THE EFFECT OF STATIC STRETCHING WARM-UP AND DYNAMIC STRETCHING WARM-UP ON ANAEROBIC POWER PERFORMANCE OF CYCLISTS

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Lindy Lunkenheimer, daughter of Tim and Tina Tompkins, was born on September 9, 1984, in Aransas Pass, Texas. She graduated from Pike Liberal Arts High School, Troy, AL in 2002. She graduated from Huntingdon College, Montgomery, AL, with a Bachelor of Arts in Human Performance and Kinesiology. After four years, in May 2006, she graduated as a member of Pi Alpha Sigma Honors Society. Upon completion of her undergraduate degree she entered Graduate School at Auburn University Montgomery to study a Master of Education in Exercise Science starting Fall 2006.

THESIS ABSTRACT

THE EFFECT OF STATIC STRETCHING WARM-UP AND DYNAMIC STRETCHING WARM-UP ON ANAEROBIC POWER PERFORMANCE OF CYCLISTS

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Traditionally, static stretching before exercise has been performed in an effort to prevent injury and enhance performance. Recent studies, however, suggest that static stretching may actually decrease athletic performance. Dynamic stretching, on the other hand, has been shown to increase athletic performance when executed before performance testing, e.g., vertical jump test, jump power, agility, strength and explosive force production. Currently, no studies have examined the effects of both types of stretching on the Wingate anaerobic cycle test. Therefore, the purpose of this study is to determine the effects of static stretching techniques and dynamic range of motion activities on anaerobic performance. Five male and five female recreationally active cyclists between that ages of 18 and 61 years participated in this study. Subjects performed a total of five Wingate anaerobic cycle tests: two following static stretching, two following dynamic stretching, and one following a control warm-up with no stretching. At least 48 hours was given between each Wingate test. Repeated measures ANOVA under three conditions was used to compare the mean change in performance outcomes between the three different warm up protocols. A follow-up LSD post hoc test was performed to pinpoint the significance. The level of significance was set at $p \leq 0.05$. Data collected includes mean anaerobic power during the thirty second Wingate anaerobic cycle test, peak anaerobic power and fatigue index. Results showed there was a significant difference in peak power output following a dynamic stretching warm-up when compared to the control warm-up, but there was not a significant difference when dynamic stretching was compared to the static stretching warm-up. There was not a significant difference in peak power between the control warm-up and the static stretching warm-up. ($p \leq 0.05$). Peak power output following the dynamic stretching warm-up was 646.02W ± 76.12W. Peak power output following the static stretching warm-up was 615.9W ± 72.67W and peak power output following the control warm-up was 593.1W± 71.12W. In addition, no significant difference in mean power or fatigue index was shown among any of the three warm-up protocols. Significant correlations were found between mean power output and peak power output during the Wingate anaerobic cycle test and leg press, leg extension and leg flexion maximum following all three of the warm-up conditions. There was a significant correlation between fatigue index of the Wingate anaerobic cycle test and leg press, leg extension and leg flexion maximum following the control warm-up, but there was no significant correlation following the static stretching warm-up or the dynamic stretching warm-up.

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My deepest appreciation goes to my family who has stood by me over the past six years. To my parents, your support and positive encouragement mean more than you will ever know. To my brothers and sisters, I cannot imagine stronger allies.

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INTRODUCTION

Brief Literature Review

It has traditionally been accepted that static stretching before exercise reduces the risk of injury and enhances sport performance. Recent literature, however, supports the idea that static stretching before exercise decreases performance (4, 7, 12, 17, 18). In addition, recent literature suggests that dynamic stretching enhances athletic performance (4, 5, 9, 12, 15, 16, 17). Therefore, the purpose of this study was to compare the effects of static stretching and dynamic stretching on the Wingate anaerobic cycle test.

The current study also sought to determine if there was a significant correlation between leg strength and mean power, peak power and fatigue index of the Wingate anaerobic cycle test following each of the three warm-up conditions. Recent literature has supported the idea that greater strength allows for greater power output. (10).

A recent study compared the effect of dynamic and static stretching warm-up on power and agility performance. Thirty cadets from the United States Military Academy participated in a dynamic stretching and static stretching warm-up, followed by three performance tests: t-drill, 5-step jump, and medicine ball throw. The results suggested that the dynamic warm up improved power and agility performance more than either static stretching as a warm-up or no warm-up at all. (9).

A study evaluated the effects of static stretching, proprioceptive neuromuscular facilitation stretching (PNF) and maximum voluntary contraction on force production and jumping performance. Results showed a significant decrease in jump performance and force production as a result of static stretching when compared to both PNF and maximum voluntary contraction warm-up (19). Results of another study on force production were similar. Running, static stretching and practice jumps were used as warm-ups before testing force production and jumping performance. The outcome was a significant decrease in jumping performance when preceded by static stretching (18).

A study on the effect of static and dynamic stretching exercises on the maximal isokinetic strength of the knee flexors and knee extensors yielded comparable results. The study evaluated the effect of each stretching warm-up with the isokinetic torque of the knee extensor and knee flexor muscles. Results showed a significant decrease in maximal isokinetic torque following static stretching. (13). Another study compared the effects of static stretching and dynamic stretching on leg extension power and found similar results. Dynamic stretching improved leg extension power when compared to static stretching. (17).

Studies have shown that dynamic stretching had a positive effect on performance. Sprint performance was measured by assessing the effects of static stretching and dynamic stretching on a 20 meter sprint. Dynamic stretching showed a significant decrease in sprint time when compared to no stretching, while static stretching had no significant difference. (4).

Though research has not shown the difference in effects of static stretching and dynamic stretching on cycling performance, the effect of static stretching on leg power during cycling has been assessed. A study by O'Connor et.al. showed that peak power and total work were significantly greater as a result of static stretching when compared to the control warm-up. (12).

Research has shown significant correlations between muscle strength and power output. A recent study examined the relationships between stretch-shortening cycle performance and maximum muscle strength. Results showed a significant correlation between one-repetition maximum bench press and muscle contraction velocity of the bicep curl at forty percent of maximum voluntary contraction. (10).

Purpose of Study

Research yields mixed evidence on the effect of static stretching and dynamic stretching on anaerobic performance. No studies have been done to compare the effect of static stretching versus dynamic stretching on the Wingate test for anaerobic power. The Wingate test for anaerobic power is a supramaximal anaerobic power test to evaluate maximal rate at which glycolysis can deliver ATP. It assesses mean power, peak power, and fatigue index. The purpose of this study was to determine the effect of static stretching and dynamic stretching on the Wingate test for anaerobic power. In addition, this study examined the correlations between leg press, leg extension and leg flexion maximum and the mean power, peak power and fatigue index of the Wingate anaerobic cycle test following control warm-up, static stretching warm-up and dynamic stretching warm-up.

Hypotheses

There will be no significant difference in mean power between the control warm-up, the static stretching warm-up and the dynamic stretching warm-up. There will be no significant difference in peak power between the control warm-up, the static stretching warm-up and dynamic stretching warm-up. There will be no significant difference in total work between the control warm-up, the static stretching warm-up and dynamic stretching warm-up. There will be no significant difference in fatigue index between the control warm-up, the static stretching warm-up and dynamic stretching warm-up. There will be no significant correlation between leg press, leg extension and leg flexion maximum and mean power, peak power and fatigue index of the Wingate anaerobic cycle test following the control warm-up. There will be no significant correlation between leg press, leg extension and leg flexion maximum and mean power, peak power and fatigue index of the Wingate anaerobic cycle test following the static stretching warm-up. There will be no significant correlation between leg press, leg extension and leg flexion maximum and mean power, peak power and fatigue index of the Wingate anaerobic cycle test following the dynamic stretching warm-up. The level of rejection will be $p \leq 0.05$.

REVIEW OF LITERATURE

Power Performance

O'Connor, D.M., Crowe, M.J., & Spinks, W.L (2006). Effects of static stretching on leg power during cycling. *Journal of Sports Medicine and Physical Fitness. 46*, 52-56.

The purpose of the study was to determine the effects of static stretching on leg power during cycling. The independent variables were the stretching protocol: static stretching or moderate paced jog. The dependent variables were peak power, time to peak power, and total work.

Sixteen male volunteers and 11 female volunteers with an average age of 21.4 and an average weight of 71.8 kg from a university participated in the study. All were healthy and free of injury. Each gave written, informed consent.

Subjects participated in a pre-session to become familiarized with each stretch. Each subject then attended two sessions no more than 24 hours apart. A leg power test was given after either a five minute moderate jog or a 15 minute static stretching protocol. The leg power test consisted of ten seconds of cycling at 5, 20, 40, and 60 minutes after the warm up. Peak power relative to body weight, time to peak power, and total work relative to body weight were assessed.

A five minute moderate-paced cycle was considered the control warm-up. It was performed on an air-braked cycle ergometer with 50 W for females and 75 W for males. The static stretching protocol took place after a five minute warm-up on the cycle ergometer. It consisted of 11 lower body static stretching exercises and lasted approximately 15 minutes.

A 2x4 (condition x time) factorial ANOVA with repeated measures was used to analyze all data. T-tests were used to compare pairwise posthoc. All analyses were executed by use of the SPSS for Windows software. The level of significance was set at $P < 0.05$.

Results showed that peak power for all four leg power tests was significantly higher after the static stretching warm up. Greatest peak power was accomplished within five minutes, but significantly decreased within forty minutes. In addition, static stretching allowed for a significant decrease in the time taken to reach peak power as compared to the control warm up. Total work achieved was significantly greater after static stretching than it was after the control warm up.

The intention of the study was to determine whether a static stretching warm up would benefit the performance of power and work output. Results support the idea of static stretching as a warm-up. In addition, peak power could be reached more quickly as a result of incorporating static stretching during warm up. Results of peak power can be compared to the results of the Wingate test in an effort to confirm whether static stretching should be incorporated during warm-up to enhance performance.

Yamaguchi, T., Ishii, K., Yamanaka, M., & Yasuda, K. (2007). Acute effects of dynamic stretching exercise on power output during concentric dynamic constant external resistance leg extension. *Journal of Strength and Conditioning Research, 21*, 1238-1244.

The purpose of the study was to determine the acute effects of dynamic stretching exercise on power output during concentric dynamic constant external resistance leg extension. The independent variables were the two warm-up protocols: dynamic movements and the non-stretching treatment. The dependent variables were the results of power output of three loads: 5, 30, and 60 percent of maximum voluntary contractile torque with isometric leg extension.

Participants included twelve healthy, recreationally active male students with an average age, height and weight of 24.1 years, 171.8cm and 62.0kg. All participants were free of injury and not active in a regular training schedule. Informed consents were signed prior to beginning the study which was approved by the ethics committee in the Graduate School of Education, Hokkaido University.

The dynamic stretching treatment involved four exercises in a standing position: two stretched the right leg extensors while two imitated the leg extension movement. Each exercise was performed five times: five times slowly and ten times as quickly as possible. A thirty second standing rest was given between each exercise. Order of stretching was as follows: buttock kick, leg extension posterior aspect of body, thigh up, and finally leg extension anterior aspect of body. Duration of the entire dynamic stretching warm-up was about eight minutes. The control, non-stretching warm-up consisted of an eight minute seated rest.

In order to examine the difference between the data under each load following both the dynamic stretching warm-up and the non-stretching, seated control warm-up, a paired t-test was used. Pearson's correlation coefficient was used to examine relationships between the data. Level of significance was set at $p \leq 0.05$.

Results showed that peak power following the dynamic stretching warm-up increased significantly compared to the peak power following the non-stretching warm-up under all three loads: 5, 30, and 60 percent of maximum voluntary contraction. Torque and velocity at peak power, however, differed among the three loads. Torque was significantly greater under the 5 percent load following the dynamic stretching warm-up, but velocity was not significantly greater. Torque and velocity following the 30 percent of maximum voluntary contraction load was not significantly greater after dynamic stretching, but it did tend to be higher. Torque and velocity of the 60 percent of maximum voluntary contraction load, though, was significantly greater as a result of dynamic stretching when compared to the control warm-up. No significant difference was shown in time to peak power output under any of the three testing conditions.

This study supports the idea that dynamic stretching increases anaerobic power, specifically concentric leg extension power. Results of this study can be compared to the results of dynamic stretching before performing the Wingate anaerobic cycle test in an effort to determine if dynamic stretching does, in fact, increase anaerobic power performance.

Tanagycgu, T., Ishii, K., Yamanaka, M., & Yasuda, K. (2006). Acute effect of static stretching on power output during concentric dynamic constant external resistance leg extension. *Journal of Strength and Conditioning Research, 20*, 804-810.

The purpose of the study was to determine the effect of static stretching on muscular performance, or power output, during concentric dynamic constant external resistance leg extension under various loads. The independent variables were the two types of pretreatment or warm-up: static stretching and no stretching warm up. The dependent variables were the outcomes of each test using different loads.

Twelve healthy men with an average age, height, and weight of 23.8 years, 173.2 inches, and 64.1 kg participated in the study. None of the subjects suffered from injury to the lower extremities. They did not take part in a consistent exercise routine, but did participate in recreational activities. All subjects gave informed consent after being made aware of the methods and purpose of the study as well as the risks involved. The ethics committee of Hokkaido University approved the study.

Subjects participated in a total of three testing days, with three to seven days of rest between each. Day one was simply an instruction and assessment day. The tester assessed the maximum voluntary contractile (MVC) torque using isometric leg extension. Also tested was concentric DCER leg extension power output. On day two participants took part in one of two types of warm-ups: six static stretching exercises on the leg extensors or twenty minutes of sitting. The warm-up was determined at random, and each subject did the opposite warm-up on day three. To evaluate power output, loads of the leg extension machine were set to five, thirty, and sixty percent of the MVC torque assessed on day one. The peak power output during each load was compared with both types of warm-up in an effort to determine the effects of static stretching on the power output of leg extensors using concentric DCER leg extensions.

In order to observe the differences between the data collection of static stretching warm- up and no stretching, the paired t-test or Wilcoxon signed rank test was used. The level of significance was set at $p \leq 0.05$.

The torque at peak power and the peak torque value of the maximal voluntary contractile did not show a significant difference between static stretching and no stretching under the various load settings. Also observed were no significant differences in the mean time to peak torque between each warm-up. The velocity at peak power, however, was significantly slower after static stretching compared to no stretching. In addition, the peak power was significantly lower after static stretching with each load.

The intention of the study was to conclude whether static stretching had a positive or negative effect on power output of leg extension. The results showed that static stretching does in fact decrease peak power. Comparing results of the effect of static stretching and dynamic stretching on the Wingate anaerobic test with this study will aid in determining the effect of different stretching protocol as a warm-up on performance.

Yamaguchi, AuthorTaichi, & Ishii, Kojiro (2005). Effects of static stretching for 30 seconds and dynamic stretching on leg extension power. *Journal of Strength and Conditioning Research. 19*, 677 -683.

The purpose of this study was to determine the effects of static stretching, dynamic stretching, and no stretching on power performance, or leg extension power. The independent variables of the study were the type of stretching involved: static stretching, dynamic stretching, or no stretching. The dependent variables were the results of the leg extension power after each stretching protocol.

Participating in this study were 11 male college students with a mean age, height, and weight, of 22.8 years, 173.3 cm, and 65.9 kg. All participants were active in recreational activities and were free of injury. None were participating in regular weight training or stretching routines at the time of the study. Every participant, however, had a history of weight training. All participants gave informed consent to begin the study after being informed of the purpose and methods of the study as well as any risks involved. The ethics committee of the Graduate School of Education, Hokkaido University approved the study.

Subjects participated in a training session before beginning the study. Instruction as to how to use the leg extension power measurement system was given and subjects performed the movement until he felt comfortable and did it correctly.

The study took place on three separate days. Static stretching, dynamic stretching, and no stretching were performed at random. The five muscle groups targeted during stretching were hip extensors, plantar flexors, hip flexors, hamstrings, and quadriceps. The duration of the stretching protocol was 500 seconds. For the no stretching warm-up, the subject simply rested for 500 seconds before performing the leg extension exercise.

Each subject's waist and ankles were fastened by Velcro straps as he sat on the seat placing both feet on the footplate. The load equaled the weight of the subject. Subjects pushed the footplate by extending both legs as quickly and with as much power as possible. This was repeated five times, both before and after each stretching protocol.

The mean of the two highest assessments was considered to be the subject's leg extension power. Therefore, each subject had a total of six leg extension power measurements.

A leg extension power measurement system was used to measure leg extension power. The system controlled the footplate load so that it was equal on both legs. In addition, it measured velocity and time to maximum velocity in order to compute explosive power.

The leg extension power in both stretching conditions as well as the non stretching condition was compared by use of repeated measures analyses of variance. If there was indication of significant relation, paired t-tests were used to determine the difference in leg extension power. Pearson's correlation coefficient tests were used to tell the relationship between leg extension power before and after both stretching protocols as well as no stretching. The level of significance was $p \leq 0.05$.

Results showed that leg extension power was no different between static stretching and no stretching. Dynamic stretching, however, improved the performance of leg extension power.

Leg extension power is used in jumping movements, such as the vertical jump. Therefore, the results of this study show that dynamic stretching before activities that require jumping would result in greater performance than would static stretching. The study on the effect of static stretching and dynamic stretching warm-up on the Wingate test for anaerobic power could be compared with this study to see if similar results are shown for the effect of static stretching and dynamic stretching on performance.

Brandenburg, J.P. (2006).Duration of stretch does not influence the degree of force loss following static stretching. *Journal of Sports Medicine and Physical Fitness. 46*, 526-534.

The purpose of the study was to determine if different static stretching durations had an effect on muscle performance. The independent variables were the durations of static stretching protocol: 15 seconds per stretch or 30 seconds per stretch. The dependent variables were the outcomes of each strength test.

Ten males and six females with at least one year of resistance training experience volunteered to participate in this study. All were free of injury and had no pain around the knee area.

Subjects visited the laboratory a total of four times. The first two visits were considered preliminary sessions where subjects became familiar with the experiment. Peak isometric force of the strength test was collected after a standard warm-up on the second day. The second two visits were used for testing. During the testing sessions, subjects performed a standard warm-up, a strength test, and a post-stretch. Subjects were selected at random to perform either the 15 second duration static stretching protocol or the 30 second duration static stretching protocol on each day.

Subjects lied in a prone position on top of a table with their feet and ankles hanging off the edge when beginning the strength test. A pad was placed under the hips and thighs in an effort to minimize lower back pain or discomfort. Each subject was given three chances to flex the knee and gain peak isometric force. The highest value was taken. A two way ANOVA was used to perform a Test-retest reliability of force for each muscle action. The level of significance was set at $P < 0.05$.

Results showed a decrease in peak isometric force after both the 15 second duration static stretching protocol (6.7 percent) and the 30 second duration static stretching protocol (6.1 percent) when compared to the standard warm-up. According to this study, static stretching, no matter the duration, decreased strength performance. The results of the study on the difference in static stretching warm-up and dynamic stretching warm-up on the Wingate test for anaerobic power can be compared with the results of this test as a way to gain knowledge about which stretching protocol is best for performance.

Kokkonen, J., Nelson, A.G., & Cornwell, A. (1998). Acute muscle stretching inhibits maximal strength performance. *Research Quarterly for Exercise and Sport. 69*, 411-415.

The purpose of the study was to determine the effects of acute muscle stretching on maximal strength performance. The independent variables were acute muscle stretching warm- up and no warm-up. The dependent variables were the results of the maximal strength performance tests: knee-flexion and knee-extension.

Fifteen male and 15 female college students with an average age of 22 participated in the study. None of the participants had a consistent stretching or exercise routine. Each participant gave written and oral consent before participation. The study was approved by the appropriate institutional review board.

Subjects performed a 1RM knee-flexion and knee-extension on two successive days. Either a static stretching warm-up or no warm-up was completed prior to the testing. No warm- up involved ten minutes of quiet sitting while the static stretching warm-up involved twenty minutes of stretching the hip, thigh, and calf muscles.

Participants performed three sets of five stretches, resting approximately five seconds between each set. All stretches were finished in 15 minutes, followed by a 10 minute resting period. The type of warm-up performed was assigned at random, with half of the subjects performing static stretching on the first day and the other half quietly sitting on the first day. On the second day, participants simply changed warm-ups. The knee-flexion 1RM was performed while in the prone position using the Nautilus knee-flexion machine. The knee-extension 1RM was performed while in a seated position on a Nautilus knee-extension machine.

In order to test 1RM for knee-flexion for women, the initial weight was set at 30lb. It was then increased to 50 lbs, next 60 lbs, and 70 lbs. Once the participant was able to lift 70lbs, the weight was increased by 5 lbs until she could no longer flex the knee. For men, the initial weight was 50 lbs. It was increased to 80 lbs, then 100 lbs, and 110 lbs. Once this weight was successfully lifted, the weight was increased by 10 lbs until the participant could no longer lift it.

In order to test 1RM for knee-extension for men, the initial weight was set at 50 lbs. Next, it was increased to 80 lbs, then 100 lbs, and 110 lbs. After reaching this, the weight was increased by 5 lbs until the participant could no longer lift the weight. For men, the initial weight was 80 lbs. It was increased to 120 lbs, then 150 lbs, followed by 170 lbs. The weight was then increased by 5 lbs until the participant could no longer lift the weight.

Paired t-tests were used to analyze the 1RM measurements. The level of significance was set at $p < 0.05$.

Results showed that the static stretching warm-up resulted in a significant decrease in both knee-flexion 1RM and knee-extension 1RM. The average decline for knee-flexion 1RM due to static stretching was 7.3 percent. The average decline for knee-extension 1RM due to static stretching was 8.1 percent.

The purpose of this study was to determine whether a static stretching warm-up was beneficial in 1RM performance for both knee-flexion and knee-extension. Results showed that static stretching had a significant decrease on performance when compared with a no stretching warm-up. Comparing results of the study evaluating the effect of a static stretching warm-up with a no stretching warm-up with the results of this study will give more information on which type of stretching warm-up is most beneficial in enhancing performance.

Papadopoulos, G., Siatras, T., & Kellis, S. (2005). The effect of static and dynamic stretching exercises on the maximal isokinetic strength of the knee extensors and flexors. *Isokinetics and Exercise Science. 13*, 285-291.

The purpose of the study was to determine the effect of static stretching and dynamic stretching warm-ups on the maximal isokinetic strength of both the knee extensors and knee flexors. The independent variables included the type of stretching warm-up: general warm-up, static stretching and dynamic stretching. The dependent variables were the maximal isokinetic strengths of both knee flexion and knee extension.

Thirty two adult males with an average age, height and mass of 20.7 years, 178.6 cm and 76.1 kg volunteered to participate in this study. All were free of injury and kept away from strength training at least two days before testing. Before participation, each subject signed an informed consent. The Institutional Review Board approved the study.

A pre-testing day took place in order for participants to become familiarized with the dynamometer. Each subject was give three sub-maximal and three maximal knee flexions and knee extensions on the machine.

The three testing days were non-consecutive. Warm up protocols included a general warm-up, general warm-up with static stretching, and general warm-up with dynamic stretching. The general warm-up consisted of a five minute warm on a cycle ergometer with a resistance of 50W. Both static stretching and dynamic stretching lasted a total of 4.5 minutes. Participants were assigned at random to a particular warm-up group each testing day. Following each warm-up was a measurement of hip and knee flexion range of motion as well as maximal isokinetic torque production of knee flexion and knee extension. A Myrin goniometer was used to test range of motion and a Cybex Norm Lumex Corporation dynamometer was used to test maximal isokinetic torque. Three torque scores for both knee flexion and knee extension were taken and the best score was recorded as maximal isokinetic torque.

A one-way analysis of variance (ANOVA) for repeated measures was used to determine the effect of each warm-up protocol on knee flexion and extension. To determine maximal isokinetic torque of knee flexor and knee extensor muscles, a two-way ANOVA repeated measures (3X2) was used. A Tukey post-hoc test was used to analyze significant differences. Level of significance was set at $p<0.05$.

Results showed no significant difference in hip and knee range of motion as a result of the three warm up protocols. There was, however, a significant decrease in maximal isokinetic torque of knee flexion and knee extension when preceded by static stretching. There was no significant difference between the general warm-up and the general warm-up with dynamic stretching.

The focus of this study was the acute effect of static stretching and dynamic stretching on knee flexor and knee extensor maximal isokinetic torque. Results showed that static stretching has a negative effect on performance. These results can be compared with the results of the study on the effect of static stretching and dynamic stretching on the Wingate anaerobic cycle test, giving more information on the importance of the two types of stretching warm-up protocols.

Power and Agility Performance

McMillian, D.J., Moore, J.H., Hatler, B.S., & Taylor, D.C. (2006). Dynamic vs. static-stretching warm up: The effect of power and agility performance. *National Strength and Conditioning Association, 20*, 492-499.

The purpose of the study was to determine if power and agility were affected by dynamic warm-up, static stretching warm-up and no warm-up. The independent variable was the type of warm-up used prior to testing the performance of subjects: dynamic, static stretching, and no warm-up. The dependent variables were the results or scores of the three performance tests: T-drill, 5-step jump, and medicine ball throw.

The United States Military Academy had 30 cadets volunteer to participate in the study. All subjects actively participated in rugby, lacrosse, or strength and conditioning teams on a weekly basis. Each cadet was fit for full military duty with no limitations. Cadets were excluded if he or she had spine or lower extremity impairment, balance disorder, vestibular dysfunction, history of surgery in either of the lower extremities, or history of a neurological disorder. Participating were 16 men and 14 women. The average age, height, and weight for men was 20.2 years, 182.4 cm, and 88.8 kg. The average age, height, and weight for women was 20.4 years, 167.1 cm, and 64 kg. Written, informed consent was given prior to participation. The Human Subjects Research Review Board of Keller Army Community Hospital, West Point, NY approved the study.

A 2-part orientation was given before subject participation. The session included training for the dynamic warm-up and the static stretching warm-up as well as practice of the three performances being measured: T-drill, 5-step jump, and the medicine ball throw. Subjects repeated the events until their scores no longer improved in order to allow the participant to fully master the skill. A rest of approximately two minutes was given between each T-drill. Between thirty and sixty seconds was given between each 5-step jump as well as the medicine ball throw.

The warm up sessions took place in small groups with the dynamic warm-up led by the primary investigator and the static stretching warm-up led by an associate investigator. When no warm-up was given, subjects rested in an area next to the testing location. The order in which the subjects performed the warm-ups was offset in an effort to avoid possible biasing effects. Each warm-up session lasted ten minutes.

The appropriate sample size was determined by use of the pre hoc power analysis. Analysis of variance was used to assess the effect of three different warm-ups on three performance skills. Tukey's honestly significant difference was used for post hoc analysis. The statistical significance of this study was $p \leq 0.05$.

Results of the study showed that gender had no significant effect; therefore, data for the post hoc testing collapsed. Tukey's HSD showed that dynamic warm-up had a much greater effect on power and agility performance than did the static stretching warm-up or no warm-up on all three performance tests: $p < 0.01$. The medicine ball throw and the T-drill showed no significant difference between static stretching warm-up and no warm-up. The 5-step jump, however, yielded better scores after the static stretching warm-up than no warm-up.

The study compared the results of different power and agility measures after a dynamic stretching warm-up, static stretching warm-up, and no warm-up. The goal was to determine which warm-up would be best to perform before participating in power and agility activities. The conclusion of the study was that dynamic stretching warm-up was better than both static stretching and no warm-up. Results of this study could be compared with the results of the proposed study of static versus dynamic stretching on the Wingate test for anaerobic power in an effort to determine the best possible warm-up for overall power performance.

Jumping Performance

Young, A. W., & Elliott, S. (2001). Acute effects of static stretching, proprioceptive neuromuscular facilitation stretching, and maximum voluntary contractions on explosive force production and jumping performance. *Research Quarterly for Exercise and Sport. 72*, 273-279.

The purpose of this study was to determine the acute effects of static stretching, proprioceptive neuromuscular facilitation stretching, and maximum voluntary contractions on explosive force production and jumping performance. The independent variables were the four types of warm-ups used prior to testing jump performance: static-stretching, proprioceptive neuromuscular facilitation stretching (PNF), maximum voluntary contractions (MVC), and the control condition involving a four minute rest. The dependent variables were the results of each jump test: squat jump and drop jump.

Fourteen male subjects with an average age, height, and body mass of 22 years, 183 cm, and 82.1 kg participated in the study. Each had at least one season of experience in a sport that required a consistent jumping performance. These sports included track and field, football, and field hockey. The Human Research Ethics Committee of the University of Ballaret approved the study and all subjects provided written, informed consent.

During static stretching, the tester passively stretched the subject until he felt an onset of pain. The stretch was then held for 15 seconds. The participant then rested for 20 seconds. This cycle continued three times for three muscle groups: triceps surae, gluteals, and quadriceps. All stretching protocols focused on these three muscle groups and in the same order. PNF stretching took on the structure of contract-relax. The tester held the stretch for five seconds against resistance, and then pressed it beyond the onset of pain for fifteen seconds. The stretch was then held for 20 seconds. This was repeated three times. The MVC included a five second maximal isometric contraction of each of the three muscle groups against an immovable wooden block. The control condition was a four minute rest period. All four warm ups took place after a five minute jog.

After one of the four warm ups, subjects participated in two vertical jump tests: squat jump and drop jump. Participants held a 10kg bar on their shoulders for the squat jump and landed on a force platform at 1000 Hz. For the drop jump, participants jumped from a 30 cm high box onto the force platform. Three trials were given for both jumps and the average was used for the results.

To determine the significance in the difference of explosive force production and jumping performance a repeated-measures multiple analysis of variance was executed. The level of significance was set at $p < 0.05$.

The outcome of this study showed a significant decrease in jump performance as a result of a static stretching warm-up compared to all other warm ups: $p=.026$. However, there was no significant difference between any of the other three warm-ups: PNF, MVC, or the control condition.

The testers set out to determine if static stretching, PNF stretching, or maximum voluntary contractions had the greatest effect on jump performance. Results supported the idea that static stretching decreases performance. This study is related to the study of dynamic stretching versus static stretching on the Wingate anaerobic power test in that the results can be compared to determine which warm-up protocol may be best in enhancing anaerobic power performance.

Unick, J., Kieffer, H.S., Cheesman, W., & Feeney, A. (2005). The acute effects of static and ballistic stretching on vertical jump performance in trained women. *Journal of Strength and Conditioning Research, 19*, 206-212.

The purpose of the study was to observe the acute effects of static stretching and ballistic stretching on vertical jump performance. The independent variables were the types of stretching warm-up: static stretching, ballistic stretching, and no stretching. The dependent variables were the two different vertical jump tests: countermovement and drop jump.

Sixteen trained women with an average age of 19.2 years participated in the study. All played basketball at the National Collegiate Athletics Association Division III level and were currently taking part in a preseason workout program. Included in the work out program were agility drills, weight training, and pickup games. Each subject provided written, informed consent and was encouraged to give maximal effort throughout the testing process. The Institutional Review Board of the College approved the study.

To begin the study, the measurement of each subject's sit-and-reach was taken as a baseline for hamstring flexibility. Following was a five minute warm up jog, and then a 30 second rest period. Subjects were then randomly assigned to either the static stretching group, the ballistic stretching group, or the non stretching group. The subjects assigned to the non stretching group simply rested for an additional six minutes. Both the ballistic stretching warm up and the static stretching warm up lasted six minutes. A four minute walking phase took place after each warm-up treatment. Next, subjects completed three countermovement jumps and then three drop jumps from a box that was 26.5 cm high. The mean scores of each test were recorded. After 15 minutes of rest, the vertical jump tests were performed again as well as the sit-and-reach. The measurements were recorded in the same way.

The (3x3x2) factorial analysis of variance (ANOVA) was used to assess the vertical jump scores for both the countermovement and drop jumps. After each of the three treatments, the vertical jump tests' reliability was assessed by use of an intraclass correlation. The statistical significance was set at $p \leq 0.05$.

Results showed no significant difference between each of the stretching warm-up treatments. Additionally, flexibility had no significant effect on jump performance.

The researchers' main goal was to examine the acute effects of static stretching and ballistic stretching on jump performance. Results concluded that there was no significant difference between each warm-up protocol. According to this study, either warm-up could be conducted and yield similar results in performance. Comparing the results of this study with the results of the study on the effect on static stretching and dynamic stretching on the Wingate anaerobic cycle test may give more information on which stretching warm up is most beneficial for anaerobic performance.

Young, A.W.B., & Behm, D.G. (2003). Effects of running, static stretching and practice jumps on explosive force production and jumping performance. *Journal of Sports Medicine and Physical Fitness*. *43*, 21-27.

The purpose of the study was to evaluate the effects of running, static stretching and practice jumps on explosive force production and jumping performance. The independent variables were the types of warm-ups: control, run, static stretch, run and stretch, and run with stretch with practice jumps. The dependent variables were the results of the three performance tests: vertical jump, concentric jump, and drop jump.

Thirteen male and 13 female volunteers participated in the study. The average age, height and weight was 26 years, 175 cm and 76.6 kg. All participants were free of injury and had experience in weight training and explosive type activities. Each provided informed consent before participating in the study. The Ethics Committee of the University Human Research approved the study.

Before beginning the study, participants attended a practice session in an effort to become familiar with the testing procedures. The other five sessions were 6 to 72 hours apart where participants were randomly assigned to a warm-up group. Each warm up was followed by a two minute standing rest. After that, subjects were tested on the vertical jump, concentric jump and drop jump.

The control condition was used as a baseline to compare the other warm up treatments. Subjects walked for three minutes at a comfortable pace, followed by five squats and five heel raises with no added resistance. The four minute run warm up took place indoors and subjects ran at a pace that allowed them to feel warm enough to sweat. The stretching session involved four exercises of the ankle plantar flexors as well as the quadriceps. The run and stretch session consisted of the four minute run with the stretching protocol. The run and stretch with jumps session consisted of the four minute run and stretch protocol along with four practice jumps: one at 80 percent of maximum effort and three at 100 percent.

Vertical jump, concentric jump, and drop jump were tested after each warm-up condition. The vertical jump assessed the explosive force production of the plantar flexors and knee extensors. The concentric jump involved jumping with a 10kg bar using a modified Smith machine. The force generated was measured by a Kistler force platform which was operating at 1000 Hz. The maximum rate of force and the peak force were considered as the explosive force production. The drop jump was completed from a 0.30 m high box. Swift Performance Equipment assessed the jump height and contact times. Subjects were given three jumps and the average was taken.

Electromyographic output of the rectus femoris, lateral gastrocnemius and triceps surae-achilles tendon was assessed using surface EMG recording electrodes. Computer software known as the Biopac System calculated the root mean of the EMG signal. Differences in warm- up protocols on explosive force production and jumping performance were measured by use of an Analysis of Variance (ANOVA) with repeated measures. Significance was set at $p<0.05$. If this occurred, pairwise comparisons were used to identify precise variation in the warm up protocols.

Results of the study showed that a significant difference was shown for all variables, excluding the contact time in the drop jump. In general, the greatest explosive force and jumping performance occurred after the run as well as the run and stretch with jump warm up protocols. When the run was compared to the control condition, results showed that running had a positive effect on jump performance. However, the control group yielded greater results than did the stretch warm-up except for contact time, in which there was no significant statistical difference. The run warm-up was significantly greater than the run and stretch warm up in all five performance test. The run and stretch warm-up had similar test results to that of the control condition. The difference was not significant. The practice jumps showed a significantly greater influence on jump performance than did the run and stretch warm up. The study showed that static stretching had a negative influence on jump performance.

The study illustrated that running as well as run and stretch with jump warm up allowed for the greatest explosive force. Results from the study comparing dynamic stretching and dynamic stretching warm-up on the Wingate anaerobic cycle test are related to this study in that the results of each can be compared to determine which stretching warm-up protocol enhances performance.

Church, J.B., Wiggins, M.S., Moode, F.M., & Crist, R. (2001). Effect of warm-up and flexibility treatments on vertical jump performance. *Journal of Strength and Conditioning Research, 15*, 332-336.

The purpose of the study was to determine the effects of a general warm-up, static stretching warm-up, and proprioceptive neuromuscular facilitation on vertical jump performance. The independent variables were the types of warm-up being used: general five minute warm-up, static stretching, and proprioceptive neuromuscular facilitation (PNF). The dependent variables were the outcomes of the average vertical jump after each warm-up activity.

Forty NCAA Division 1 female athletes volunteered for the study. Sports played included tennis, rowing, and volleyball, as well as jumpers, throwers, and sprinters from track and field. Ages of athletes ranged from 18 to 22 years. All participants were familiar with the vertical jump due to their training; therefore, no practice time was necessary. Each subject was screened by a certified trainer before participation in the study. The purpose of the study, the procedures of the experiment, and the side effects were explained to the subjects. Each signed an informed consent statement. The institutional review board of Murray State University approved the study.

Vertical jump was tested using the Just Jump system. A mobile square mat attached to a handheld computer tested both the distance of the vertical jump and the amount of time the subject was suspended in the air. Data was revealed on the computer.

The three testing days were consecutive. On day one, subjects performed three vertical jumps after a general warm-up. The general warm-up consisted of ten exercises set up as a circuit using body weight for 20 second intervals. Rest period between each exercise was ten seconds. The total time for the general warm-up was five minutes. On day two, subjects participated in a static stretching warm-up which focused mainly on the quadriceps and hamstrings groups. On day three, warm-up consisted of PNF of the quadriceps and hamstrings muscle groups. For both the static stretching and PNF warm-up, the subjects performed three sets of each stretch. After the warm-up, subjects performed three vertical jumps and the average was taken.

A 1-way repeated-measures analysis of variance (ANOVA) was used to determine the effect of each warm-up on the vertical jump test. AVOVA presented the mean differences between each warm-up. If a significant difference was found by ANOVA, a follow-up was done by Scheffe's post hoc analysis. The statistical difference was set at $p \leq 0.05$.

Results showed a significant difference in vertical jump performance in response to PNF as compared to static stretching and no stretching. The mean vertical jump after a PNF warm-up was 47.18 cm. For no stretch, the mean was 48.65 cm and for a static stretching warm-up the mean was 48.06 cm. According to this study, PNF significantly reduced vertical jump performance.

The study sought to determine which type of warm-up produced the greatest results in vertical jump performance. The conclusion was that PNF significantly reduced performance when compared to no stretching and static stretching warm-ups. The results of the effect of different stretching protocols can be compared to the results of the study on static stretching versus dynamic stretching on the Wingate anaerobic test to establish which stretching protocol is most effective in enhancing performance.

Koch, A.J., Bryant, H.S., Stone, M.E., Sanborn, K., Proulx, C., & Hruby, J., Shannonhouse, E., Boros, R., Stone, M.H. (2003). Effect of warm-up on the standing broad jump in trained and untrained men and women. *17*, 710-714.

The purpose of this study was to examine the effect of different warm-up protocols on the standing broad jump in both trained and untrained men and women. The independent variables were the types of warm-ups being used: high-force warm-up, high-power warm-up, stretching warm-up, and no-activity, warm-up. The dependent variables were the results of the standing broad jump test.

A total of 32 subjects participated in this study. Eight men and 13 women were healthy college students and were enrolled in a 6 week weight-training class. The remaining eight men and three women were members of the University's NCAA division I track and field team. They were either sprinters or jumpers and had several years of experience in weight training. The mean age, body mass, and height of the subjects was 20 years, 73.92 kg, and 172 cm. Each subject submitted a written, informed consent before participating in the study. The study followed the University policies and American College of Sports Medicine guidelines regarding human subject use.

Before beginning the study, the tester measured the height and body mass of each subject as well as the 1RM squat. The average 1RM squat for all subjects was 93.2 kg. The subjects were assigned at random to one of four warm-up protocols on days one through four. The high-force warm-up consisted of one set of three repetitions of squats performed at 50, 75 and 87.5 percent of 1RM. A rest of three minutes was given between each set. The high-power warm-up consisted of one set of three repetitions of explosive squats at 20, 30 and 40 percent on 1RM. The stretching warm-up consisted of eight minutes of static stretching exercises. The no-activity warm-up was simply eight minutes of quiet sitting with no activity.

Subjects performed three standing broad jumps immediately following each warm-up protocol. A steel measuring tape was used to measure the distance of each jump. The best score of the three jumps was considered to be the subject's greatest broad jump.

A 4 x 2 repeated measures analysis of covariance (ANCOVA) was used to evaluate differences in broad jump performance between each warm-up protocol. The difference in 1RM squat and broad jump between genders as well as athletes versus non-athletes was assessed by use of independent t-tests. A Pearson' product-moment correlation was used to test the correlation between 1RM squat and broad jump performance. The level of significance was set at $p \leq 0.05$.

T-tests showed that men had a much great 1RM squat than did women as did athletes versus non-athletes. In addition, broad jump distance was much greater in men versus women and athletes versus non-athletes. Results of ANCOVA showed that there was no difference in warm-up protocol on the performance of the broad jump. Data collection from this study can be compared to the results of the study on static stretching versus dynamic stretching on the Wingate test on anaerobic power in an effort to gain more knowledge on what warm-up protocol is best for performance enhancement.

Strength Endurance

Nelson, A.G., Kikkonen, J., & Arnall, D.A. (2005). Acute muscle stretching inhibits muscle strength endurance performance. *Journal of Strength and Conditioning Research. 19*, 338-343.

The study had two purposes: the effect of static stretching warm-up and no warm-up on muscle strength endurance as well as the repeatability of the differences. Therefore, two experiments were evaluated: experiment one and experiment two. The research hypothesis for experiment one was that there is no significant difference between static stretching warm-up and no warm-up on muscle strength endurance. The research hypothesis of experiment two was that there is no significance in the repeatability of differences in static stretching warm-up and no warm-up.

The independent variables of experiment one were the types of warm-up used prior to testing the muscle strength endurance of the subjects: static stretching warm-up or no warm-up. The dependent variable was the outcome of the knee flexion test. The independent variables of experiment two were the types of warm-up used prior to testing: static stretching warm-up or no warm-up. The dependent variable was the significance in the repeatability of differences.

Eleven female and 11 male college students who were enrolled in professional physical education classes participated in experiment one. None of the subjects took part in consistent or organized stretching and/or resistance training activity, but all were physically active. The average age, weight, and height of the female subjects was 21 years, 60 kg, and 165 cm. The average age, weight, and height of the male subjects was 25 years, 85 kg, and 181 cm. Experiment two consisted of 14 female and nine male college students who were enrolled in professional physical education classes. Like the subjects of experiment one, none took part in consistent or organized stretching and/or resistance training activity, but all were physically active. Average age, weight, and height for female subjects was 22 years, 63 kg, and 166 cm. For males, the average age, weight, and height was 24 years, 86 kg, and 183 cm. The Brigham Young University-

Hawaii institutional review board approved the study. Written and oral consents were attained from each subject.

For experiment one, each subject participated in a total of four days of activity. Days one and two were successive, followed by a three to four month break, then two more successive days of testing. The two warm ups were either ten minutes of quiet sitting or 15 minutes of static stretching of calf, hip, and thigh muscle groups. No warm-up and static stretching warm-up were assigned at random. Half of the subjects participated in a static stretching warm-up on days one and three and no warm-up on days two and four. The other half of the subjects did just the opposite with no warm-up on days one and three, and static stretching warm-up on days two and four. A workload equal to about 60 percent or 40 percent of the person's body weight was used to perform the first experiment. Each subject performed knee flexion while lying in the prone position until fatigue. This was after either static stretching warm-up or no warm-up.

The same protocol was followed for experiment two in an effort to test the repeatability of the differences. Each subject participated in repetitious prone-knee flexion for four days. One week was given between each day. Warm up was the same as in experiment one. Half of the subjects participated in a static stretching warm-up on days one and three and no warm-up on days two and four. The other half of the subjects did just the opposite with no warm-up on days one and three and static stretching warm-up on days two and four. The workload was different in experiment two with only 50 percent of body weight, rather than sixty percent of body weight as in experiment one.

Experiment one used a two-way repeated-measures analysis of variance: treatment versus pre-post. Paired t-tests analyzed the strength endurance measurements.

Significance was set at $p \leq 0.05$. Experiment two used an intraclass correlation coefficient to measure the repeated muscle strength endurance. A two-way repeated-measures ANOVA was used to analyze the muscle strength endurance measurements. Again, significance was set at $p \leq 0.05$.

At both 60 percent and 40 percent of body weight, static stretching warm-up showed significantly less knee flexion repetitions than did no warm-up. The average decline was 24.4 percent. Experiment two used the test-retest reliability. Both the static stretching warm-up and no warm-up tests were high. For the two days of no warm-up, $R= 0.941$. For the two days of static stretching warm-up, $R=0.970$.

Results of this study supported the idea that a static stretching warm-up may decrease performance. In this study, static stretching decreased muscle strength endurance when compared to a no stretching warm-up. Comparing the results of the effect of a static stretching warm-up with a dynamic stretching warm-up on the Wingate test for anaerobic power with the results of this study will give more information on the importance of stretching protocols for performance.

Sprint Performance

Fletcher, A.I.M., & Jones, B. (2004). The effect of different warm-up stretch protocols on 20 meter sprint performance in trained rugby union players. *Journal of Strength and Conditioning Research. 18*, 885-888

The purpose of the study was to determine if static and dynamic stretching protocols had an effect on 20 meter sprint performance. The independent variables were the types of warm-up protocol: passive static stretching, active dynamic stretching, active static stretching, and static dynamic stretching. The dependent variables were the results of the 20 meter sprints, both before and after each stretching protocol.

Ninety seven rugby union players from local amateur clubs were recruited for the study. Each subject had been playing rugby union for at least one year. Also, each subject participated in a consistent exercise training program. The average age, height, and body weight of the subjects were 23 years, 181 cm, and 86.5 kg. Each subject completed a health questionnaire and signed an informed consent document. The Departmental Committee for Ethics approved the study.

Twenty eight subjects participated in passive static stretching, 22 in active dynamic stretching, 24 in active static stretching, and 23 in static dynamic stretching. Essentially, the time of a 20 meter sprint both before and after each stretching intervention was recorded.

To begin, each subject jogged for ten minutes. After that, two 20 meter sprints were timed. A two minute recovery was given between sprints. After the first two sprints, the subjects took part in their designated stretching protocol which was supervised by a qualified sports therapist. Next, two more 20 meter sprints were timed. The participants wore rugby boots and began the sprint with his dominant foot in the front. The subjects received no feedback.

A coefficient of variation was used to determine the reliability of the 20 meter sprint measurement and an intraclass correlation coefficient was used on pretest measures. The mean coefficient of variation was 1.7 percent and the intraclass correlation coefficient was 0.94 between the two sprint times. The four sprint times were averaged and the scores were analyzed using a factorial analysis of variance (ANOVA).

Post hoc analysis was made possible by use of Bonferroni. SPSS 10 for Windows was used for statistical analysis.

The passive static stretching group showed a significant increase in sprint time while the active dynamic stretching showed a significant decrease in sprint time. The static dynamic stretching group did have a decrease in sprint time, but it was not significant. When comparing the pre and post test stretching intervention, no group showed a significant difference as a result of stretching.

The goal of the study was to determine which type of stretching protocol would decrease 20 meter sprint time. Results showed active dynamic stretching to be the most beneficial for performance. Comparing the results of the study determining the effect of static stretching warm-up and dynamic stretching warm-up on the Wingate test for anaerobic power may get researchers one step closer to a conclusion on what stretching warm-up enhances performance the most.

Anaerobic Performance

Hoffman, J.R. (2006). Dynamic warm-up protocols, with and without a weighted vest, and fitness performance in high school female athletes. *Journal of Athletic Training, 41*, 357-363.

The purpose of the study was to observe the effects of four warm-up protocols on anaerobic performance in female high school athletes. The independent variables included four warm-up protocols: static stretching, dynamic exercises, dynamic exercises with weighted vest at two percent of body mass and dynamic exercises with weighted vest at six percent of body mass. The dependent variables were the four anaerobic tests: vertical jump, long jump, seated medicine ball toss, and ten yard sprint.

Twenty female high school athletes volunteered to participate in the study, and 18 completed it. The mean age, height, and weight of the subjects were 15.3 kg, 166.3 cm, and 61.6 kg. Subjects participated in interscholastic high school athletics including track, basketball, volleyball, soccer, and lacrosse. All subjects had experience in the area of weight training, but agreed to not increase intensity, mode, duration, or frequency of the work out. Parents and subjects alike completed a health history questionnaire and signed an informed consent. The study was approved by the institutional review board for use of human subjects.

Before beginning the study, subjects participated in a training session in which each became familiar with the weighted vest and practiced the dynamic movements. The subjects were then put into groups of two to three and randomly designated to a particular warm up protocol. One research assistant and one physical education teacher supervised each group. All procedures took place in a high school gymnasium. Each warm up protocol lasted for a duration of 15 minutes. The first five minutes consisted of a jog at a comfortable pace. Testing days were not consecutive.

Vertical jump was measured using the Vertec Jump Training System. Subjects jumped to the highest vane and the standing reach was subtracted. The long jump was performed on a long jump mat. Subjects began with their toes behind the line and jumped along the mat as far as possible. A 4kg medicine ball was used for the seated medicine ball toss. Subjects sat on the floor with backs against the wall as they threw the ball as far as possible with both hands. The 10-yard sprint was timed with the electronic Speed Trap II Timing System.

After each warm-up protocol, subjects were given two minutes to recover, and were then tested under one of the four testing conditions. It took less than 15 minutes to complete all four tests, and each subject completed the study within a 14 day time frame.

Repeated-measures analysis of variance was used to analyze differences in the measures of the four warm-up protocols. A 1-way, repeated-measures analysis of variance was used to assess the effect of allocating warm-up protocol. If the value was significant, post hoc comparisons were performed. All analyses used the SPSS statistical package and the significance was set at $P \leq 0.05$.

The results of the study showed that dynamic exercises resulted in better performance compared to a static stretching warm up. Dynamic exercises and dynamic exercises with a weighted vest at two percent of body weight resulted in significantly greater performance on the vertical jump. Performance was significantly greater on the long jump after dynamic stretching with a weighted vest at two percent of body weight. There were no significant differences found in any warm-up protocol after the seated medicine ball toss or the 10-yard sprint. This study concludes that dynamic exercises have a greater effect on anaerobic performance than does static stretching.

The goal of this study was to determine which stretching warm-up yielded the greatest results of anaerobic performance. The results showed that dynamic exercises and dynamic exercises with two percent of body weight enhance performance the greatest. The study on the effect of static stretching warm-up and dynamic stretching warm-up on the Wingate anaerobic cycle test could be compared with the results of this test in an effort to determine which stretching warm-up is best for performance.

THE EFFECT OF STATIC STRETCHING WARM-UP AND DYNAMIC STRETCHING WARM-UP ON ANAEROBIC POWER PERFORMANCE OF CYCLISTS

INTRODUCTION

Brief Literature Review

It has traditionally been accepted that static stretching before exercise reduces the risk of injury and enhances sport performance. Recent literature, however, supports the idea that static stretching before exercise decreases performance (4, 7, 12, 17, 18). In addition, recent literature suggests that dynamic stretching enhances athletic performance (4, 5, 9, 12, 15, 16, 17). Therefore, the purpose of this study was to compare the effects of static stretching and dynamic stretching on the Wingate anaerobic cycle test.

The current study also sought to determine if there was a significant correlation between leg strength and mean power, peak power and fatigue index of the Wingate anaerobic cycle test following each of the three warm-up conditions. Recent literature has supported the idea that greater strength allows for greater power output. (10).

A recent study compared the effect of dynamic and static stretching warm-up on power and agility performance. Thirty cadets from the United States Military Academy participated in a dynamic stretching and static stretching warm-up, followed by three performance tests: t-drill, 5-step jump, and medicine ball throw. The results suggested that the dynamic warm up improved power and agility performance more than either static stretching as a warm-up or no warm-up at all. (9).

A study evaluated the effects of static stretching, proprioceptive neuromuscular facilitation stretching (PNF) and maximum voluntary contraction on force production and jumping performance. Results showed a significant decrease in jump performance and force production as a result of static stretching when compared to both PNF and maximum voluntary contraction warm-up (19). Results of another study on force production were similar. Running, static stretching and practice jumps were used as warm-ups before testing force production and jumping performance. The outcome was a significant decrease in jumping performance when preceded by static stretching (18).

A study on the effect of static and dynamic stretching exercises on the maximal isokinetic strength of the knee flexors and knee extensors yielded comparable results. The study evaluated the effect of each stretching warm-up with the isokinetic torque of the knee extensor and knee flexor muscles. Results showed a significant decrease in maximal isokinetic torque following static stretching. (13). Another study compared the effects of static stretching and dynamic stretching on leg extension power and found similar results. Dynamic stretching improved leg extension power when compared to static stretching. (17).

Studies have shown that dynamic stretching had a positive effect on performance. Sprint performance was measured by assessing the effects of static stretching and dynamic stretching on a 20 meter sprint. Dynamic stretching showed a significant decrease in sprint time when compared to no stretching, while static stretching had no significant difference. (4).

Though research has not shown the difference in effects of static stretching and dynamic stretching on cycling performance, the effect of static stretching on leg power during cycling has been assessed. A study by O'Connor et.al. showed that peak power and total work were significantly greater as a result of static stretching when compared to the control warm-up. (12).

Research has shown significant correlations between muscle strength and power output. A recent study examined the relationships between stretch-shortening cycle performance and maximum muscle strength. Results showed a significant correlation between one-repetition maximum bench press and muscle contraction velocity of the bicep curl at forty percent of maximum voluntary contraction. (10).

Purpose of Study

Research yields mixed evidence on the effect of static stretching and dynamic stretching on anaerobic performance. No studies have been done to compare the effect of static stretching versus dynamic stretching on the Wingate test for anaerobic power. The Wingate test for anaerobic power is a supramaximal anaerobic power test to evaluate maximal rate at which glycolysis can deliver ATP. It assesses mean power, peak power, and fatigue index. The purpose of this study was to determine the effect of static stretching and dynamic stretching on the Wingate test for anaerobic power. In addition, this study examined the correlations between leg press, leg extension and leg flexion maximum and the mean power, peak power and fatigue index of the Wingate anaerobic cycle test following control warm-up, static stretching warm-up and dynamic stretching warm-up.

Hypotheses

There will be no significant difference in mean power between the control warm-up, the static stretching warm-up and the dynamic stretching warm-up. There will be no significant difference in peak power between the control warm-up, the static stretching warm-up and dynamic stretching warm-up. There will be no significant difference in total work between the control warm-up, the static stretching warm-up and dynamic stretching warm-up. There will be no significant difference in fatigue index between the control warm-up, the static stretching warm-up and dynamic stretching warm-up. There will be no significant correlation between leg press, leg extension and leg flexion maximum and mean power, peak power and fatigue index of the Wingate anaerobic cycle test following the control warm-up. There will be no significant correlation between leg press, leg extension and leg flexion maximum and mean power, peak power and fatigue index of the Wingate anaerobic cycle test following the static stretching warm-up. There will be no significant correlation between leg press, leg extension and leg flexion maximum and mean power, peak power and fatigue index of the Wingate anaerobic cycle test following the dynamic stretching warm-up. The level of rejection will be $p \leq 0.05$.

METHODS

Participants

The population for this study included recreationally active cyclists in Montgomery, Alabama. Five males and five females between the ages of 18 and 61 years volunteered to participate. Descriptive statistics are found in Table 1. The participants were given an informed consent which they signed and returned before beginning the study. An ACSM questionnaire and a Physical Awareness Readiness Questionnaire (PAR-Q) were also completed by each participant. The study was approved through the Institutional Review Board at Auburn University Montgomery. (Appendix A)

Overview

Each participant visited the Human Performance Laboratory at Auburn University Montgomery a total of six times. Day one included the measurement of each subject's age, weight, height, and sit and reach without warm up along with maximum leg press, leg extension, and leg curl power. The maximal force setting on the cycle ergometer was set at 0.075 kg per kilogram of body weight. The subject became familiarized with the Monark ergometer as well as each stretching protocol. The tester explained the purpose and procedures of the test, and clarified the importance of giving maximum effort for 30 seconds. The seat height was documented for each subject. Five separate days of testing took place with at least 48 hours between each testing day. The Wingate test was performed one time after a control warm-up and two times after both a static stretching warm-up and a dynamic stretching warm-up.

To begin the experiment, the subject pedaled for five seconds at 50-60 rpm. Next, the tester dropped a load of 0.075 kg per kilogram of body weight and the subject pedaled as quickly as possible. The subject pedaled at a maximal rate for thirty seconds.

Control Warm-up

The control warm up consisted of a five minute cycling warm-up on the Monark ergometer at 50-60 rpm. Force setting was set at one kilogram. A five second maximum sprint took place each minute of the five minute warm up. The subject was then given a two minute seated rest before beginning the testing protocol.

Static Stretching Warm-up

The static stretching protocol included three exercises focusing on the quadriceps, hamstrings and calves. Three sets of each stretch were held for 30 seconds. The static stretching protocol lasted approximately ten minutes. Following static stretching, subjects were given a five minute warm-up on the Monark ergometer at 50-60 rpm with a five minute sprint each minute. After a two minute seated rest, the testing protocol began.

One static stretch was completed for the hamstrings muscle group. The modified hurdler stretch was performed by the subject beginning in the seated position with one leg straight out in front with the knee fully extended, and the other knee flexed with the bottom of the foot beside the opposite knee. The subject then leaned forward until mild discomfort while keeping the back straight. Subjects performed three sets of 30 seconds with each leg.

The static stretch for the quadriceps group was the standing stretch. The subject began in a standing position with both feet flat on the floor. While balancing with one hand on a wall, the subject pulled the ankle toward the gluteals and held for 30 seconds. The subject then returned to starting position. This was performed with each leg for three sets of 30 seconds.

The static stretch for the calves was the gastrocnemius standing stretch. The subject placed both hands on a wall in front with one leg in front of the other. The front knee was flexed and the back knee was fully extended. The subjects pushed the back heel into the ground so that the posterior portion of the shank stretched. The stretch was held for three sets of 30 seconds on each leg.

Dynamic Stretching Warm-up

The dynamic stretching protocol included three exercises concentrating on the hamstrings, quadriceps and calves. The duration was approximately ten minutes. Ten seconds of rest was given between each set. Subjects participated in a five minute warm-up on the Monark ergometer at 50-60 rpm with a five second sprint each minute immediately following the dynamic stretching protocol. The testing protocol began after a two minute seated rest.

The dynamic stretch for the hamstrings began by the subject flexing one hip at a time while in a standing position, keeping the knee fully extended. Subjects mimicked a stiff-leg walking motion with one leg swinging to the anterior portion of the body. The subjects performed ten steps in one direction, turned around, and performed ten steps back. Three sets were completed.

In order to stretch the quadriceps group in a dynamic fashion, the subjects flexed the knee while in a standing position, forcing the heel of the foot to the buttock, alternating the left and right leg. This was performed at a slow, controlled pace for three sets of ten.

The dynamic exercise to stretch the calves was the skip. Subjects stepped and then hopped, landing on the same leg, and then immediately did the same with the opposite leg. Subjects skipped five times on each leg in one direction, turned around, and skipped five time on each leg in the opposite direction. Three sets were completed.

Variables:

The independent variables include the control, static stretching and dynamic stretching warm-up conditions. The dependent variables include mean anaerobic power, peak anaerobic power and fatigue index. Static stretching exercises are those that slowly apply a stretch to a muscle group, with this position held for 10-30 seconds. Dynamic stretching exercises ar slow, rhythmic movements throughout the full range of joint motion. Mean anaerobic power is the average power during the entire 30 seconds of the

Wingate anaerobic cycle test. Peak anaerobic power is based on the highest power level averaged usually over a five second period during the Wingate test. Fatigue index measures the rate of power decrease from the point of peak anaerobic power to the finish of the test. (1).

Data Collection

Ratio data collected included age, gender, weight, height, seat height, force setting, maximal leg press power, maximal leg extension power, maximal leg curl power, peak anaerobic power, mean anaerobic power and fatigue index. Weight in inches was gathered by use of a digital scale. Each subject's height was measured in nearest half inch. Seat height was adjusted so that the subject's knee was slightly bent when at greatest extension. Maximal force setting was based on each subject's body weight: 0.075kg per kilogram of body weight. Peak anaerobic power was considered the greatest power output produced during the Wingate test: Power (W) = Resistance (kp) x 11.76 x Pedal Revolutions in five seconds. Peak power usually occurred during the first five second interval of the test. Mean anaerobic power was considered the average of power output over the entire 30 second interval: Mean anaerobic power (W) = Total work (J) / Time (s). Fatigue index revealed the subject's level of fatigue over the 30 second Wingate test: Fatigue index (%) = Highest P (W) – Lowest P (W) / Highest P (W) x 100. SMI Opto-sensor Model 2000 was used as software for the Wingate anaerobic cycle test.

Statistical Analysis

A repeated measures ANOVA under three conditions was used to determine if there was a significant difference among the three warm-up protocols. A follow-up LSD post hoc test was used to further analyze and pinpoint the significant difference.

Pearsons correlation was performed on leg press, leg extension and leg flexion maximum with the results of each warm-up condition. The level of significance was set at $p \leq 0.05$.

RESULTS

The age of subjects participating in the current study was 30.6 ± 14.74 years. Weight was 96.09 ± 24.79kg and height was 68.5 ± 3.0in. Leg extension maximum of subjects participating in the current study was 133 ± 30.2 kg. Leg flexion maximum was 96 ± 34.06kg and leg press maximum was 333.5 ± 75.13kg.

Repeated measures ANOVA revealed a significant difference in peak power across the three trials ($p \leq 0.05$). A follow-up LSD post hoc revealed that peak power was significantly greater following the dynamic stretching warm-up when compared to the cycling control warm-up, but the dynamic stretching warm-up was not significantly greater compared to the peak power following the static stretching warm-up ($p \leq 0.05$). Peak power as a result of the static stretching warm-up was not significantly different than either the dynamic stretching warm-up or the control warm-up ($p \leq 0.05$). No significant difference in mean power or fatigue index was found among any of the three warm-up protocols ($p \leq 0.05$). (Results: Tables 2).

Significant correlations were found in leg press, leg extension and leg flexion maximum in relation to mean and peak power of the Wingate anaerobic cycle test under all three warm-up conditions. Significant correlations were found in fatigue index and the control warm-up, but no significant correlations were found in fatigue index of either the static stretching warm-up or the dynamic stretching warm-up ($p \leq 0.05$). (Results Table 3).

Discussion and Conclusion

Discussion

The present study reveals that peak power output increases as a result of a dynamic stretching warm-up in recreationally active cyclists during a thirty second Wingate test. The study also reveals that a static stretching warm-up neither increases nor decreases peak power output during a thirty second Wingate test. Mean power and fatigue index were not significantly different for any of the groups.

Previous studies have shown an increase in anaerobic performance as a result of a dynamic stretching warm-up (4, 5, 8, 12, 16, 17, 18). Yamaguchi et.al. studied the acute effects of dynamic stretching exercises on power output during concentric dynamic constant external resistance leg extension. Twelve recreationally active males performed four dynamic stretching exercises of the leg extensors before performing concentric leg extensions at 5, 30 and 60 percent of maximum voluntary contraction. Results showed that peak power was significantly greater following dynamic stretching compared to no stretching. These results support the findings of the current study in that peak power increased significantly as a result of a dynamic stretching warm-up. (16). In addition, Yamaguchi et. al. compared the effects of static stretching for thirty seconds and dynamic stretching on leg extension power. Eleven male subjects performed static stretching, dynamic stretching and no stretching followed by leg extension power measurement system. Results showed that leg extension power was not significantly different between static stretching and no stretching, or between static stretching and dynamic stretching. Dynamic stretching, however, significantly improved leg extension power. These results support the present study in that a dynamic stretching warm-up is most beneficial related to anaerobic power performance. (17).

Though the current study did not show a decrease in anaerobic power performance as a result of static stretching, previous studies have shown a decrease in anaerobic performance as a result of static stretching (4, 7, 12, 18, 19). Tanagycgu et.al. examined the acute effects of static stretching on power output during concentric dynamic constant external resistance leg extension. Twelve men performed static stretching exercises, followed by concentric leg extensions. Results showed that static stretching did, in fact, decrease peak power. (14). A reason for the decrease in anaerobic power as a result of static stretching is that static stretching causes stiffness in the musculotendinous unit; thus, there is a delay in muscle activation. The delay causes the velocity of force production to decrease because the transfer of force is less efficient. (4).

The current study concentrated on the effects of dynamic stretching and static stretching warm-up protocols on anaerobic power performance during the Wingate anaerobic cycle test. The dynamic stretching warm-up resulted in a significantly higher peak power when compared to the control warm-up while the static stretching warm-up had no significant impact on peak power when compared to the control warm-up. ($p \leq 0.05$). Results of this study support recent literature that suggests dynamic stretching is the most beneficial form of stretching when used as a warm-up prior to activities that involve anaerobic power.

In addition to an increase in peak power following a dynamic stretching warm-up, the current study demonstrated a strong correlation between leg strength and mean and peak power of the Wingate anaerobic cycle test. Leg press, leg extension and leg flexion maximum significantly correlated with both the mean power and peak power of all three warm-up conditions. Results showed a significant correlation in fatigue index between the control warm-up and leg press, leg extension and leg flexion maximum, but not between the static stretching warm-up or the dynamic stretching warm-up and leg press, leg extension and leg flexion maximum. Results suggest that greater leg strength according to leg press, leg extension and leg flexion maximum produces a higher mean and peak power during the thirty second Wingate anaerobic cycle test. Miyaguchi et.al. studied the relationship between stretch-shortening cycle performance and maximum muscle strength. Results showed a significant correlation between one-repetition maximum of the bench press and muscle contraction velocity of the bicep curl at forty percent of maximum voluntary contraction. (10). Results of the current study suggest that greater muscle strength allows for greater power output.

Conclusion

While recent literature suggests that dynamic stretching as a warm-up may be more beneficial than static stretching as a warm-up in increasing performance, no study has compared the two stretching warm-ups preceding the Wingate anaerobic cycle test. The current study concluded that dynamic stretching increases anaerobic power performance significantly when compared to a control warm-up. Though anaerobic power was greater following the dynamic stretching warm-up when compared to the static stretching warm-up, the increase was not statistically significant. The current study supports recent literature that suggests dynamic stretching is the most beneficial form of stretching when used as a warm-up prior to anaerobic power performance.

In addition, the current study supports literature that suggests greater muscle strength has a significant correlation with maximum power output. (10). Results suggest that increasing strength of muscles will increase power performance. Therefore, strength training plays a key role in improving performance of activities that require maximum power output.

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Table 1: Descriptive Statistics

Variable	**Mean** ± SD
Age	30.60 ± 14.74 years
Weight	96.09 ± 24.79 kg
Height	68.50 ± 3.00 in
Leg extension maximum	133.00 ± 30.20 kg
Leg flexion maximum	96.00 ± 34.06 kg
Leg press maximum	333.50 ± 75.13 kg

N = 5 men, 5 women

Table 2

	Control WU	Static Stretching WU	Dynamic Stretching WU
Peak power	593.10W ± 71.12W	615.90W ± 72.67W	*646.01W ± 76.12W
Mean power	478.80W ± 47.38W	489.00W ± 45.99W	497.50W ± 45.11W
Fatigue index	36.50% ± 15.09%	38.05% ± 11.96%	39.32% ± 15.48%

*Peak power after the dynamic stretching warm-up was significantly greater than after the control warm-up ($p \leq 0.05$). Peak power after the static stretching warm-up was not significantly different than after either the control warm-up or the dynamic stretching warm-up ($p \leq 0.05$).

Table 3

	- Control warm-up -			**-Static warm-up -**			**- Dynamic warm-up -**		
	Mean	Peak	Fatigue index	Mean	Peak	Fatigue index	Mean	Peak	Fatigue index
Leg press	r=.82*	r=.79*	r=.70*	r=.84*	r=.813*	r=.49	r=.83*	r=.76*	r=.37
Leg ext.	r=.95*	r=.93*	r=.77*	r=.93*	r=.88*	r=.53	r=.93*	r=.89*	r=.55
Leg flex.	r=.96*	r=.94*	r=.75*	r=.96*	r=.91*	r=.45	r=.95*	r=.86*	r=.37

*=Significant correlation ($p \leq 0.05$).