147, p=0.755, η^2=0.014). A significant main effect of condition was observed (F=3.887, p=0.038, η^2=0.280) where PLY showed a significantly greater time to contraction (p=0.023, d=0.24 "small") compared to DYN and a trend was noted for PLY and SSG (p=0.068, d=0.28 "small"). However, there was no significant difference between SSG and DYN (p=0.897, d= 0.07 "small").

In the analysis of the RF-Td the three-way ANOVA did not reveal a significant condition × leg × time interaction (F=0.710, p=0.504, η^2=0.066). A significant main effect for time was observed (F=29.890, p< 0.001, η^2=0.749), where Td of the RF muscle decreased from PRE to POST.

Three-way ANOVA revealed no significant condition × leg × time interaction for RF-Dm (F=0.445, p=0.647, η^2=0.043). No main effects were noted.

In analysis of the BF-Tc the three-way ANOVA did not reveal a significant condition × leg × time interaction (F=1.314, p=0.305, η^2=0.180). A significant main effect of time was observed (F=5.537, p=0.035, η^2=0.299) where Tc of the BF muscle decreased from PRE to POST.

Three-way ANOVA analysis of the BF-Td did not indicate a significant condition × leg × time interaction (F=0.306, p=0.179, η^2=0.023). However, a significant main effect of time (F=9.749, p=0.008, η^2=0.429) was observed where BF-Td decreased from PRE to POST.

Three-way ANOVA revealed no significant condition × leg × time interaction for BF-Dm (F=0.708, p=0.502η^2=0.052). No main effects were noted.

CHAPTER FIVE: DISCUSSION

The primary findings of this study revealed that performing a warm up protocol had a significant effect on performance assessments, training stress and the mechanical characteristics of the knee flexors and extensors in a sample of collegiate male soccer players. TMG parameters such as the time delay of both the RF and BF, as well as contraction time of the BF, showed significant decreases from pre- to post-warmup regardless of the experimental intervention. Interestingly, contraction time of the RF was significantly greater following PLY compared to DYN and SSG. In terms of performance assessments PLY showed significant improvements in sit and reach when compared to DYN, while a trend was shown when compared to SSG. A significant reduction in 20-m sprint time was shown following SSG and a trend was observed when comparing PLY to DYN.

Numerous studies have identified the benefits associated with participation in an organized warm up protocol prior to athletic competition (Febbraio et al., 1996; Bishop 2003a; Bishop, 2003b; Arnason, Andersen, Holme, Engebretsen, & Bahr, 2008; Fradkin et al., 2010). Studies have also shown performance improvements following training programs that incorporate plyometric exercises and jumps into the warm up routines (Young & Behm, 2003; Vetter, 2007; da Silva et al., 2017). The previously identified benefits and improvements include physiological improvements, increased preparedness and improvement in sport performance skills such as sprinting, jumping and change of direction (Bishop, 2003a; Bishop, 2003b; Little & Williams, 2006; Gabbett et al., 2008; Holt & Lambourne, 2008; Yaicharoen, Wallman, Morton, & Bishop, 2012). While studies may disagree on what warm up protocols produce the best results, there is a consensus that the warm up performed should consist of dynamic movements as well as an active stretching routine for agonist and antagonist muscles groups to reduce risk of injury and improve sport related performance (Febbraio et al. 1996, Bishop, 2003a; Bishop, 2003b; Fletcher & Jones, 2004; Gabbett et al., 2008; Fletcher & Monte-Colombo, 2010; Fradkin et al., 2010).

This study showed no significant differences in measured CMJ variables between PLY, DYN and SSG warm ups. This may be due to the acute nature of this investigation, in contrast to other studies that have used multiple training sessions incorporating plyometric exercises that have shown improvements in jump performance following warm ups inclusive of jumping exercises (Young & Behm, 2003; Vetter, 2007). Previous research has shown that skeletal muscle performance is affected by the contractile properties of the muscle (Sale, 2002). However, the single PLY session used in this study may not have increased contractile properties of the muscle associated with repeated activation of the stretch shortening cycle (SSC) induced by jumping type exercises used in longer duration studies (Markovic & Mikulic, 2010); (Turner, Bellhouse, Kilduff, & Russell, 2015).

Assessment of 20-m sprint time reveled a significant improvement following completion of SSG. While these findings are similar to a number of studies showing improvements in sprint time following active warm ups and dynamic stretching routines (Fletcher & Jones, 2004; Little & Williams, 2006; Vetter, 2007; Turki et al., 2012) they contrast those of Gabbett et al. (2008) who found that there was no significant difference in sprint times for players completing an open skill or closed skill warm up. This may be attributed to the specificity of the open skill tasks completed by basketball players over similar distances and intensities regardless of ball possession. Conversely, the present study used a “rondo” drill in which the soccer players intensity and distance varied throughout the warm up. The rondo used in this study incorporated 4 offensive players who attempted to maintain ball possession passing around one defensive player, who ran back and forth within a 7m x 7m square field area trying to win the ball. The rounds were 45 seconds in duration, resulting in all 5 players needing to work one round at the high intensity defensive position and 4 rounds as an offensive player only making small lateral movements to pass and receive the ball. Further investigation of performance benefits from these types of drills that incorporate a competitive stimulus should be explored.

Further analysis regarding the 20-m sprint assessments revealed a trend wherein PLY showed improved sprint times when compared to DYN. While past studies have examined the effectiveness of dynamic warmups for improving sprint time, they have typically examined the difference in dynamic and passive warm up routines (Fletcher & Jones, 2004; Little & Williams, 2006). We know of no other study to date that has compared the effectiveness of a dynamic warm up series to a warm up inclusive of a large plyometric component on agility, sprint and jump performance. In an 8-week training study examining the effects of plyometric training, investigators found that athletes who completed sprint specific plyometric exercises showed significant improvements in 40-m sprint time (Rimmer & Sleivert, 2000). Söhnlein, Müller, and Stöggl (2014) observed 20m sprint time was improved after plyometric exercise was incorporated into the training programs of elite youth soccer players. These improvements over short distances were attributed to the reduced ground contact time associated with plyometric exercises, which may be the reason for potential improvement in 20-m sprint time in the PLY group compared to the DYN group observed in this study.

Sit and reach performance was improved following PLY with a significant increase reported compared to DYN and a trend when compared to SSG. The improved flexibility observed here may be attributed to the increased eccentric component associated with the movement patterns and muscle activation that accompanies repeated jumping type exercises

(Faigenbaum et al., 2007). Recurring bouts of eccentric training have been shown to shown to improve the muscle length-tension curve which results in improvements in range of motion (O'Sullivan, McAuliffe, & Deburca, 2012). The present findings are consistent with previous studies that have shown improvements in flexibility associated with repeated training sessions that incorporated plyometric type exercises (Faigenbaum et al., 2007; da Silva et al., 2017).

The current study aimed to evaluate the underlying changes in contractile properties that may support performance improvements following an organized warm up protocol. We believe the current study is the first to examine the changes in TMG parameters in response to specific warm up protocols while also assessing sport specific performance in an athletic sample. The contractile properties of the RF and BF were altered following the warm up protocols performed in this study.

Delay time, also termed reaction time (Rey et al., 2012), of the RF and BF showed a significant improvement from PRE to POST following each of the prescribed warm ups. This improvement, or decrease, in delay time following warm up activities is most likely due to the post-activation potentiation effect generated by the exercises in the warm up protocols. Previous studies have proposed that initiating neuromuscular potentiation may improve force production and performance (Turner et al., 2015). Plyometric and jumping type exercises have been shown to be the most common prescribed methods to enhance PAP (Gelen, 2010) however the findings of this study may be indicative of an acute PAP response following the exercises used in the three warm up protocols. Improved PAP has been postulated to increase the rate of force development in voluntary force production in dynamic muscle contractions (Docherty & Hodgson, 2007). Further investigation of the PAP response, as measured by TMG, is warranted utilizing jumping exercises as part of chronic warm up protocol intervention.

Contraction time of the BF showed a significant decrease from PRE to POST following participation in all of the prescribed warm-ups. This may be due in part to the improvements in the central nervous system nerve conduction rate associated with the increased muscle temperature following an active warm up (Karvonen, 1992). However, when examining Tc in the RF, PLY showed a significantly greater time to contraction compared to DYN and SSG regardless of time. While speculative, this may be attributed to the PAP associated with plyometric type exercises. While we are unaware of any studies to date that have examined the effect of such training on contraction time using TMG. Therefore, evaluation of Tc following plyometric training warrants further investigation in order to gain additional knowledge in the area of muscle mechanical response.

Maximal displacement, as measured by TMG, showed no significant differences between warm up protocol; however, previous studies have reported that this parameter is traditionally lower in soccer players compared to the general population (Rey et al., 2012). Low values of maximal displacement are usually indicative of higher muscle tone (Rodríguez-Ruiz et al., 2012) Therefore, based on the movement patterns and training of high level soccer players, changes in this parameter may be difficult to elicit during a warm up due to the relatively short duration of exercise. A potential limitation to this study is that the population examined was a homogenous group of male athletes with similar playing experience and competitive level. Future research should include groups of different playing experience or competitive level, or a control group of non-soccer athletes.

The warm up protocols performed in this study represent variations of commonly used exercises for soccer athletes. The DYN warm up examined herein positively impacted the contractile properties of leg muscles after performing a standardized series of dynamic movements. These exercises are familiar to the athlete and are completed in movement planes similar to those encountered in sport participation. Previous research has already established the performance improvements associated with DYN, however they may seem less evident here, because DYN was compared to more novel SSG and PLY protocols, rather than typically employed passive stretching or running only routines. The PLY exercises examined were shown to improve flexibility, as indicated by the improved sit and reach scores and improved 20-m sprint time, potentially via post-activation potentiation.

In regard to the training stress variables assessed during the warm up protocols, differences between conditions were noted in total distance and average heart rate. Total distance and AvgHR% were significantly greater in PLY compared to both DYN and SSG. The SSG protocol in this study showed improvement in assessed sprint performance and had a significantly lower total distance than PLY and DYN along with a significantly lower AvgHR% than the PLY protocol. However, despite these noted differences, there was no significant difference in PL between any of the warm up protocols. PL is an important variable to monitor when assessing training stress-balance of the athlete throughout the course of the season. This lack of difference in PL should be considered when monitoring the cumulative effect of training stress and could result in substantially less physiological stress over the course of a competitive season. These results may support that the warm up routines may be interchanged in some part without negatively impacting training stress.

The selection of warm up protocols may be influenced by coaches and or players attitudes or preferences for specific warm ups. Another factor in warm up selection and administration may be time constraints or objectives the coaching staff needs to meet prior to match play, such as positioning, set piece formation, etc. However, the findings of this study should illustrate the benefits of incorporating more plyometric exercises and small-sided game situations to a standard pre-training or pre-competition warm up. While extensive study has been done on the purported benefits of warm ups, there is no consensus on which warm up produces the best results for sport performance. The differences in previous findings may be inherently due to the individual responses of athletes to the various exercises or intensities at which they are performed as well as individual neuromuscular properties and fiber type composition. Future research should include studies examining the long-term effects of warm up administration with larger samples of athletes at different levels of play and/or maturity status.

APPENDIX A: FIGURES

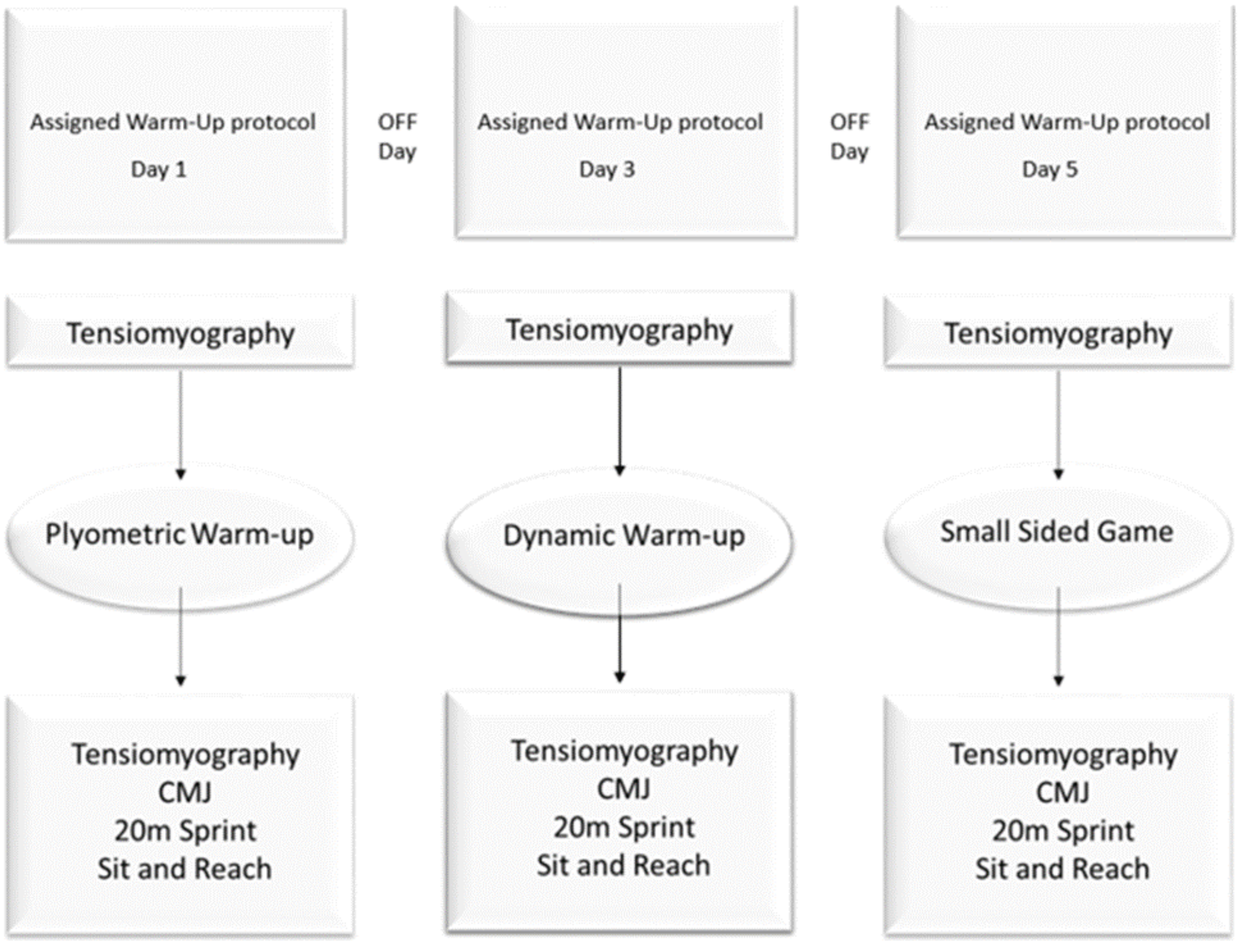

Figure 1: Study Design

APPENDIX B: TABLES

Table 1
Means and Standard Deviations of Selected Characteristics by Player Position

	GK (n=3)	**DF (n=6)**	**MF n=6)**	**FW (n=3)**
Age (y)	20.33 ± 0.94	19.25 ± 4.97	20.83 ± 1.07	19.67 ± 1.25
Height (cm)	185.67 ± 3.23	164.35 ± 42.64	172.98 ± 5.90	178.06 ± 3.40
Body Mass (kg)	88.66 ± 4.13	72.73 ± 18.45	75.00 ± 7.65	76.46 ± 6.91
Body Fat (%)	16.15 ± 2.35	12.30 ± 3.49	14.50 ± 2.29	9.77 ± 4.01

GK= goalkeeper; DF= defender; MF= midfielder; FW = forward; *n* = sample size

Table 2
Training Stress Variables between Different Warm up Protocols

Measure	Dynamic	Plyometric	Small Sided Games
Player Load (AU)	13.25 ±3.09	13.75 ± 5.79	14.25 ± 7.67
Heart Rate (Avg %)	64.25 ± 5.96	63.25 ± 4.03	58.75 ± 5.67
Distance (km)	.77 ± .08	.81 ± .05	.76 ± .17

Table 3
Performance Test Results

Test	Dynamic	Plyometric	Small Sided Games
20m Sprint (s)	2.85 ± 0.30	2.71 ± 0.15	2.67 ± 0.16*
T-Test (s)	10.13 ± 0.27	10.21 ± 0.30	10.16 ± 0.33
Sit and Reach (cm)	33.85 ± 6.90	37.44 ± 6.79†	36.87 ± 7.57

* Significantly lower than Plyometric ($p < 0.05$)
† Significantly greater than Dynamic ($p < 0.05$)

Table 4
Counter Movement Jump Data Following Completion of Selected Warm up Protocol

CMJ Variable	**Dynamic**	**Plyometric**	**Small Sided Games**
Height (cm)	59.04 ± 7.74	59.31 ± 8.14	59.76 ± 8.42
Flight Time (ms)	695.80 ± 49.13	693.80 ±49.13	691.40 ± 52.44
Velocity ($m \cdot s^{-1}$)	1.71 ± .11	1.70 ± .12	1.70 ± .13

Table 5
Tensiomyography Measurements Pre and Post Selected Warm up Protocol

Muscle	**TMG Measure**	**Dynamic**		**Plyometric**		**Small Sided Games**	
		Pre	Post	Pre	Post	Pre	Post
R Rectus Femoris	Tc (ms)	27.67 ± 4.16	27.11 ± 3.33	28.64 ± 4.47	27.69 ± 4.61	28.10 ± 3.72	27.09 ± 3.99
	Td (ms)	24.60 ±2.00	23.21 ± 1.71	25.27 ± 2.56	23.79 ± 1.70	24.36 ± 2.06	23.23 ± 2.02
	Dm (mm)	7.42 ±2.13	6.83 ± 1.74	6.97 ± 2.09	7.26 ± 1.79	7.12 ± 2.57	7.12 ± 2.46
L Rectus Femoris	Tc (ms)	28.78 ± 4.51	27.64 ± 3.67	28.05 ± 4.76	28.86 ± 3.88	27.95 ± 3.75	27.11 ± 4.94
	Td (ms)	24.83 ± 1.61	23.78 ± 2.01	24.35 ± 2.16	24.29 ± 1.85	24.63 ± 2.14	23.05 ± 1.57
	Dm (mm)	7.50 ± 1.61	7.34 ± 1.75	6.41 ± 2.01	7.82 ± 2.09	7.63 ± 2.14	7.08 ± 2.75
R Biceps Femoris	Tc (ms)	23.25 ± 10.74	20.69 ±4.85	20.00 ± 5.55	20.20 ± 5.50	23.12 ± 11.57	20.52 ± 6.12
	Td (ms)	22.27 ± 2.92	21.02 ± 1.81	21.78 ± 2.53	20.19 ± 2.88	21.87 ± 2.20	20.88 ± 1.95
	Dm (mm)	3.27 ± 1.99	3.10 ± 1.64	3.21 ± 2.51	3.13 ± 2.21	3.31 ± 1.74	2.86 ± 1.45
L Biceps Femoris	Tc (ms)	20.31 ± 3.80	20.18 ± 4.15	23.68 ± 11.74	20.23 ± 3.82	23.14 ± 6.44	20.99 ±5.06
	Td (ms)	21.59 ± 2.05	20.66 ± 1.72	21.62 ± 2.33	20.68 ± 1.91	21.87 ± 2.45	21.06 ± 1.76
	Dm (mm)	2.77 ± 1.36	2.80 ± 1.43	3.35 ± 2.16	2.99 ± 1.45	3.47 ± 1.55	3.18 ± 1.71

R=right leg; L= left leg; TMG = tensiomyography; Pre = pre testing value; Post = post testing value; Tc = contraction time; Td = delay time; Dm = maximal displacement.

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