THE INFLUENCE OF DIFFERENT DURATION DYNAMIC WARM-UPS ON VERTICAL JUMP PERFORMANCE

by

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ABSTRACT

GAVIN STUART. The influence of different duration dynamic warm-ups on vertical jump performance

(Under the direction of DR. ABBEY THOMAS)

The benefits of a proper warm-up have long been well known but the specifics on warm-up duration have been lacking. The purpose of this study was to determine differences in vertical jump and muscular strength following 5 minute and 10 minute warm-up programs. A total of 12 healthy adults adults were used with 6 males and 6 females (age: 22.25±2.49 years, height: 171.77±12.96 cm, BMI: 24.73±3.41 kg/m2). Each participant completed two warm-up programs of differing durations on separate days with one week between sessions. Vertical jump and muscular strength were immediately tested using a Vertec and an isokinetic dynamometer. Differences in jump height and muscular strength were analyzed with repeated measures ANCOVAs using sex as covariate. T-tests were used in the event of significant interactions for all analyses. The results showed no differences in vertical jump following either duration warm-up. Knee extension strength showed a significant decrease following intervention while knee flexion strength showed an increase. Despite conflicting results, a warm-up should still be performed as part of an exercise routine.

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CHAPTER 1: INTRODUCTION

The American College of Sports Medicine (ACSM) has suggested adults should participate in at least 150 minutes of cardiorespiratory fitness per week as well as resistance train major muscle groups two to three days per week [1]. The ACSM recommends dividing the cardiorespiratory fitness time into 30-60 minutes of moderate-intensity exercise for five days per week or 20-60 minutes of vigorous-intensity exercise for three days a week. With roughly 243 million adults living in the United States, this potentially adds to a large number of person hours spent participating in exercise. With such a large population working out, the potential for injury during exercise can be rather large.

An important element to any exercise protocol is a proper warm-up. An improper warm- up protocol may have negative effects in both training and competitive play. A warm-up, put simply, primes an individual's body to meet the demands of the subsequent exercise program or sports activity. Warm-up protocols generally do not follow any rigid guidelines, which allows for a great deal of flexibility with programming in order to meet specific demands. The variables which go into the designing of warm-up, such as intensity, duration, and specific movements, can all be manipulated to best suit the activities that follow. However, the lack of recommendations on program variables has led to confusion on how to properly structure a warm-up. It can be very easy to design a warm-up that either fatigues the participant or does not adequately prepare him/her for the upcoming activity. Both situations can lead to an increased risk for injury. One important step in designing the optimal warm-up is determining an ideal warm-up length that prepares the body for activity without inducing muscular or cardiorespiratory fatigue. Investigating the ideal duration of a warm-up will allow any individual participating in exercise, or leading a group through exercise, to more adequately prepare to meet the demands of the upcoming activity as well as reduce injury risk and improve performance.

Physiologically, preparing the body to meet the demands of physical activity goes beyond a “warm” feeling and a slightly increased heart rate. While an increase in baseline heart rate is an important factor for warming up, other measures such as baseline oxygen volume (VO2) body temperature, muscular extensibility and excitability, among others, are equally important to performance in physical activity. A comparison of VO2, heart rate, blood lactate levels, and blood pH between active and passive warm-ups demonstrated a greater increase in VO2 and blood lactate at a lower heart rate in the active warm-up than the passive [2]. The increased VO2 and lower heart rate, when compared to the passive program, were concluded to be the result of an increased vasodilation which allows for faster blood flow to working musculature and an increased rate of oxidative metabolic activity [2]. These effects are believed to reduce the temporary mismatch between O2 supply and O2 demand that exists in the early stages of physical activity. The conclusions listed in the previous study corroborate the positive effects of warm-up in examples using other markers. Several studies have examined the effects warm-up has on performance-based tasks such as speed, agility, jumping, and other quickness drills with positive benefits recorded following the specific warm-up programs [3,4,5,6,7,8]. Jumping, in particular, is an important outcome to examine due to its presence in a wide variety of sports as well as the use of a vertical, or horizontal, jump test as an easy power standard for numerous athletes.

While the effect of warm-up on performance has been studied extensively, there is little direct examination into the mechanisms behind these benefits. Several studies have pointed to the link between increases in heart rate, VO2, muscle length, etc. as possible mechanisms, but conclusive evidence is lacking. While the effects of a warm-up on performance have been well documented, the optimal way to administer a warm-up is still undetermined. As stated previously, the lack of guidelines on warm-up variables can easily lead to designing programs which ultimately have a negative impact overall (i.e., induce injury or impair performance). A program that takes too long can lead to fatigue during the activity that follows or can take away from valuable practice time in regards to sports teams. Likewise, a program that is too short can lead to negative performance by not preparing an individual well enough to meet demands. Other factors such as intensity can also be poorly manipulated and have negative consequences. It is important to determine proper warm-up guidelines so individuals, and coaches, can properly structure a training session to maximize performance and safety.

Warm-up duration is an important factor and can have profound effects on the effectiveness of the program. A warm-up which is too short will not prepare the body for activity while too long of a warm-up can result in fatigue which will also hinder performance [9]. An analysis of the effects warm-up duration has on peak power output was performed on professional track cyclists. Between a 30 minute “traditional” cyclist warm-up and a 15 minute experimental program, the shorter duration program produced higher power outputs and lower markers of fatigue than the traditional program [10]. Blood lactate concentration and average heart rate were both higher during the traditional program [10]. While increases of both markers have been seen in other programs, these levels were sustained for a much greater duration following the 30 minute warm-up, leading to fatigue prior to the peak power test. It is important the warm- up duration be sufficient enough to allow for metabolic and biochemical markers to elevate over baseline but not last too long or fatigue prior to activity will become an issue. Determining an ideal warm-up length can assist coaches in properly planning a practice session to allow for ample time to work on sport skills while not cutting back on preparatory work prior to practice. If a coach can properly prepare athletes with a 5-10 minute general warm- up versus one approaching 20 or more minutes, this leaves more time to practice sport skills. Also, improving the efficiency of the general warm-up program can open more time for planning and specific skill work prior to a competition. Warm-ups do not follow strict guidelines and instead rely on the coach’s manipulation of duration, intensity, and specific movements in order to prepare athletes. By examining the effects duration has on performance, coaches can better structure a training session.

Statement of the Problem

Proper warm-up is imperative to physiologically preparing the body for activity at all levels of fitness and competition. With more and more people turning to physical activity to improve health and quality of life, combined with greater numbers of individuals participating in competitive sports, optimizing warm-up procedures to maximize efficacy and minimize injury potential during athletic activity is imperative.

Presently, the optimal warm-up duration is unknown. Too short of a warm-up may not adequately prepare the body for activity, while too long of a warm-up may induce fatigue and increase injury potential during subsequent activity. This study aims to determine the influence of two different duration warm-ups (5 vs. 10 minutes) on athletic performance as measured by vertical jump height. This knowledge represents one important step in optimizing warm-up duration and, therefore, warm-up protocols.

Specific Aims and Hypotheses

Specific Aim 1: To compare vertical jump height performance between a short (5 minute) and long-duration (10 minute) dynamic warm-up protocol.

Hypothesis 1.1: The long-duration warm-up will produce a greater improvement in vertical jump height than the short-duration program.

Specific Aim 2: To determine if there is a difference in quadriceps and hamstrings muscle strength following completion of a short- and long-duration dynamic warm-up protocol.

Hypothesis 2.1: The long-duration will result in a greater improvement in quadriceps and hamstrings muscular strength than the short-duration program.

Specific Aim 3: To determine if there is a difference in heart rate and rating of perceived exertion (RPE) following completion of a short- and long-duration dynamic warm-up protocol.

Hypothesis 3.1: The long-duration protocol will result in a greater increase to resting heart rate and RPE than the short-duration program.

Limitations

As with any research investigation, this study is not without limitations. This study enrolled only healthy, physically active adults. However, this population is more likely to engage in physical activity and, thus, benefit from dynamic warm-up than sedentary individuals. Only two warm-up durations were employed in this study.

Significance of the Study

This study is significant because it will enhance our understanding of the optimal warm- up protocol by determining the influence of short vs. long duration warm-up on vertical jump performance.

CHAPTER 2: REVIEW OF THE LITERATURE

Musculoskeletal Injuries and Imbalances

Musculoskeletal injury has long been associated with loss of function and varying degrees of pain, both of which can lead to altered joint mechanics and impairment of functional tasks such as gait. Data from the National Health Interview Survey demonstrates nearly 23 million musculoskeletal injuries occurring in 2008, which account for over 60% of total unintentional injuries reported in the United States [10]. Sprains and strains were most common, accounting for 44% of musculoskeletal injuries. Lower extremity injuries are particularly common among individuals who regularly engage in athletic activity. Between 2005 and 2011, approximately 15% of injuries sustained by high school athletes were knee injuries with ligament sprains accounting for nearly half of these [11]. Additionally, over 20% of sports injuries at the high school level occurred at the ankle with 85% of those reported as ligament sprains [12]. Musculoskeletal injuries are often treated with physical rehabilitation with reduction in pain and restoration to strength and function as the primary goals; however, if left untreated or poorly treated these injuries can lead to additional long-term complications. Chronic deficits in quadriceps strength, for example, have been shown in patients following anterior cruciate ligament (ACL) reconstruction [13]. This lack of strength in spite of an otherwise successful surgical intervention and post-operative rehabilitation can have particularly bad effects on athletes who are required to strength train regularly in order to compete. Since the quadriceps strength loss occurs in the reconstructed leg, an asymmetry is produced which can carry over into movement patterns utilized during strength training and other daily and athletic tasks. For example, asymmetries present during a barbell back squat, which is commonly utilized by a wide variety of athletes and programs to increase lower extremity muscle strength, resulted in greater degrees of angular and rotational bar displacement [14]. Essentially, the athlete is training an improper movement pattern which not only increases injury risk during the training motion but may also carry over into sport performance.

Muscular imbalances do not have to be injury related. Many athletes who rely on a dominant leg, such as jumpers, for certain sport motions may develop imbalances [15, 16]. These muscle imbalances, no matter the cause, can result in many long-term deficits as well as increase the risk for sustaining an acute musculoskeletal injury. Practice and matches start with a proper warmup in order to physically prepare the athletes for the upcoming session. Improper warmup that either lasts too long or is too short can result in an increase to injury risk as an athlete's body is simply no prepare whatever demands may be present during the game or practice session.

Measurement and Performance

Warm-up

A staple of any sports or recreational activity is a warm-up procedure designed to adequately prepare the body for activity be it competition, practice, or recreation. Most warm-up programs can be split into one of two categories, dynamic and static. Static warm-ups typically include placing a limb towards end-range motion in order to lengthen the target musculature. Dynamic warm-ups put limbs through active ranges of motion in order to achieve the same outcome. There has been much debate over which protocol is ideal for performance, with many conclusions pointing towards dynamic as preferable over static (8). Warm-up programs including dynamic movements, compared to static and no stretching, resulted in greater vertical jump than both groups. Flexibility between dynamic and static groups were the same, but still improved over the no stretch group. Reaction time was also improved over the no stretch group [3]. These results compare favorably with others [4, 5]. Increases in agility have also been documented when comparing dynamic to static programs, while no difference in vertical jump or sprint times were also recorded [4]. Not only are improvements in raw performance seen when comparing differing warm-up protocols, but sport skills have also shown enhancements following dynamic warm-ups[5]. Ball handling skills and penalty kick performance both were improved following dynamic warm-up movements, as opposed to static movements. While some conflicts between dynamic and static movements exist, the general consensus points towards dynamic movements as more ideal for sport performance. Particularly in regards to technically advanced skills performed at high speeds.

Since there are no defined protocols for structuring a warm-up, coaches and sports professionals must rely on general information regarding warm-up mechanisms in order to design an effective program. The primary goal of any program is to prepare an athlete for performance. However, certain aspects must be taken into consideration before programming a warm-up. Warm-up intensity (% of VO_2max), duration, and recovery (time between ending of warm-up and beginning of activity), as well as sport specificity, can drastically change the movements that go into a warm-up and can alter the effects on performance if improperly managed. Many warm-up outcomes fit into two mechanisms, increased muscle temperature and baseline VO_2. Overall, the goal of a warm-up is to increase one, if not both depending on sport, in order to improve performance. Increases in muscle temperature have been linked to decreased joint stiffness, improved nerve impulse transmission, alterations in the force-velocity relationship, and increased metabolic activity [9]. Many of these mechanisms are imperative to short-term performance and may explain why performance is improved following an adequate warm-up. Improvements in moderate to long-term performance appear to be attributed to an increase in baseline VO_2 in addition to increased muscle temperature [9].

As with any exercise program, the balance between intensity, duration, and recovery is key to success. A warm-up is no different as the goal is to prepare the body by increasing temperature and baseline VO_2 without resulting in fatigue or decreased metabolic substrates. In general, higher intensity activity should be performed at decreased duration. Much research has shown a 10-20 minute warm-up at 40-60% VO_2max is linked to improvement in short-term performance across a wide variety of tasks and skills [9]. Muscle temperature increases dramatically within 3-5 minutes following onset of activity and will plateau around 10-20 minutes. With regards to short-term performance, going beyond 60% VO_2max typically results in a decrease in performance. Likewise, below 40% VO_2max does not illicit enough of an increase in baseline measures to result in improved performance [9]. While short-term performance seems to be hindered following a warm-up above 60% VO_2max, intermediate performance seems to benefit after a warm-up at 70% VO_2max for around 10 minutes. Baseline VO_2 has been shown to increase and reach a steady state within 5-10 minutes of moderate to heavy intensity. Going beyond 10 minutes does not appear to induce any additional benefits as VO_2 has most likely reached steady state. Continuing to warm-up at this intensity may result in an impairment of performance by affecting muscle glycogen stores. The same guidelines for intermediate performance can also be applied to long-term outcomes.

Adding to the previously mentioned work, other investigations into warm-up duration and certain markers of performance have yielded similar conclusions. A 2-phase warm-up consisting of low-intensity cardiovascular activity and specific high-intensity movements produced reductions in fastest and mean 20m sprint times compared to a 3-phase program which included static stretching. A 3-phase group that added dynamic stretching along with cardiovascular work and high-intensity drills produced similar benefits as the 2-phase program. While not specifically examining duration, the results indicate a “less is more” approach to administering team warm-ups may be beneficial to overall performance and health. Similarly, a comparison to two track cycling warm-ups found the longer, more traditional, program led to early fatigue on a Wingate test while the shorter program produced much more favorable results. It is important to note the difference in duration between the programs was quite large with the traditional program lasting roughly 45 minutes while the shorter program was cut to 15 minutes. Both included steady-state cycling and high-intensity sprints but at differing intensities, durations, and number of sprints. It is clear there is still much to learn regarding the effects of warm-up duration on performance markers.

Conclusions

A properly structured warm-up program is essential for success in any activity, particularly at high levels of competition. It is important the coaching staff properly consider the intensity, duration, movements, and even sport specificity in designing and implementing a comprehensive warm-up. Since there is a lack of defined guidelines for warm-up, it is imperative the staff pull from various research-based sources in order to maintain education on current techniques and methods. While this study will only examine one variable, the results will have applicable carryover into any warm-up program for any sport. Other variables can be investigated with future research.

CHAPTER 3: METHODS

Study Design

This study followed a crossover design, with participants completing two different dynamic warm-up protocols on 2 different days separated by 1 week.

Participants

Twelve healthy adults (six males and 6 females) participated in this study. To be eligible for participation, individuals had no: 1) lower extremity or low back orthopedic injury in the previous 6 months; 2) history of lower extremity or low back surgery; or 3) any condition that precludes safe participation in physical activity. The Tegner Activity Scale was utilized in order to estimate the physical activity level of the participants. All participants provided informed consent after procedures were thoroughly explained and any participant questions/concerns were addressed. The institutional review board at UNC Charlotte approved this study.

Vertical Jump Assessment

Initial and follow-up testing procedures were identical and involved a standard maximum vertical jump recorded using a Vertec vertical jump measuring device. Participants stood with their feet flat on the ground and shoulder width apart. Standing height was recorded by having the participants straighten one arm overhead with the hand outstretched to touch the highest possible vane on the Vertec. Participants were then instructed to jump vertically for maximal height, again touching the highest possible vane on the Vertec. Vertical jump height was taken as the difference between the standing and jumping heights. A series of warm-up trials were permitted for familiarization with the task. Three maximal effort trials were performed. The trial with the highest jump distance will be taken as the true max and used for statistical analysis.

Muscle Strength Assessment

Participants had quadriceps and hamstrings concentric strength measured one week prior to and after completion of each dynamic warm-up protocols. Vertical jump height assessment was always performed prior to strength assessment and both assessments were performed following each warm-up exercise bout. (Figure 1).

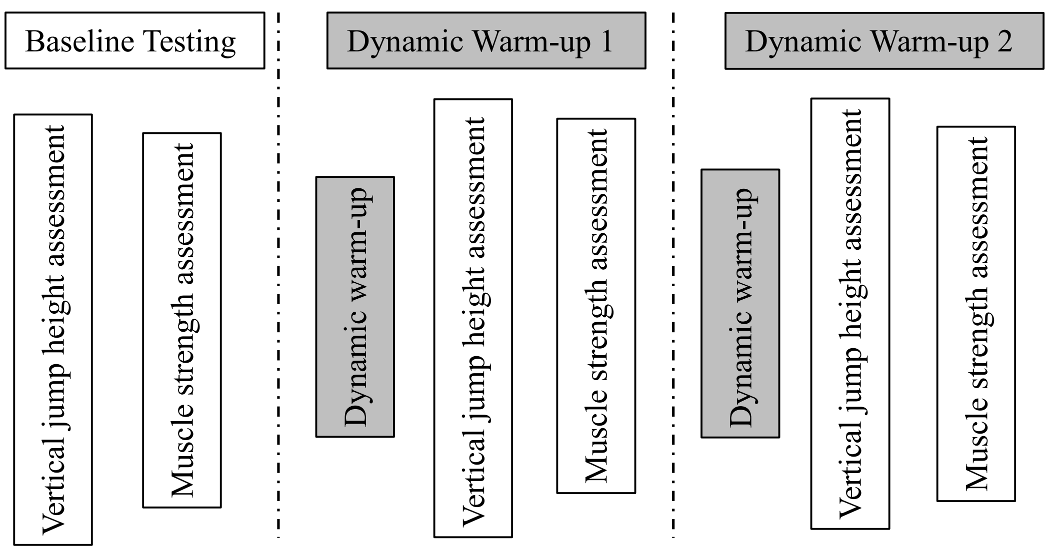

Figure 1. Order of testing procedures for sessions 1, 2, and 3

Strength was measured at 60°/s using a Biodex isokinetic dynamometer (System 3, Biodex, Inc., Shirley, NY). Participants were seated on the dynamometer with the hips flexed to85° and knees flexed to 90°. The fulcrum of the dynamometer was aligned with the knee joint center. Participants were instructed to extend and flex the knee through the full, available range of motion while maintaining their arms folded over their chests. They will complete warm-up repetitions at 25, 50, and 75% of the maximal intensity followed by a 1 minute rest period. Next, participants performed one set of 5 repetitions at maximal intensity, from which the peak measurements were recorded and normalized to participant body mass (Nm/kg) for statisticalanalysis. All strength assessments were performed bilaterally with participants receiving verbaland visual feedback to encourage maximal effort. The Biodex system has been shown in the past to serve as a valid measurement for muscular strength [17].

Heart Rate and Rate of Perceived Exertion (RPE)

Heart rate was taken using a Polar Heart Rate Monitor at rest prior to any activity and again at the conclusion of the warm-up protocol. The RPE was measured using the Borg 6-20 scale [18] at rest and immediately following cessation of the warm-up protocol.

Dynamic Warm-up

Following the pre warm-up testing, participants completed one of 2 dynamic warm-up protocols (short and long). The remaining dynamic warm-up was completed during the second testing session 1 week later. Protocol order was randomized by means of a coin flip on the first session one week after baseline testing. The short dynamic warm-up was a series of dynamic lower-extremity movements followed by a low-intensity plyometric circuit which participants continued until 5 minutes was achieved. The longer warm-up program was the short program completed twice, participants were instructed to complete the series again after 5 minutes for a total of

10 minutes. All exercises were explained and demonstrated prior to the testing session.

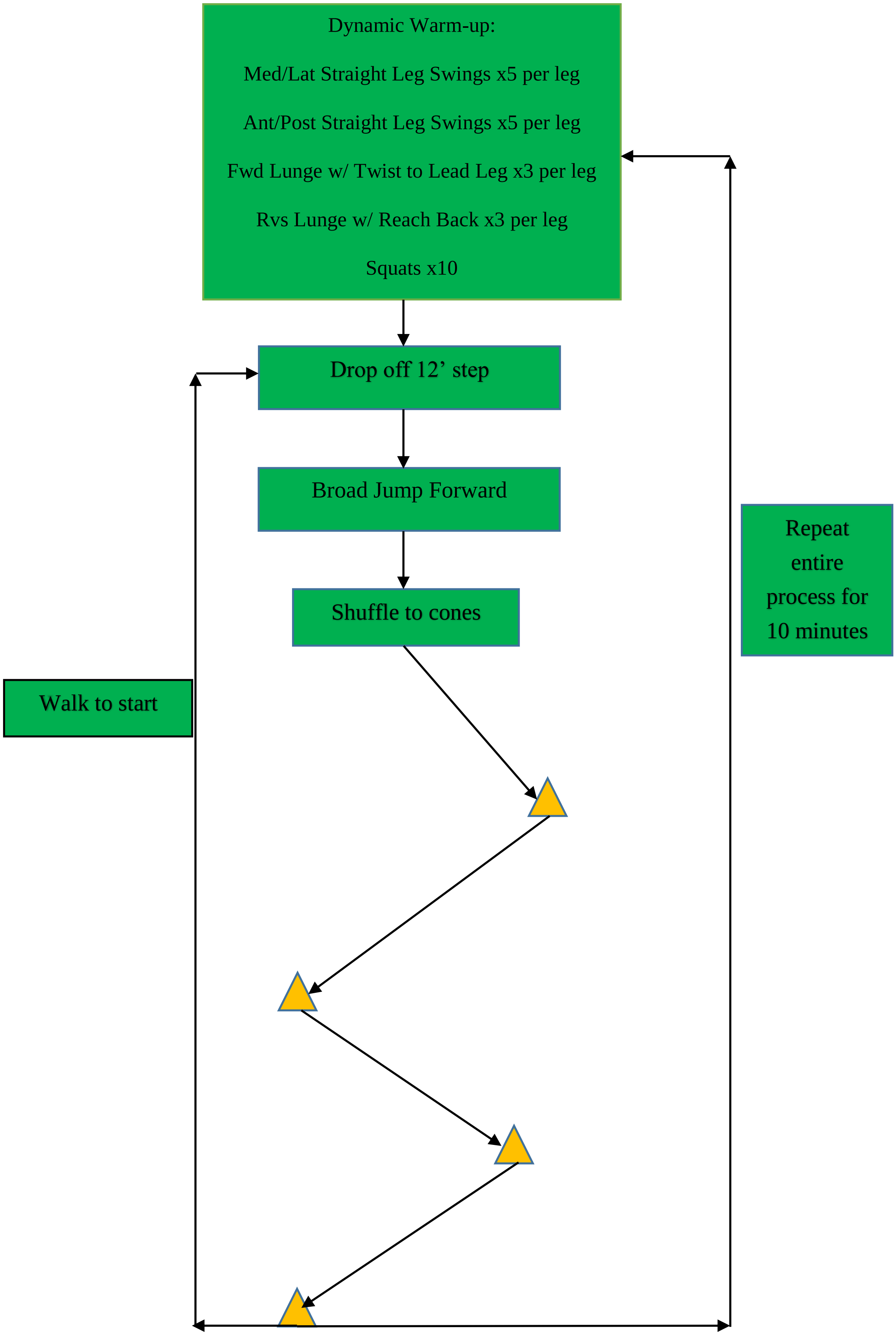

Figure 2: Flowchart for warm-up programs

Statistical Analysis

Demographic data and physical activity level at baseline were compared between male and female participants using one-way ANOVAs. The independent variables for analysis included condition (short vs. long duration dynamic warm-up) and time (pre- or post- warm-up). Dependent variables included vertical jump height, muscle strength for the knee extensors and flexors, heart rate, and RPE. To examine for differences in muscle strength at baseline between limbs, paired samples t-tests were performed. To determine differences between conditions and over time for vertical jump height and muscle strength, a series of repeated measures ANCOVAs were performed with participant sex as a covariate. Heart rate was similarly analyzed using repeated measures ANOVAs. Sex was not used as a covariate in the heart rate analysis as there were no baseline differences in heart rate on independent samples tests. T-tests were used in the event of significant interactions for all ANOVA and ANCOVA analyses. Wilcoxon signed ranks tests were used to examine changes RPE over time. The alpha level for all analyses was set *a priori* at <0.05. Statistical analyses were completed in SPSS (v21, IBM Corporation, Armonk, NY)

CHAPTER 4: RESULTS

Male participants were taller and had greater body mass than female participants (Table1). There were no differences in the ages or activity levels of males and females in this study.

Table 1. Demographic and Tegner Activity Level Scale Data. Data are mean ± standard deviation except for Tenger scale data, which are median (range).

	Age (years)	Body Mass Index (kg/m^2)	Tegner Activity Level Score
Male	23.00±0.90	27.08±2.48	7.00 (5.00, 10.00)
Female	21.50±3.39	22.38±2.46‡	5.50 (3.00, 9.00)
Total	22.25±2.49	24.73±3.41	6.50 (3.00,10.00)

* different from males P<0.001
† different from males P=0.001
‡ different from males P=0.008

Vertical Jump

Males jumped significantly higher than females (P<0.001). With participant sex included as a covariate in the analysis, participant vertical jump height did not differ between protocols(P=0.082; Figure 3)

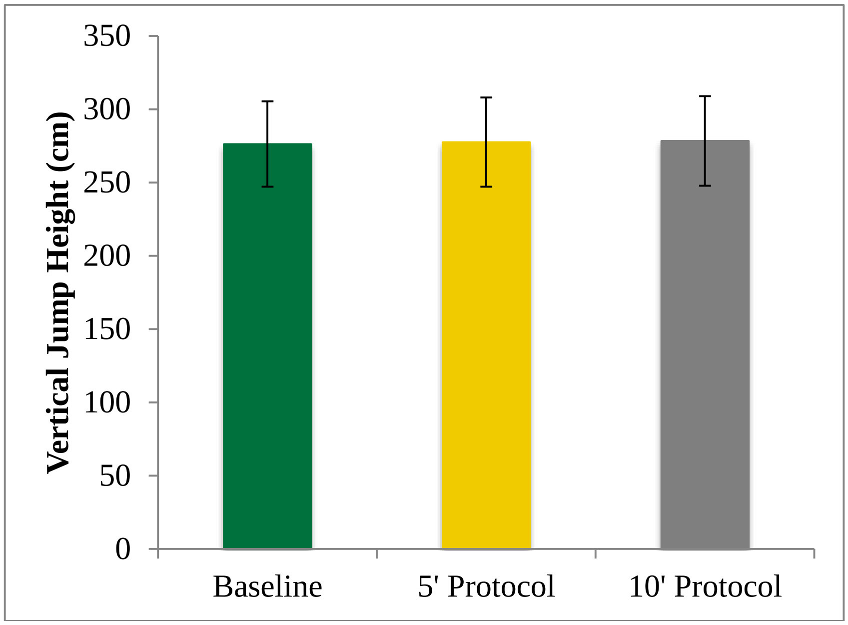

Figure 3**.** Vertical jump height at baseline and following the five and ten minute dynamic warm-up protocols. Data are mean ± standard deviation.

Strength

Analysis of baseline strength data revealed no differences in strength between limbs (extensors: *P*=0.432; flexors: *P*=0.684). Therefore, data were averaged across limbs to yield a single extensor strength and flexor strength measure for each participant. There was a significant time*sex interaction for knee extension (*P*=0.003; Figure 4) but not flexion (*P*=0.518; Figure 5) *Post-hoc* tests revealed significant strength differences in extension between males and females only at baseline (*P*=0.017) but not following the five (*P*=0.091) or 10 minute (*P*=0.729)

protocols. Finally, there was an overall condition main effect for extension (*P*<0.001) and flexion

(*P*=0.004) strength, indicating muscle strength was greater at baseline for extension and lower for flexion.

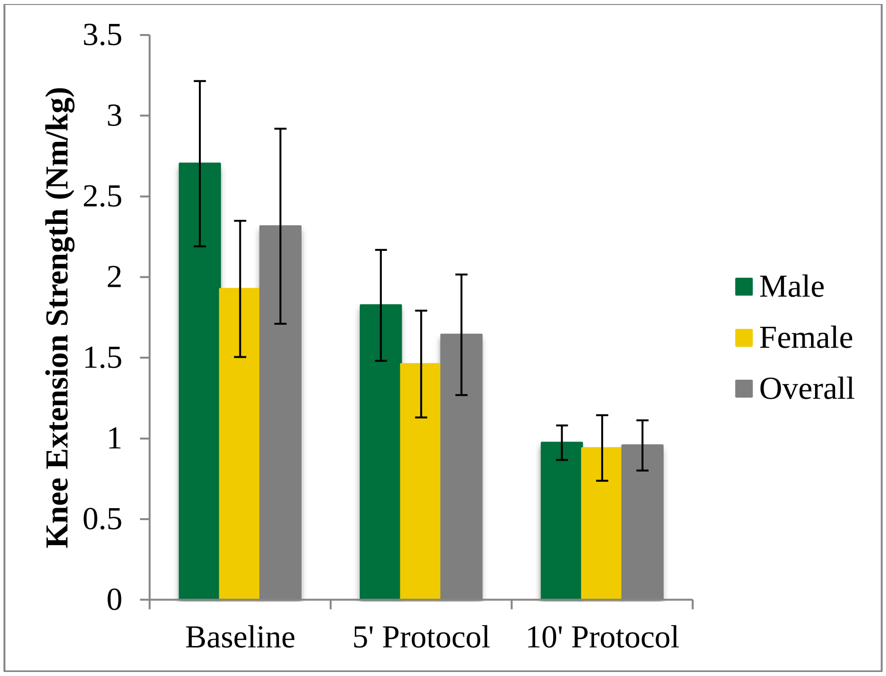

Figure 4: Knee extension strength data (mean ± standard deviation). * Indicates males demonstrated greater strength than females and baseline (P=0.017). † Indicates strength was greater at baseline than following the five and 10 minute warm-up protocols (P<0.001).

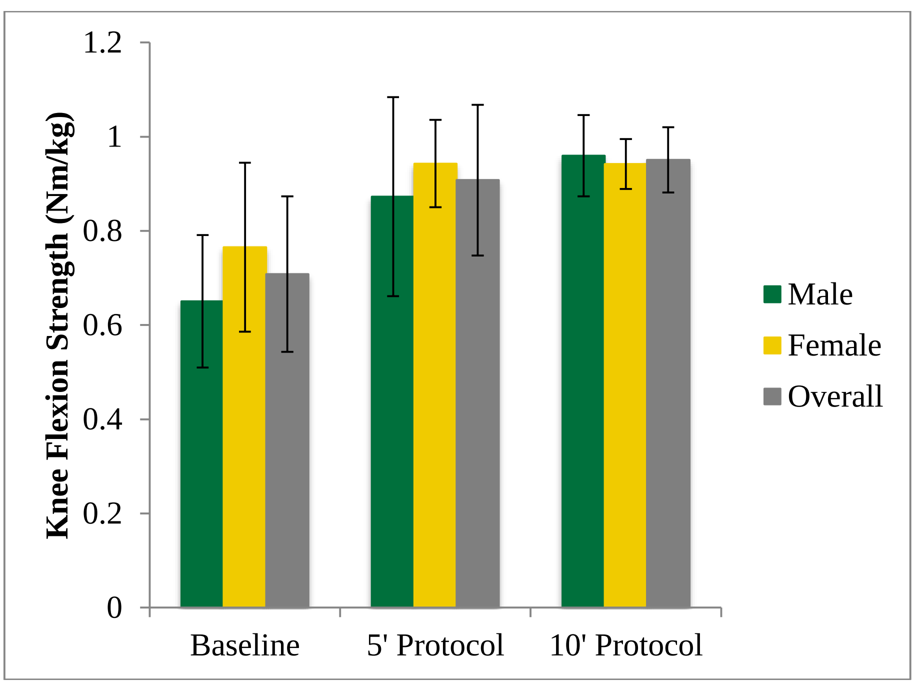

Figure 5. Knee flexion strength data (mean ± standard deviation)† Indicates strength was lower at baseline than following the five and 10 minute warm-up protocols (*P*=0.004).

Heart Rate and Rating of Perceived Exertion

Heart rate was significantly greater following the five (*P*<0.001) and ten (*P*<0.001) minute protocols compared to baseline (Figure 6). The RPE was significantly greater following both the five (*P*=0.002) and ten (*P*=0.002) minute protocols compared to baseline (Figure 6).

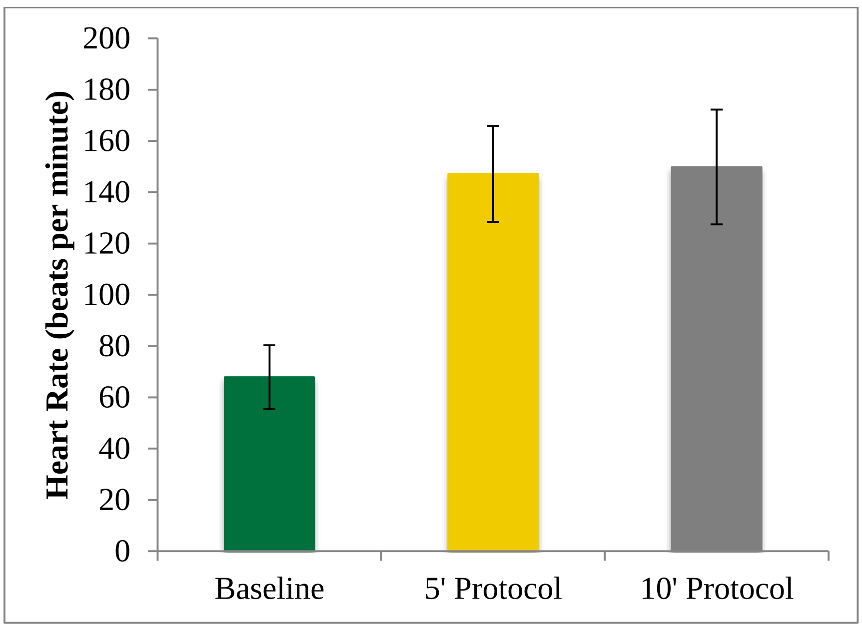

Figure 6. Heart rate data (mean ± standard deviation). † Indicates heart rate was significantly greater following the five (*P*<0.001) and ten (*P*<0.001) minute protocols compared to baseline. Solid line indicates estimated maximal heart rate for all participants.

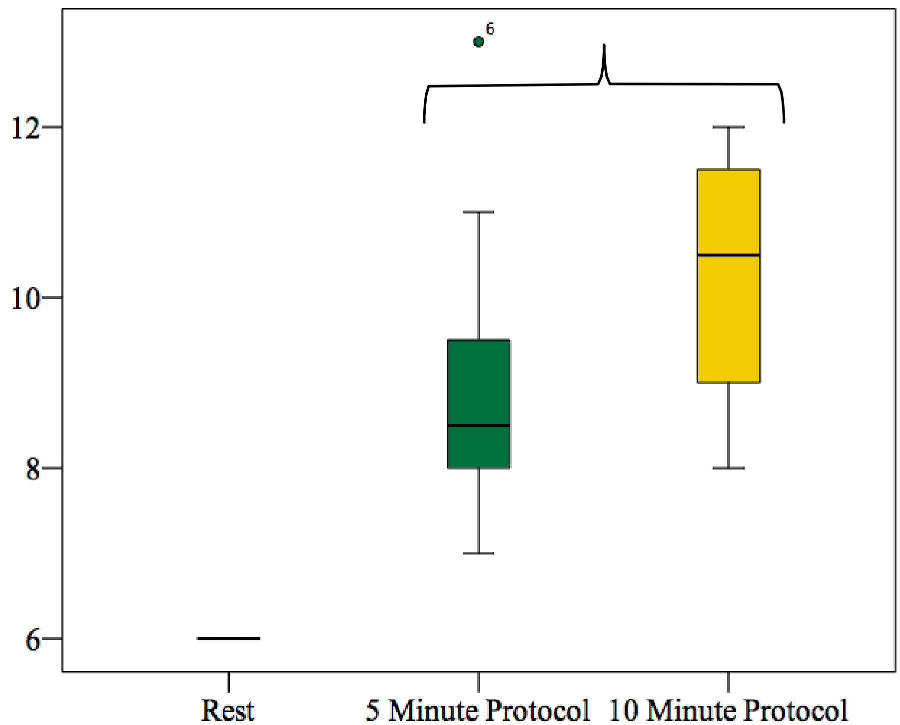

Figure 7. Box plot of RPE data (median and interquartile ranges). † Indicates RPE was significantly greater following the five (P=0.002) and ten (P=0.002) minute protocols compared to baseline

CHAPTER 5: DISCUSSION

This study sought to determine the effects of different duration dynamic warm-ups may have on vertical jump performance and muscle strength as well as heart rate and RPE. The results demonstrated no significant differences in vertical jump following either protocol. Muscle strength was not affected by the 10 minute warm-up but was adversely affected following the 5 minute program.

The results of this study differ from prior research on warm-up and performance measurements. Typically, improvements to vertical jump have been found following a warm-up session [19, 20, 21]. However, no significant changes in vertical jump were seen following either warm-up protocol. These results suggest that while the dynamic warm-up protocols employed did not enhance performance, they also did not impair performance. It is possible these programs simply did not produce the neuromuscular stimulus required for improving explosive-based movements. Results could be altered if different movement patterns were implemented. For example, dynamic stretching involving various skips, shuffles, and walking drills has been shown to improve countermovement jump height. The present study did not include a dynamic stretching component. Crow et al. found increases in peak power in the knee during an unloaded counter movement jump on a Smith machine following a targeted gluteal group warm up which included double leg bridges, quadruped lower extremity lift, and side line hip abduction [22]. Thompson et al. also found increases in vertical jump and rate of torque development in the knee extensors and flexors following a training program primarily focused on a deadlift [23]. These previous studies highlight the overall importance of hip extension during jumping tasks. Jumping is an explosive movement involving rapid triple extension at the ankles, knees, and hips. The warm-up design could also have affected the results and it is possible that had we incorporated different exercises into the warm-up protocols the outcome could have been different. Improvements to jump height have been observed following loaded and unloaded warm ups which only utilized plyometrics [20].Other studies used differing performance tasks to measure speed, agility, and other forms of jumping to examine the effectiveness of warm-up programs [4, 5]. However, these studies looked at professional and amateur soccer players who already possess higher levels of training and will respond differently to performance testing.

Similarly to the vertical jump data, there were no improvements in knee extensor strength following either duration warm up. In fact, muscle strength was greater at baseline for the knee extensors than it was following either warm-up protocol. A reduction in muscle strength would be expected in the presence of neuromuscular fatigue. In fact, muscle strength has been shown to be reduced following a single bout of maximal intensity exercise [24]. However, we do not believe participants were fatigued following either dynamic warm-up protocol. During the five-minute warm-up, participants increased their heart rates to 74% of their predicted maxima and, indicating they were exercising at a moderate intensity. This is supported by a median RPE of 8.5, suggesting a “very light” level of exertion. Similarly, during the 10 minute warm-up, participants experienced an increase in heart rate to 76% of their predicted maxima, with median RPE scores of 10.5. In both programs, heart rate increased steadily over the duration of each program. The highest recorded values were not achieved until the final minute, indicating participants were not sustaining high percentages over the entire duration (Appendix A). Collectively, these data suggest participants were working at a high intensity heart rate but felt their exercise required "light" exertion. Further, studies demonstrating reduced strength following single bouts of activity have utilized eccentric-specific movement, which are known to result in greater muscle damage than the concentric based exercises employed in the present study. Additionally, decreases in knee flexion strength would have been seen if fatigue from exercise was truly a factor. Why flexion strength improved following warm-up despite reductions in extension strength is unclear. However, it is possible the movements utilized were quad-dominant by nature and did not recruit the hamstrings to nearly the same extent. Forward lunges, when performed to fatigue, have been shown to increase activation of vastus lateralis, vastus, medialis, and biceps femoris but not semitendinosus [24]. Other authors have reported large coactivation ratios between quadriceps and hamstrings during variations of lunges and squats, suggesting greater quadriceps than hamstrings activation [25]. While the quadriceps and hamstrings do experience a degree of coactivation, this varies depending on the specific movement pattern. The movements used for this study may have had large differences in muscle activation, which might explain the differing results between flexion and extension. Future investigations may benefit from the use of electromyography to determine which muscles are being activated during dynamic warm-up activities.

While all 3 joints are important, the knee joint was isolated for this project due to ease of testing on the Biodex, the use of quadriceps and hamstrings strength in a jump, and the point of ensuring strength was not decreased in any significant way following the exercise.

Within this study, there are limitations that may have affected the outcomes. While fatigue and training effect within the study design are unlikely, the possibility of a level offatigue developing that would impair strength cannot be ruled out. Additionally, the participants were all recreational athletes but with little to no specific jump training. The results of the study could be different if a pool of more skilled athletes were used. These athletes may already have reached a maximum jump height that could only be improved with specific training.

Conclusion

Dynamic warm-ups performed at light to very light intensity did not increase vertical jump in participants. Despite no negative changes resulting from warm-up, knee extension strength did begin to decline, which may lead to decreased activity performance. Regardless, a dynamic warm-up should still be utilized for the musculoskeletal and cardiorespiratory benefits; but care should be taken when programming in order to not impair performance during the following activity.

REFERENCES

(1) Thompson WR, Gordon NF, Pescatello LS. *ACSM's Guidelines for Exercise Testing and Prescription*. Philadelphia: Lippincott Williams & Wilkins; 2010.

(2) Brunner-Ziegler S, Strasser B, Haber P. Comparison of Metabolic and Biomechanic Responses to Active vs. Passive Warm-up Procedures before Physical Exercise. *Journal of Strength and Conditioning Research*. 2011;25(4):909-914. doi:10.1519/jsc.0b013e3181d640da

(3) Perrier ET, Pavol MJ, Hoffman MA. The Acute Effects of a Warm-Up Including Static or Dynamic Stretching on Countermovement Jump Height, Reaction Time, and Flexibility. *Journal of Strength and Conditioning Research*. 2011;25(7):1925-1931. doi:10.1519/jsc.0b013e3181e73959.

(4)Little T, Williams AG. Effects of Differential Stretching Protocols During Warm-Ups on High-Speed Motor Capacities in Professional Soccer Players.*J Strength Cond Res The Journal of Strength and Conditioning Research*. 2006;20(1):203. doi:10.1519/r-16944.1.

(5) Gelen E. Acute Effects of Different Warm-Up Methods on Sprint, Slalom Dribbling, and Penalty Kick Performance in Soccer Players. *Journal of Strength and Conditioning Research*. 2010;24(4):950-956. doi:10.1519/jsc.0b013e3181cb703f

(6) Fletcher IM, Monte-Colombo MM. An Investigation into the Effects of Different Warm-Up Modalities on Specific Motor Skills Related to Soccer Performance. *Journal of Strength and Conditioning Research*. 2010;24(8):2096-2101. doi:10.1519/jsc.0b013e3181e312db..

(7) Taylor JM, Weston M, Portas MD. The Effect of a Short Practical Warm-up Protocol on Repeated Sprint Performance. *Journal of Strength and Conditioning Research*. 2013;27(7):2034-2038. doi:10.1519/jsc.0b013e3182736056.

(8) Tomaras EK, Macintosh BR. Less is more: standard warm-up causes fatigue and less warm- up permits greater cycling power output. *Journal of Applied Physiology*. 2011;111(1):228-235. doi:10.1152/japplphysiol.00253.2011.

(9) Bishop D. Warm Up II. *Sports Medicine*. 2003;33(7):483-498. doi:10.2165/00007256-200333070-00002.

(10) *National Institute of Health Bulletin*. Washington: U.S. Govt. Print. Off.

(11) Swenson DM, Collins CL, Best TM, Flanigan DC, Fields SK, Comstock RD. Epidemiology of Knee Injuries among U.S. High School Athletes, 2005/2006–2010/2011. *Medicine & Science in Sports & Exercise*. 2013;45(3):462-469. doi:10.1249/mss.0b013e318277acca.

(12) Nelson AJ, Collins CL, Yard EE, Fields SK, Comstock RD. Ankle Injuries Among United States High School Sports Athletes, 2005–2006. *Journal of Athletic Training*. 2007;42(3):381-387.

(13) Otzel DM, Chow JW, Tillman MD. Long-term deficits in quadriceps strength and activation following anterior cruciate ligament reconstruction. *Physical Therapy in Sport*. 2015;16(1):22-28. doi:10.1016/j.ptsp.2014.02.003.

(14) Sato K, Heise GD. Influence of Weight Distribution Asymmetry on the Biomechanics of a Barbell Back Squat. *Journal of Strength and Conditioning Research*. 2012;26(2):342-349. doi:10.1519/jsc.0b013e318220e0a3.

(15) Luk H-Y, Winter C, O'Neill E, Thompson BA. Comparison of Muscle Strength Imbalance in Powerlifters and Jumpers. *Journal of Strength and Conditioning Research*. 2014;28(1):23-27. doi:10.1519/jsc.0b013e318295d311.

(16) Hootman JM, Dick R, Agel J. Epidemiology of Collegiate Injuries for 15 Sports: Summary and Recommendations for Injury Prevention Initiatives. *Journal of Athletic Training*.2007;42(2):311-319.

(17) Valovich-Mcleod TC, Shultz SJ, Gansneder BM, Perrin DH, Drouin JM. Reliability and validity of the Biodex system 3 pro isokinetic dynamometer velocity, torque and position measurements. *European Journal of Applied Physiology*. 2004;91(1):22-29. doi:10.1007/s00421-003-0933-0.

(18) Heath EM. Borg's Perceived Exertion and Pain Scales. *Medicine& Science in Sports & Exercise*. 1998;30(9):1461. doi:10.1097/00005768-199809000-00018.

(19) Holt BW, Lambourne K. The Impact of Different Warm-Up Protocols on Vertical Jump Performance in Male Collegiate Athletes. *Journal of Strength and Conditioning Research*. 2008;22(1):226-229. doi:10.1519/jsc.0b013e31815f9d6a.

(20) Chattong C, Brown LE, Coburn JW, Noffal GJ. Effect of a Dynamic Loaded Warm-Up on Vertical Jump Performance. *Journal of Strength and Conditioning Research*. 2010;24(7):1751-1754. doi:10.1519/jsc.0b013e3181ddf665.

(21) Carvalho FL, Carvalho MC, Simão R, et al. Acute Effects of a Warm-Up Including Active, Passive, and Dynamic Stretching on Vertical Jump Performance. *Journal of Strength and Conditioning Research*. 2012;26(9):2447-2452. doi:10.1519/jsc.0b013e31823f2b36.

(22) Crow JF, Buttifant D, Kearny SG, Hrysomallis C. Low Load Exercises Targeting the Gluteal Muscle Group Acutely Enhance Explosive Power Output in Elite Athletes. *Journal of Strength and Conditioning Research*. 2012;26(2):438-442. doi:10.1519/jsc.0b013e318220dfab..

(23) Thompson BJ, Stock MS, Shields JE, et al. Barbell Deadlift Training Increases the Rate of Torque Development and Vertical Jump Performance in Novices. *Journal of Strength and Conditioning Research*. 2015;29(1):1-10. doi:10.1519/jsc.0000000000000691.

(24) Pincivero DM, Aldworth C, Dickerson T, Petry C, Shultz T. Quadriceps-hamstring EMG activity during functional, closed kinetic chain exercise to fatigue. *European Journal of Applied Physiology*. 2000;81(6):504-509. doi:10.1007/s004210050075.

(25) Begalle RL, DiStefano LJ, Blackburn T, Padua DA. Quadriceps and Hamstrings Coactivation During Common Therapeutic Exercises. *Journal of Athletic Training*. 2012;47(4):396-405.

APPENDIX A: VERTICAL JUMP HEIGHT DATA

Table A1. Vertical jump height data (mean ± standard deviation) for all study time points.

	Overall	
Baseline (cm)	276.22±29.20	
5 minute warm up (cm)	277.49±30.50	
10 minute warm up (cm)	278.34±30.50	

Table A2. Knee extension strength data (mean ± standard deviation) for all study time points.

	Male	Female	Overall
Baseline (Nm/kg)	2.70±0.51	1.93±0.42	2.31±0.60
5 minute warm up (Nm/kg)	1.83±0.34	1.46±0.33	1.64±0.37
10 minute warm up (Nm/kg)	0.97±0.16	0.94±0.20	0.96±0.16

Table A3. Knee flexion strength data (mean ± standard deviation) for all study time points.

	Male	Female	Overall
Baseline (Nm/kg)	0.65±0.14	0.77±0.18	0.71±0.17
5 minute warm up (Nm/kg)	0.87±0.211	0.94±0.09	0.91±0.16
10 minute warm up (Nm/kg)	0.96±0.09	0.94±0.05	0.95±0.07

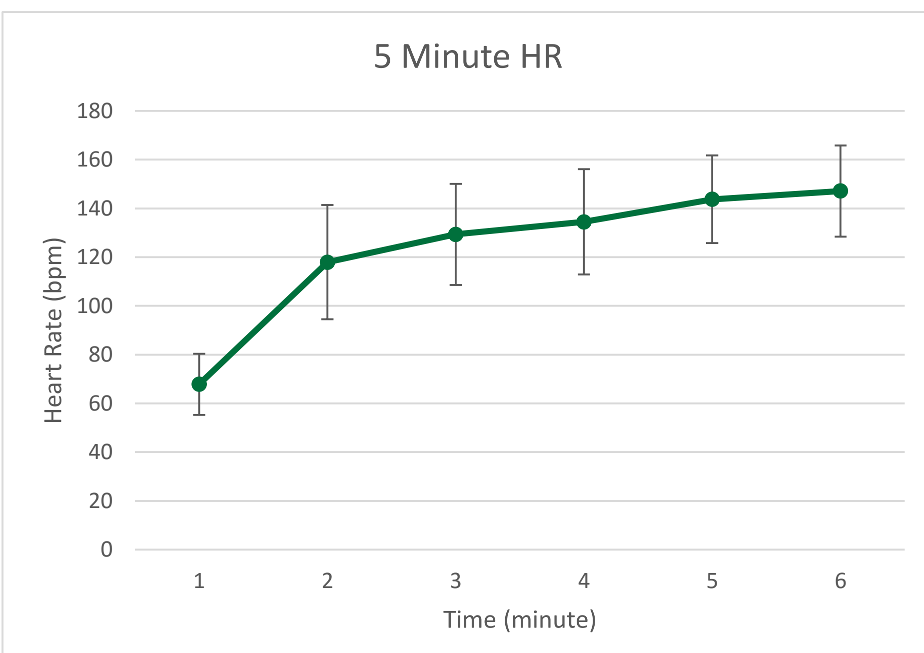

Figure A1, Heart rate data for five minute warm-up

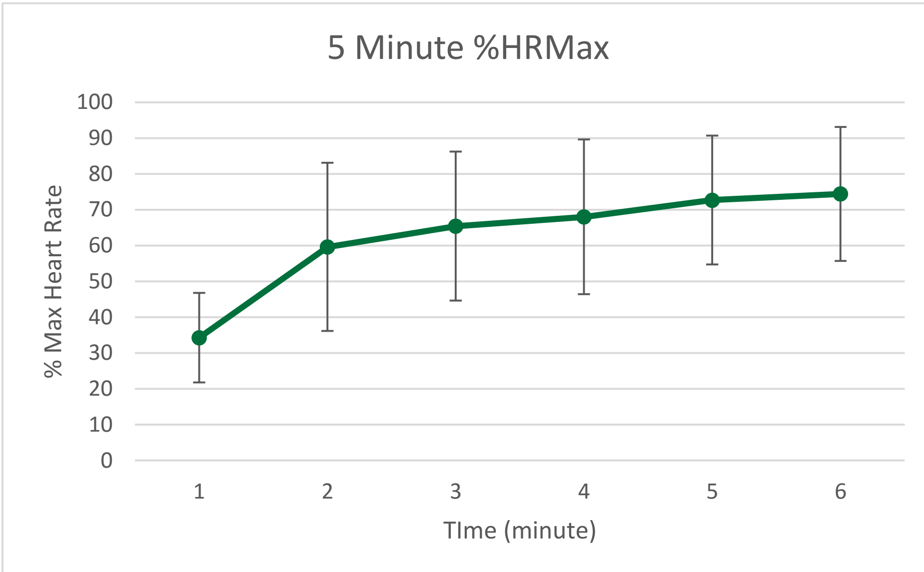

Figure A2: Percent max heart rate data for five minute warm-up

Figure A3. Heart rate data for 10 minute warm-up

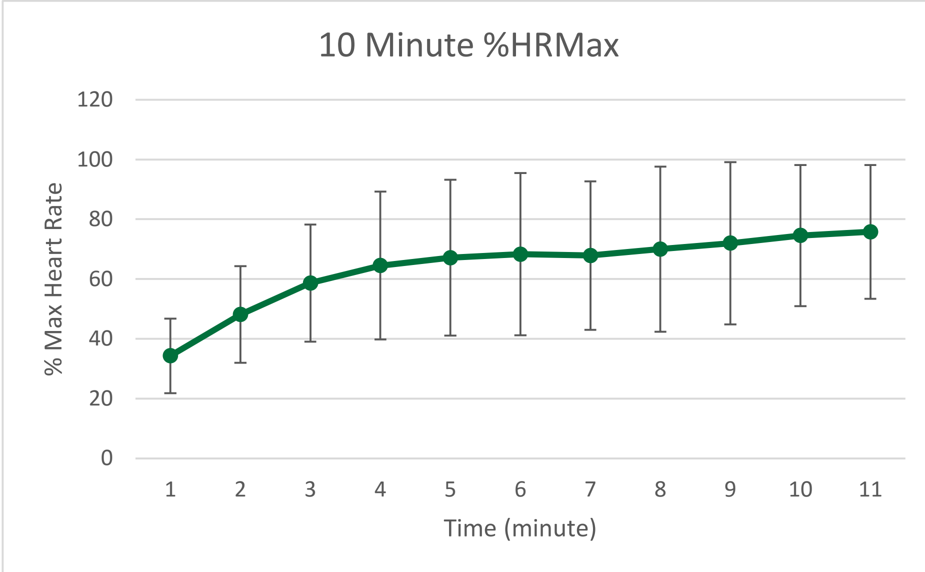

Figure A4, Percent max heart rate data for 10 minute warm-up

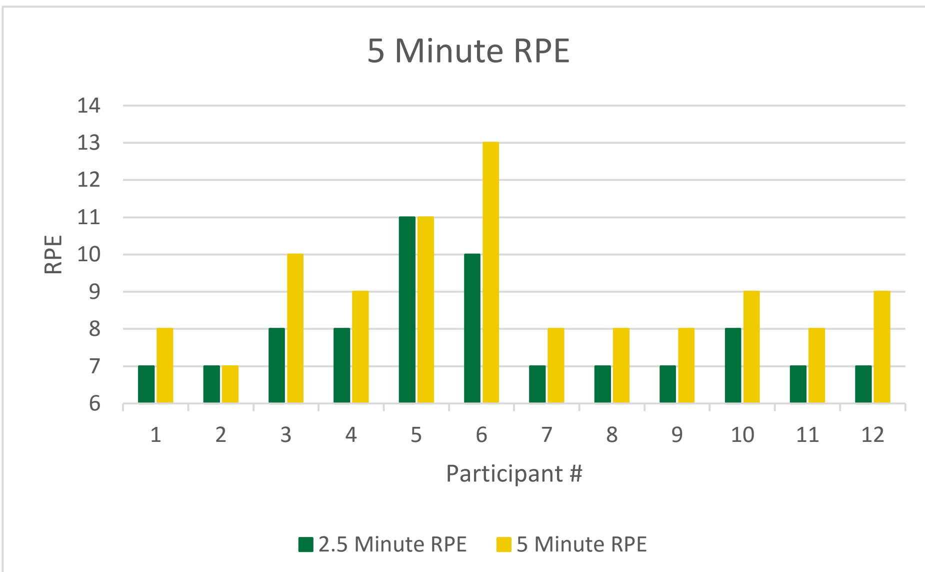

Figure A5. RPE data for five minute warm-up for each participant

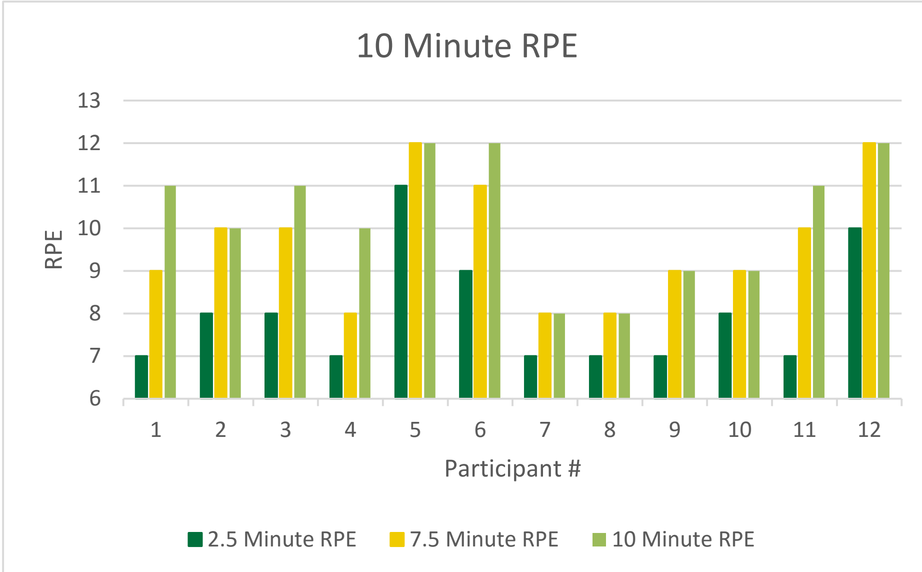

Figure A6. RPE data for ten minute warm-up for each participant