

THE EFFECTS OF STATIC AND DYNAMIC STRETCHING
ON FLEXIBILITY AND VERTICAL JUMP

by

John M. Coons

A Dissertation Submitted to
the Faculty of The Graduate School at
Middle Tennessee State University
in Partial Fulfillment
of the Requirements for the Degree
Doctor of Philosophy

Murfreesboro, TN
May 2008

UMI Number: 3309127

INFORMATION TO USERS

The quality of this reproduction is dependent upon the quality of the copy submitted. Broken or indistinct print, colored or poor quality illustrations and photographs, print bleed-through, substandard margins, and improper alignment can adversely affect reproduction.

In the unlikely event that the author did not send a complete manuscript and there are missing pages, these will be noted. Also, if unauthorized copyright material had to be removed, a note will indicate the deletion.

UMI[®]

UMI Microform 3309127

Copyright 2008 by ProQuest LLC.

All rights reserved. This microform edition is protected against unauthorized copying under Title 17, United States Code.

ProQuest LLC
789 E. Eisenhower Parkway
PO Box 1346
Ann Arbor, MI 48106-1346

APPROVAL PAGE

THE EFFECTS OF STATIC AND DYNAMIC STRETCHING
ON FLEXIBILITY AND VERTICAL JUMP

November 21, 2007
Date of Final Defense

Jennifer L. Caputo
Dr. Jennifer L. Caputo, Committee Chair

Richard S. Farley
Dr. Richard S. Farley, Committee Member

Jwa K. Kim
Dr. Jwa K. Kim, Committee Member

Dianne A. R. Bartley
Dr. Dianne A. R. Bartley, Health and Human Performance Department Chair

Michael D. Allen
Dr. Michael D. Allen, Vice Provost for Research and Dean of Graduate Studies

ACKNOWLEDGEMENTS

I would like to thank Colleen Mahoney for her assistance in the data collection and implementation of the intervention in this study. I appreciate Coach Jennifer Hignite and Coach Jeff Frazier allowing me to work with their volleyball teams and want to thank the Riverdale High School and Franklin High School volleyball teams for their participation in this study. Also, I want to thank Dr. Richard Farley, Dr. Jwa Kim, and especially Dr. Jennifer Caputo for revisions, consultation, and data analyses involved with this study. Lastly, I want to thank my fiancé, Katherine, for her personal support, advice, and patience throughout my dissertation.

COONS, JOHN M., M.S., M.Ed. The Effects of Static and Dynamic Stretching on Flexibility and Vertical Jump. (2007)
Directed by Dr. Jennifer L. Caputo. 82pp.

The purpose of this study was to examine the effects of a 4-week static stretching and a 4-week dynamic stretching program on dynamic-delay hamstring flexibility, dynamic-movement hamstring flexibility, and vertical jump performance in high school volleyball players. Participants included 25 females (13 years to 19 years of age) from two local high schools. Dynamic-delay and dynamic-movement flexibility were measured before and after the stretching programs on a Biodex System 3 isokinetic dynamometer. Pre-test and post-test vertical jump height were measured using a Vertec. A one-way multivariate analysis of variance (MANOVA) showed that there was a significant difference between the 4-week static stretching program and the 4-week dynamic stretching program on the combination of dominant leg hamstring dynamic-delay flexibility, non-dominant leg hamstring dynamic-delay flexibility, dominant leg hamstring dynamic-movement flexibility, non-dominant leg hamstring dynamic-movement flexibility, and vertical jump, $F(10, 38) = 3.89, p < .001$, Wilk's Lambda = .24. Increases in non-dominant leg dynamic-delay hamstring flexibility were significantly higher in the static stretching group than in the dynamic stretching group, $F(2, 23) = 3.68, p = .041$. Gains in dominant leg dynamic-delay hamstring flexibility were significantly higher in the dynamic stretching group than in the static stretching group, $F(2, 23) = 5.48, p = .011$. Increases in non-dominant leg dynamic-movement hamstring flexibility were significantly higher in the static stretching group than in the dynamic stretching group, $F(2, 23) = 5.81, p = .009$. Gains in dominant leg dynamic-movement

hamstring flexibility were not significantly different between the static stretching group and the dynamic stretching group, $F(2, 23) = 3.12, p = .06$. Gains in vertical jump were significantly higher in the static stretching group than in the dynamic stretching group, $F(2, 23) = 9.16, p < .001$. The different findings between dominant and non-dominant legs indicate leg dominance could be a factor when comparing static and dynamic stretching for increasing flexibility. Also, the results indicate that static stretching produces greater changes in vertical jump height than dynamic stretching.

TABLE OF CONTENTS

| | Page |
|---|------|
| ACKNOWLEDGEMENTS..... | iii |
| ABSTRACT..... | iv |
| LIST OF TABLES..... | viii |
| LIST OF APPENDICES..... | ix |
| CHAPTER | |
| I. INTRODUCTION..... | 1 |
| Purpose Statement..... | 5 |
| Hypotheses..... | 5 |
| Definition of Terms..... | 6 |
| Basic Assumptions..... | 6 |
| Delimitations..... | 6 |
| Limitations..... | 7 |
| Significance of the Study..... | 7 |
| II. LITERATURE REVIEW..... | 8 |
| Static and Dynamic Flexibility..... | 8 |
| Assessment of Flexibility..... | 10 |
| Methods to Increase Flexibility..... | 11 |
| Stretching..... | 11 |
| Research on stretching..... | 12 |
| Acute effects of stretching..... | 16 |
| Effects of static stretch duration and training program length on flexibility..... | 17 |
| Muscle Fibers and Flexibility..... | 19 |
| Eccentric training..... | 20 |
| Physiological Mechanisms of Increasing Range of Motion..... | 22 |
| Static stretching..... | 22 |
| Ballistic stretching..... | 24 |
| Proprioceptive neuromuscular facilitation..... | 25 |
| Dynamic stretching..... | 26 |
| Long-term adaptations to stretching..... | 27 |
| Flexibility and Sports Performance..... | 28 |
| Muscle strength..... | 28 |
| Running speed..... | 29 |
| Economy of locomotion..... | 29 |

| | |
|--|----|
| Vertical jump | 31 |
| Conclusions..... | 33 |
| III. METHODOLOGY | 34 |
| Participants..... | 34 |
| Instrumentation | 34 |
| Demographic information | 34 |
| Height | 34 |
| Weight | 34 |
| Dominant leg status..... | 35 |
| Dynamic-delay and dynamic-movement flexibility | 35 |
| Reach | 36 |
| Vertical jump height | 36 |
| Procedures..... | 36 |
| Static stretching program | 37 |
| Dynamic stretching program | 38 |
| Data Analysis..... | 38 |
| IV. RESULTS | 40 |
| V. DISCUSSION AND CONCLUSIONS | 44 |
| Background of the Problem | 44 |
| Characteristics of the Sample..... | 45 |
| Discussion of Results..... | 47 |
| Dynamic-delay flexibility | 47 |
| Dynamic-movement flexibility | 49 |
| Vertical jump | 50 |
| Overall Conclusions and Future Considerations..... | 52 |
| REFERENCES | 55 |
| APPENDICES | 63 |

LIST OF TABLES

| | Page |
|---|------|
| Table 1. Demographic Characteristics of Participants ($N = 25$) | 42 |
| Table 2. Descriptive Statistics for Final Model ($N = 25$)..... | 43 |

LIST OF APPENDICES

| | Page |
|--|------|
| Appendix A. Informed Consent Form | 64 |
| Appendix B. Assent Form..... | 69 |
| Appendix C. Demographic Questionnaire/Data Collection Form | 71 |
| Appendix D. Rutherford County School Board Approval Letter | 73 |
| Appendix E. Williamson County School Board Approval Letter | 75 |
| Appendix F. Permission from Riverdale High School Principal..... | 77 |
| Appendix G. Permission from Franklin High School Principal | 79 |
| Appendix H. University Institutional Review Board Approval | 81 |

CHAPTER I

INTRODUCTION

Flexibility is “the ability to move a joint through its complete range of motion,” (American College of Sports Medicine [ACSM], 2006, p. 85). Prentice (1999) divided flexibility into static and dynamic components. Static flexibility is the extent to which a joint can passively move to end points in the range of motion. Dynamic flexibility refers to the extent a joint can be moved to end ranges of motion by active muscle contraction. Subcategories of dynamic flexibility include dynamic-delay flexibility and dynamic-movement flexibility. Dynamic-delay flexibility is the extent to which a joint is actively moved through the complete range of motion with a pause at the end of the range of motion. Dynamic-movement flexibility is the degree that a joint is actively moved through the complete range of motion without a pause at the end of the range of motion. Generally, measurement of static flexibility has been used for injury assessment and rehabilitation whereas measurement of dynamic flexibility has been utilized for sports performance.

Norms have been established for static flexibility and are intended for injury assessment, rehabilitation, and health-related fitness. On the other hand, specific norms have not been established for dynamic flexibility. Rather, Andersen (2006) indicated that dynamic flexibility requirements should be based on movements required for specific sports and specific positions or events in sport.

Some clinicians suggest that dynamic flexibility assessment should be performed while a person performs motions that mimic typical sport movements (Sexton & Chambers, 2006). Traditional devices, such as sit-and-reach boxes and goniometers, which measure flexibility, do not consistently measure movement patterns that replicate motions used in sports. A device that could be used for measuring dynamic flexibility is the isokinetic dynamometer. An isokinetic dynamometer is a machine that provides reliable measurements of muscular torque, constant velocity, and joint position. In addition, the isokinetic dynamometer can control compensatory movement patterns that can skew dynamic flexibility measurements.

Traditionally, stretching has been used to increase or maintain levels of flexibility. Forms of stretching include static, ballistic, proprioceptive neuromuscular, and dynamic. Static stretching has been consistently shown to be the most effective mode for increasing range of motion when compared to ballistic and proprioceptive neuromuscular facilitation (Davis, Ashby, McCale, McQuain, & Wine, 2005; LaRoche & Connolly, 2006). Furthermore, Bandy et al. (1998) found that static stretching was more effective than dynamic stretching at increasing hamstring flexibility. However, the protocol used for dynamic stretching by Bandy et al. did not match widely accepted protocols. In general, there is a lack of research on the long-term effects of dynamic stretching protocols on flexibility.

Another issue with flexibility training is the appropriate length of stretching programs. Comprehending appropriate length of stretching programs can assist strength coaches in scheduling flexibility programs for maximal effectiveness. Chan, Hong, and Robinson (2001) examined the effects of similar static stretching protocols that varied in

length, one lasting 4-weeks and the other lasting 8-weeks. They found that participants did not have different gains in range of motion between the two stretching protocols and concluded that flexibility training programs need not last longer than 4-weeks in duration. Unfortunately, literature on appropriate length of training of dynamic stretching is lacking.

Customarily, static stretching has been used as part of warm-up routines for sports training and competition. However, several researchers have shown that static stretching has an acute negative effect on performance (Burkett, Phillips, & Ziuraitis, 2005; Fletcher & Jones, 2004; McNeal & Sands, 2003; Nelson, Kokkonen, & Arnall, 2005; Papadopoulos, Siatras, & Kellis, 2005; Siatras, Papadopoulos, Mameletzi, Gerodimos, & Kellis, 2003; Wallmann, Mercer, & McWhorter, 2005). Dynamic stretching has recently gained popularity because it has been shown to acutely enhance certain performance parameters. Faigenbaum et al. (2006) reported that acute dynamic stretching improved vertical jump, the medicine-ball toss, and 10-yard sprint when compared to static stretching. Such positive findings support the use of dynamic stretching programs over static stretching programs. Regretably, research is lacking on the long-term effects of dynamic stretching on sports performance.

Increasing flexibility has been shown to increase muscle strength and running speed (Dintimann, 1964; Handel, Horstmann, Dickhuth, & Gulch, 1997; Worrell, Smith, & Winegardner, 1994). On the other hand, results on the effects of increasing flexibility on economy of locomotion have varied (Craib et al., 1996; Godges, MacRae, & Engelke, 1993). Furthermore, higher vertical jump heights in countermovement jumps as compared to squat jumps have been attributed to greater use of elastic recoil (Finni,

Komi, & Lepole, 2000). Some researchers suggest that increasing elastic recoil would enhance vertical jump (Finni et al.). Wilson, Elliot, and Wood (1992) reported that increasing range of motion through static stretching flexibility training increased work with concentric contractions. They proposed that observed increases were a result of increased elastic recoil from flexibility training. From these results, Kubo, Kanehisa, Kawakami, and Fukunaga (2001) speculated that stretching may increase elastic recoil by decreasing hysteresis. In muscle-tendon units, greater energy is absorbed than is dispelled during unloading. The energy that is left after unloading is dissipated as heat and is called hysteresis. Kubo et al. found that static stretching decreased stiffness and hysteresis (viscosity) and increased elasticity. Mechanisms for the decrease in viscosity and increase in elasticity are unknown. Whether or not dynamic stretching programs would produce the same effect on viscosity and elasticity is unknown.

Dynamic stretching is an attractive alternative to static stretching because dynamic stretching mimics sport movements and reflects the principle of specificity of training. Also, dynamic stretching has been shown to have a positive acute effect on performance (including vertical jump) whereas static stretching has been shown to have a negative acute effect on performance (including vertical jump). Unfortunately, studies examining the long-term effects of dynamic stretching programs on flexibility and vertical jump height have yet to be conducted. Providing data on the long-term effects of dynamic stretching on flexibility and vertical jump height would better direct clinicians on appropriate methods of stretching.

Purpose Statement

The purpose of this study was to examine the effects of the 4-week static stretching and dynamic stretching program on dynamic-delay hamstring flexibility, dynamic-movement hamstring flexibility, and vertical jump performance in high school volleyball players. The dependent variables were vertical jump height, degree of dynamic-delay hamstring flexibility, and degrees of dynamic-movement hamstring flexibility. The independent variable was the training program with two levels, static stretching and dynamic stretching.

Hypotheses

1. As a main hypothesis, it was hypothesized that there would be a significant difference between the 4-week static stretching program and the 4-week dynamic stretching program on the combination of dynamic-delay hamstring flexibility, dynamic-movement hamstring flexibility and vertical jump.
2. As a nested hypothesis, it was hypothesized that there would be a significant difference between the 4-week static stretching program and the 4-week dynamic stretching program on dynamic-delay hamstring flexibility.
3. As a nested hypothesis, it was hypothesized that there would be a significant difference between the 4-week static stretching program and the 4-week dynamic stretching program on dynamic-movement hamstring flexibility.
4. As a nested hypothesis, it was hypothesized that there would be a significant difference between the 4-week static stretching program and the 4-week dynamic stretching program on vertical jump height.

Definition of Terms

For the purposes of this study, terms that may unfamiliar have been defined:

1. Dynamic-delay flexibility: active movement through the complete range of motion with a 5-second pause at the end of range of motion (Bandy, Irion, & Briggler, 1998).
2. Dynamic-movement flexibility: active movement through the complete range of motion without a pause at the end of range of motion.
3. Static-active stretching: stretching that involves holding the end of range of motion with force produced only by the antagonist muscle.
4. Dynamic stretching: stretching that includes movements that avoid bouncing and are similar to warm-up drills with an emphasis on the end range of motion (Baechle & Earle, 2000).

Basic Assumptions

The researcher has assumed that:

1. The participants did not participate in any other form of flexibility training during the 4-week study.
2. The participants followed the description of appropriate level of stretch intensity for both static-active stretching and dynamic stretching.

Delimitations

1. This study included female high school volleyball players ages 13 years to 19 years of age.
2. Participation and compliance in the flexibility training program was monitored by the principal investigator.

3. Participants were required to attend 80% of all training session to be included in the data set.

Limitations

1. Appropriate intensity of stretch was limited to the subjective description given by the principal investigator to each of the participants.

Significance of the Study

Increased flexibility has been shown to increase strength and running speed (Dintimann, 1964; Handel et al., 1997; Worrell et al., 1994). Traditionally, static stretching has been the modality of choice for achieving flexibility, but results of recent studies have shown that the acute effects of static stretching may hinder performance. This has prompted some strength coaches to use other forms of stretching such as dynamic stretching. However, research is lacking on the long term effects of dynamic stretching on flexibility. Acute dynamic stretching has been shown to have positive effects on vertical jump performance (Fagenbaum et al., 2006). However, research is lacking on the chronic effects of dynamic stretching on vertical jump. Results from this research revealed the chronic effects of static and dynamic stretching on vertical jump, dynamic-delay hamstring flexibility, and dynamic-movement hamstring flexibility.

CHAPTER II

LITERATURE REVIEW

Flexibility is the “ability to move a joint through its complete range of motion,” and it is a component of health-related fitness (ACSM, 2006, p. 85). Static stretching has been the customary tool for increasing or maintaining flexibility for decades. Recently, dynamic stretching has gained popularity as an instrument for addressing flexibility. Unfortunately, research is lacking on the chronic effects of dynamic stretching on flexibility and athletic performance. This review begins with an introduction to static and dynamic flexibility. Topics related to the effects of stretching and training on flexibility, the physiological mechanisms of increasing range of motion, assessing flexibility, and methods to increase flexibility are then reviewed. The chapter ends with a discussion of the effect of flexibility on sports performance, a summary, and the purpose of the study.

Static and Dynamic Flexibility

Flexibility can be classified into static and dynamic components. Static flexibility refers to the degree to which a joint can be passively moved to the end points in the range of motion without muscular contraction (Prentice, 1999). Dynamic flexibility is the degree to which a joint can be moved to end points in range of motion by active muscle contraction (Prentice).

Static flexibility is often measured during rehabilitation of injuries. It provides a measure of the degree of motion beyond normal active limits and has been proposed to be important in decreasing injury rate (Prentice, 1999). According to Prentice, dynamic

flexibility is not a good indicator of muscle stiffness. Muscle stiffness is the amount of resistance the muscle exerts as it is stretched (LaRoche & Connolly, 2006). Prentice's assertion that dynamic flexibility is a poor gauge of muscle stiffness is based on measuring flexibility as an indicator of the likelihood of injury and not as a component of fitness.

Differentiation between dynamic flexibility with and without a pause at the end range of motion is lacking in the literature. The term dynamic-delay flexibility will be given to flexibility that is actively performed through the complete range of motion by the participant that has a pause at the end of range of motion. Dynamic-movement flexibility describes active movement through a complete range of motion without a pause at the end of the range of motion. Comparisons of these two classifications of dynamic flexibility will be made during this study.

Some clinicians suggest that flexibility measurements should be carried out while a person performs controlled functional motions (Sexton & Chambers, 2006). It has also been suggested that range of motion needs in sports are dependent upon the movements required in the sport and the player's position in the sport (Andersen, 2006). Hurdling is an example of an activity that has specific range of motion demands. Video analysis of elite hurdlers has shown that range of motion of the knee can progress up to 165° flexion (Beckenham & Rosemond, 2006). Flexibility requirements for knee flexion in hurdlers could be based upon this biomechanical requirement. Dynamic flexibility assessment should be performed in a manner that is controlled and in a manner that mimics movements seen in sport. Various forms of assessing dynamic flexibility are presented in the following section.

Assessment of Flexibility

Several devices have been designed to measure joint specific flexibility because of joint size differences and movements that involve more than one joint. One example is the sit-and-reach box. The sit-and-reach box is used to measure dynamic-delay low back and hip-joint flexibility (ACSM, 2006). The sit-and-reach test is said to better assess hamstring flexibility than low-back flexibility (ACSM). One drawback to the traditional sit and reach test is that both limbs are measured simultaneously, which does not assess unilateral limb tightness. The back-saver unilateral sit-and-reach test allows each limb to be assessed separately (ACSM). However, because movement originates from the trunk, the sit-and-reach tests are not applicable for measuring dynamic flexibility of the lower extremities. Also, movements produced during the sit-and-reach tests do not replicate movements produced during sport and activities. Therefore, other tools should be used to measure dynamic flexibility during movements that are more like movements created during sports and activities. Another tool commonly used for measuring flexibility is a goniometer.

A goniometer is a large protractor with measurements in degrees (Prentice, 1999). Measurement of range of motion is made by aligning the arms of the goniometer parallel to the longitudinal axis of the two body segments involved in the motion being assessed. Goniometers can be used for assessing both static and dynamic flexibility, but the end of the range of motion must be held when assessing dynamic flexibility. Holding the end of the range of motion does not replicate movements seen in most activities or sports. Also, muscle tightness can cause compensatory movement during flexibility assessment.

Goniometer measurement does not restrict compensatory movement. Controlling for

movements in undesired planes becomes especially difficult when assessing dynamic flexibility. However, an isokinetic dynamometer can be used to assess dynamic flexibility without the need to hold end range of motion and this measurement technique also limits movement in undesired planes.

Isokinetic dynamometers are primarily used for resistance exercise and testing in isokinetic, isometric, isotonic, passive, and reactive eccentric modes. Dynamometers provide joint specific range of motion data and restrict movement in undesired planes through mechanical holds and straps. The isokinetic dynamometer is an attractive tool because it can measure individual joints, can control compensatory movements, and can give measures of both dynamic-delay flexibility and dynamic-movement flexibility. Several methods to increase flexibility have been studied and are presented in the following paragraphs.

Methods to Increase Flexibility

Proposed benefits of improved flexibility include decreased risk of injury (Bandy & Irion, 1994; Hartig & Henderson, 1999), pain relief (Henricson et al., 1984), and improved athletic performance (Handel et al., 1997; Worrell et al., 1994). There are several stretching techniques to increase range of motion.

Stretching. Stretching is the primary training modality for increasing flexibility. There are several forms of stretching including static, dynamic, ballistic, and proprioceptive neuromuscular facilitation (PNF). Static stretching is slow and constant pressure held at the end position of the range of motion for 30-seconds (Baechle & Earle, 2000). Subcategories of static stretching include static-active stretching and static-passive stretching. Static-active stretching involves holding a position with no assistance

other than using the force of the agonist muscles. A static-passive stretch involves holding a position with some part of the body, the assistance of a partner or other apparatus, or gravity. Recently, dynamic stretching has been gaining popularity as a component of pre-exercise warm-up routines. Dynamic stretching utilizes speed of movement that avoids bouncing and includes sport specific movements (Baechle & Earle). The movements used in dynamic stretching are similar to warm-up drills often implemented prior to training and competition, with an emphasis on the end range of the motion. Ballistic stretching involves bouncing-type active muscle movements in which the end position in the range of motion is not held (Baechle & Earle). A drawback of ballistic stretching is that the “bouncing” movements may induce a stretch reflex that inhibits relaxation. Proprioceptive neuromuscular facilitation is a stretching technique that uses muscular inhibition for increased ability to stretch muscle. However, PNF techniques are not often used in group stretching because a partner is required and some expertise is needed. Several studies on the effects of stretching are presented in the following section.

Research on stretching. Kubo et al. (2001) observed the impact of static stretching on the viscoelastic properties of tendons of the medial gastrocnemius. The participants included 7 healthy males (age = 25.3 years \pm 1.4 years) and the stretching protocol entailed a static stretch of the plantar flexors to 35° of dorsiflexion. Pre- and post-test measures of the tendon and the aponeurosis were measured through ultrasonography while the participants executed ramp isometric plantar flexion maximal voluntary contractions (MVC), followed by relaxation of the muscle in the ramp position. Stretching elicited no significant change in maximal voluntary contraction, but decreased

stiffness and hysteresis. Hysteresis is the amount of energy released as heat by the muscle-tendon complex between stretch and recoil. Low hysteresis represents high recoil ability of the muscle-tendon complex, a characteristic beneficial to performance. The stretching protocol increased range of motion while increasing the recoil ability of the muscle. Kubo, Kanehisa, and Fukunago (2002) performed a similar study to compare stiffness and hysteresis of tendon structures in vivo after static stretching and repeated muscle contractions of the medial gastrocnemius. The participants included 8 males (age = 24.1 years \pm 1.6 years) who carried out static stretching for 5-minutes at 35° dorsiflexion and 50 repetitions of 3-second isometric MVCs followed by 3-seconds of relaxation. Ultrasonography was administered before and after intervention to measure elongation of the tendon and aponeurosis of the muscle. Static stretching decreased both stiffness and hysteresis and repeated muscle contraction decreased stiffness, but not hysteresis. These results support using static stretching over repeated muscle contractions to increase range of motion and recoil ability of muscle.

Davis et al. (2005) examined the effectiveness of static-active stretching, static-passive stretching, and PNF stretching on hamstring flexibility in a 4-week program. There were 19 participants (age = 23.1 years \pm 1.5 years) in the study. Requirements for participation included having tight hamstrings as defined by a knee extension angle greater than 20° with the hip fixed in 90° flexion and an age between 18 years and 40 years. A control group that performed no stretching was used for comparison. The effectiveness of the stretching techniques was dependent upon the length of the stretching program. At the 2-week point, the only technique that resulted in significant increases in range of motion from baseline was the static passive-stretch group. At 4-weeks, all three

groups showed significant improvements in flexibility. However, the static passive-stretch group was the only group to be significantly greater than the control group. These results indicate that the most effective type of stretch in this study was static-passive stretching.

LaRoche and Connolly (2006) observed the effects of 4-weeks of static and ballistic stretching on the decreased flexibility that occurred after eccentric exercise in the hamstrings. The participants included 29 males (age = 31.6 years \pm 15.2 years) that were recreationally active, but had not participated in a coordinated strength training or flexibility program in the prior 6 months. Participants were randomly assigned to either the control group ($n = 10$), static stretching group ($n = 9$), or the ballistic group ($n = 10$). There were no preliminary differences in the groups for range of motion (ROM), peak passive torque, stiffness, work absorption, or minutes of stretching per week. Both static and ballistic stretching significantly increased range of motion, but there was no change in muscle stiffness or work absorption. The authors asserted that the results supported the concept that no long term adaptations in elastic properties were attained during the 4-week period. However, the authors failed to consider possible plasticity changes in the length of the muscle during the study. Even though muscle fiber length was not directly measured, a logical assertion could be made that adaptation in the length of the muscle during the 4-week training period explained why stiffness and work absorption did not significantly change.

Minimal information is available comparing the effects of dynamic stretching with other stretching techniques. However, the effects of dynamic “range of motion” exercises and static stretching on hamstring flexibility were compared in a study by

Bandy et al. (1998). The participants included 58 volunteers (41 males and 17 females, age = 26.2 years \pm 5.5 years) that did not have a history of pathology of the hip, knee, or low back and exhibited a lack of knee extension of more than 30° with 90° hip flexion. Both dynamic range of motion and static stretching groups significantly increased hamstring flexibility. Static stretching was more than two times more effective than dynamic stretching at increasing hamstring range of motion. While the authors related the dynamic range of motion exercise performed in their study to a “relatively new stretching technique,” they never actually termed the tested technique dynamic stretching. According to Baechle and Earle (2000), dynamic stretching employs speed of movement in sport or movement patterns that avoids the bouncing motion that occurs during ballistic stretching. A dynamic stretch can be compared to a sprinter performing long strides that emphasize hip extension while maintaining a posterior tilt of the pelvis (Baechle & Earle). The protocol that Bandy et al. used had participants lying supine, holding their hip in 90° flexion, and then actively extending the leg for 5-seconds. Once the leg reached the end of knee extension it was held for 5-seconds and then slowly lowered for 5-seconds. Obvious differences between the two descriptions include the speed of the movement and holding of the stretch at the end of the movement. These protocol differences for dynamic stretching could result in differing results. Unfortunately, there are a lack of studies using the dynamic stretching description put forth by Baechle and Earle.

Static stretching, PNF stretching, ballistic stretching, and dynamic range of motion exercises have been shown to be effective at increasing flexibility. The research shows that static stretching appears to be the most effective stretching technique for

increasing flexibility. However, research on the effect of dynamic stretching on flexibility is lacking. Another topic that has been recently debated is the acute effect of stretching.

Acute effects of stretching. Stretching is typically included as an element of pre-exercise/competition routines. However, recent studies have shown that pre-exercise static stretching hinders or has no effect on strength, power, sprint time, agility drill time, vertical jump performance, sport specific tasks, and muscular endurance (Burkett et al., 2005; Fletcher & Jones, 2004; Little & Williams, 2006; McNeal & Sands, 2003; Nelson et al., 2005; Papadopoulos et al., 2005; Siatras et al., 2003; Wallmann et al., 2005; Yamaguchi & Ishii, 2005). Some researchers in these studies suggested that the possible impairment of performance may be caused by reducing musculotendinous stiffness and increasing autogenic inhibition. Faigenbaum et al. (2006) compared the acute effects of static and dynamic stretching on vertical jump, medicine-ball toss, 10-yard sprint, and pro-agility shuttle run in teenage athletes (age = 15.5 years; 26 males and 4 females). Performance on vertical jump, the medicine ball toss, and the 10-yard sprint were significantly improved after dynamic stretching when compared with static stretching. These findings support the use of dynamic stretching programs over static stretching programs as a warm-up. Overall, these studies would seem to motivate strength coaches to eliminate static stretching from pre-exercise and pre-event warm-up routines and to use dynamic stretching in warm-ups. Unfortunately, there is a lack of research on the effectiveness of dynamic stretching on flexibility. If increasing or maintaining flexibility is desired, then appropriate stretch duration and proper length of flexibility training programs must be considered.

Effects of static stretch duration and training program length on flexibility.

Several researchers have investigated the consequences of stretch duration on changes in range of motion. Madding, Wong, Hallum, and Medeiros (1987) compared the effects of three passive stretch durations (15-seconds, 45-seconds, and 2-minutes) on the hip adductors. The participants included 72 males (age = 27.1 years \pm 4.4 years) who were in good health and had less than 40° hip abduction range of motion. All three stretch durations significantly increased range of motion and significantly decreased passive resistance. The only significant difference between the groups was that the 45-second group showed significantly greater gains in range of motion when compared to the 15-second group. The authors concluded that the 15-second stretches were as effective as 2-minute stretches.

Bandy and Irion (1994) examined the effects of 15-, 30-, and 60-second static stretch durations on passive range of motion of the hamstring muscles. The study included 57 participants (40 males and 17 females) that were divided into one of three groups that stretched 5 days per week for 15-, 30-, and 60-seconds or into a fourth group, which functioned as a control group that did not stretch. The 30-second duration was the minimum duration for effective increases in range of motion. These results do not substantiate the findings put forth by Madding et al. (1987) that 15-second durations were as effective as longer durations. From the findings of these studies, Ford, Mazzone, and Taylor (2005) developed the idea to compare the effects of 90- and 120-second duration static hamstring stretches to the effects of 30- and 60-second duration static hamstring stretches over a 5-week period. The study included 35 participants (24 males and 11 females) with a mean age of 22.7 years \pm 2.4 years that exhibited passive knee extension

range of motion less than 160° as measured with 90° hip flexion. There were no differences among the four stretch-duration groups and they concluded that there was no need to perform static stretches lasting longer than 30-seconds.

Incorporation of flexibility components into overall training schemes requires knowledge of appropriate training intervals. Chan et al. (2001) compared equal duration (30-seconds) static stretching flexibility training groups, one that lasted 4-weeks and one that lasted 8-weeks with two control groups. The training groups performed static stretching on the hamstrings of their dominant legs with each stretching set consisting of 5 repetitions of a single stretch with a rest interval of 30 seconds. Group 1 performed one set per session; three times a week for 8-weeks. Group 2 completed two sets per session, each time with a 1-minute rest interval between sets; three times a week for 4-weeks. Groups 3 served as a control group for group 1, group 4 served as a control group for group 2, and neither received the stretching intervention. Significant increases were found in the two training groups when compared to the control groups, but no difference in increased range of motion was found between the two training groups. However, significant increased passive resistance at maximal hip flexion was found in the 4-week training group. The authors concluded that both protocols were effective at increasing flexibility, but if lower passive resistance at upper limits of the range of motion would decrease rate of injury, then an 8-week program would be suggested.

The results of studies indicate that static stretches do not need to be held longer than 30-seconds. This is an interesting finding considering ACSM still has recommendations for stretching that are longer than 30-seconds. No difference in range of motion gains was found between 4-week and 8-week training groups. Because of this

finding, the length of training programs need not last longer than 4-weeks. Research on stretch duration and appropriate length of training for dynamic stretching is lacking.

Future research should focus on appropriate stretch duration and length of training for dynamic stretching. Another topic that has been investigated is muscle fiber type and flexibility. Studies have shown that fast twitch and slow twitch muscle fibers differ in flexibility.

Muscle Fibers and Flexibility

Muscle fibers can be classified by myosin heavy chain isoforms (Bruton, 2002). Further characterization of muscle fibers involves enzyme activity, contractile speed, and morphology. Recent reclassifications of muscle fibers include type 1, type 2A, and type 2X (Bruton). Type 1 muscle fibers have enzyme activity that is slow and oxidative, contractile speed that is slow, and a red morphology. Type 2A muscle fibers have fast oxidative enzyme activity, a fast contractile speed, and a white morphology. Lastly, type 2X muscle fibers have fast glycolytic enzyme activity, a fast contractile speed, and white morphology (Bruton). Another feature of muscle that may differ according to muscle fiber type is quantity and structure of collagen. The overall amount of collagen has been shown to be two times higher in type 1 muscle fibers than in type 2 muscle fibers (Kovanen, Suominen, & Heikkinen, 1984). Another characteristic of type 1 muscle fiber is increased cross-linked intramuscular collagen (Kovanen et al.). Some researchers suggest that these characteristics explain the superior isometric performance and enhanced ability to maintain posture that type 1 muscle fibers have when compared to type 2 muscle fibers (Kovanen et al.). These collagenous variations in muscle fiber types

could bring forth differing levels of flexibility if training targets a specific muscle fiber type.

Muscle fiber modification as a result of training is well established. Several studies have shown endurance training can provoke histochemical and morphological changes that modify type II fibers to be more like type I fibers (Pousson, Perot, & Goubel, 1991). Furthermore, it has been shown that endurance training results in an increase in stiffness (Kovanen et al., 1984). Due to these changes, assertions have been put forth that type I and type II fibers may have different elastic properties. These claims were substantiated by Petit, Filippi, Emonet-Denand, Hunt, and Laporte (1990) who demonstrated that slower motor units have greater stiffness than faster motor units in cat peroneus longus muscle. Due to the results of these studies, it could be put forth that training techniques that stress fast twitch muscle may lead to a decrease in muscle-tendon stiffness. Pousson et al. (1991) confirmed this line of reasoning when they found that jump training caused a decrease in the number of type I-like fibers and an increase in type II-like fibers in rat soleus muscle. The researchers compared a training group that performed vertical jumps that progressed in number of sessions and number of jumps for 11-weeks to a control group that did not train. Decreases in muscle stiffness were observed with the muscle fiber modification. The results from this study have led some researchers to suggest that adaptation to training could lead to an increase or decrease in flexibility depending on the muscle fiber targeted by training. Eccentric training is another form of training that has been proposed to affect flexibility.

Eccentric training. Nelson and Bandy (2004) suggested that eccentrically training a muscle could not only reduce injury rates, but also improve athletic

performance and flexibility. To study this idea, they randomly assigned participants into groups that included a 6-week eccentric exercise program, a 6-week static stretching program, or control group with no exercises. The participants included 69 males (age = 16.45 years \pm 0.96 years) that had a 30° knee-extension deficit with the hip at 90° flexion. The protocol for the eccentric group included having the participants perform resistive eccentric exercise through the full range of motion in the supine position. Once full flexion was achieved, the participants were instructed to hold the position for 5-seconds and then slowly lower the leg. The static stretching group protocol consisted of performing static-active stretching for 30-seconds. The training protocols were performed 3 days per week for 6-weeks. Both eccentric and static groups had significant gains in range of motion when compared to the control group, but no significant differences between the eccentric and static groups were observed. They concluded that both static stretching and eccentric exercise were effective at increasing range of motion, but neither was found to be significantly more effective.

Pousson, Hoecke, and Goubel (1990) examined the effect of an eccentric strength training program on the muscular series elastic component of the triceps surae. The authors of this study randomly assigned 10 sedentary males (age = 29 years \pm 5 years) into a sedentary control group ($n = 4$) or into an eccentric training group ($n = 6$). The eccentric group performed progressively overloaded eccentric exercises 2 days a week for 6-weeks and was compared to a sedentary control group. The training group was less compliant than the control group at the conclusion of the study. These results contradict the previous findings by Nelson and Bandy (2004). A possible reason for the differing results could be the difference in eccentric protocol design. The eccentric group in the

study performed by Nelson and Bandy held the end of the range of motion for 5-seconds whereas the eccentric group in the study by Pousson et al. (1990) did not hold the end of range of motion. Holding the end position mimics a static stretch and could produce results similar to static stretching.

Despite differences in results of the studies on the effect of eccentric training on flexibility, it appears that these differences can be explained by varying protocols. After examining the methods to increase flexibility, it is important to understand mechanisms by which increases in flexibility are attained.

Physiological Mechanisms of Increasing Range of Motion

The mechanisms responsible for increased flexibility are diverse. The physiological mechanisms of static, ballistic, proprioceptive neuromuscular facilitation, and dynamic stretching as well as the long term adaptations that occur as a result of stretching are presented in the following paragraphs.

Static stretching. Increases in range of motion from static stretching have been found to be a result of both mechanical (Magnusson, Simonsen, Aagaard, Sorensen, & Kjaer, 1996) and neurological (Avela, Kyrolainen, & Komi, 1999; Vujnovich & Dawson, 1994) properties of the muscle-tendon complex. Even though static stretching effectively increases range of motion as measured statically, it does not affect dynamic flexibility as measured by passive or active stiffness (Cornwell & Nelson, 1997; Magnusson, Simonsen, Aargaard, & Kjaer, 1996). Static stretching increases range of motion by way of the mechanical properties of “creep” and reducing stress relaxation (Weerapong, Hume, & Kolt, 2004). Creep is described by a new length acquired through tissue deformation. Stress relaxation is best described as the force that gradually declines when

tissues are held at a specific length (Weerapong et al.). Decreasing stress relaxation reduces the compulsory load across the myotendinous junction by adaptations of the parallel elastic components. Even though this is where injury occurs, evidence is contentious on whether static stretching reduces rate of injury (Bixler & Jones, 1992; McHugh et al., 1999; Pope, Herbert, Kirwan, & Graham, 2000; Shrier, 1999; Witvrouw, Mahieu, Daneels, & McNair, 2004).

The neurological mechanisms linked to increases in range of motion are under debate. Similar responses have been noted between neurologically intact participants and those with spinal injuries with complete motor loss. Also, several authors have shown no electromyography (EMG) activity during passive stretching. These findings would lead one to put forth that the effects of static stretching do not include neurological mechanisms. Additionally, static stretching has been reported to decrease neuromuscular sensitivity by altering H-reflex responses (Rosenbaum & Henning, 1995). The H-reflex is a reflex action of the muscles after stimulation of sensory fibers (e.g. Ia afferents coming from the muscle spindles) inside the innervating nerves. Static stretch of the triceps surae has been shown to reduce peak force production during reflex, decrease rate of acceleration of force, and lower EMG activity (Rosenbaum & Henning). Vujnovich and Dawson (1994) compared amplitude changes of static and ballistic stretching and found that the H-reflex was acutely decreased by up to 55% during static stretching that was maintained for 160-seconds. However, the reduced H-reflex returned to baseline immediately upon cessation of stretching. The reported reductions in neuromuscular sensitivity, as revealed by the change in amplitude of the stretch reflex, during static stretching could be due to external forces applied to the muscle that are higher than the

resistance from the protective stretch reflex of muscle (Weerapong et al.). Diminished sensitivity of muscle spindles, which would reduce sensitivity of the H-reflex, could result from muscles being stretched further than normal and an inability to resist external force. The finding that the H-reflex amplitude regresses back to baseline levels after cessation of the static stretch further indicates that the increase in flexibility in response to static stretching is most likely not due to neuromuscular mechanisms.

Findings from studies examining physiological mechanism of static stretching indicate that increases in range of motion from static stretching are more a result of mechanical tissue deformation than of neurological influences. Physiological mechanisms have also been examined for ballistic stretching.

Ballistic stretching. Ballistic stretching has been shown to increase flexibility (LaRoche & Connolly, 2006), decrease electromuscular activity (Wiemann & Hahn, 1997), and decrease the H-reflex (Vujnovich & Dawson, 1994). More than likely, the increases in flexibility from this mode of stretching are attained through a neurological mechanism. During ballistic stretching, muscles are progressed to the end ranges of motion by the agonist muscle. This repeated stretch at the end ranges of motion may stimulate golgi tendon organs (GTO) which would inhibit alpha motor neurons and result in greater stretch relaxation. When compared to static stretching, ballistic stretching has been shown to lower mean amplitudes of the H-reflex (Vujnovich & Dawson). Because tension is released immediately after applying force at the end of motion, more than likely, not enough time is permitted to affect stress relaxation or creep. Neurological and mechanical properties of proprioceptive neuromuscular facilitation have also been examined.

Proprioceptive neuromuscular facilitation. Techniques of proprioceptive neuromuscular facilitation (PNF) include slow-reversal hold, contract-relax, and hold-relax. These techniques employ combinations of alternating contraction and relaxation of both agonist and antagonist muscles. Contracting muscles act to lengthen non-contractile elements of the muscle-tendon complex, therefore causing decreased passive tension and increased relaxation of muscle. In addition to working on non-contractile elements, contraction of muscle during PNF stretching excites sensory receptors (muscle spindles and golgi tendon organs) within the muscle and tendon to aid in easing tension to stretch.

The slow-reversal hold technique employs reciprocal inhibition to increase range of motion. Reciprocal inhibition develops when the nervous stimulus for the agonist muscle is conveyed by neurons in the spinal cord to produce muscle contraction while inhibitory signals are employed to restrain the tension in the antagonist muscle. Isometric contractions are often used with PNF techniques. Brief decreases in H-reflexes have been observed to last for 10-seconds following isometric contractions (Gollhofer, Shopp, Rapp, & Stronik, 1998). This decreased neural feedback provides an opportune time to apply force that may influence stress relaxation and creep.

Proprioceptive neuromuscular facilitation stretching employs both mechanical and neurological means to increase range of motion. Utilizing both of these processes would seem to make PNF stretching an efficient method for increasing range of motion. However, static stretching has been shown to be more effective than PNF stretching at increasing flexibility (Davis et al., 2005). Further detriments of PNF stretching include the need for a partner, increased blood pressure (Cornelius, Jenson, & Odell, 1995), and

increased EMG activity which places the muscle-tendon complex at risk for strain during stretch (Osternig, Robertson, Troxel, & Hansen, 1997).

Dynamic stretching. Dynamic stretching has been described as being essential to athletic performance because during sport movements it is important that the extremities be able to move through a “non-restrictive range of motion” (Shellock & Prentice, 1985). Bandy et al. (1998) called for holding the end range of motion while performing dynamic stretching, which is in contrast to the description given by Baechle and Earle (2000). Baechle and Earle noted that dynamic stretching is similar to ballistic stretching except that it avoids bouncing and it moves through patterns similar to movements in particular activities or sports. These similarities to ballistic stretching make it plausible that dynamic stretching employs comparable modes for increasing range of motion. Unfortunately, there is no published research on mechanisms involved in increasing range of motion with dynamic stretching. In addition, because dynamic stretching is performed in a controlled manner, similar to static stretching, mechanical influences may also be utilized.

From the research, it appears that static stretching employs mechanical means to increase flexibility, ballistic stretching uses neurological means, and PNF stretching involves both mechanical and neurological means. There is a lack of research into the mechanism(s) for increasing range of motion through dynamic stretching. Future research should be directed towards revealing such mechanisms. Muscle and tendon adaptations to increases in range of motion have been studied. These adaptations could have effects on muscle characteristics and will be discussed in the following paragraphs.

Long-term adaptations to stretching. Muscle plasticity is the adaptability of muscle in response to functional demands (Bruton, 2002). Resulting adaptations in muscular tissue are limited to the specific stresses that are experienced (Anderson, 2006). Adaptive remodeling of skeletal muscle is demonstrated by changes in myofiber cross-sectional area, fiber length, the number of sarcomeres in series and in parallel, the number and functional capacity of mitochondria, the configuration of cellular junctions of muscle fibers with tendons and nerves, fiber-types, and motor units. The central nervous system coordinates these adjustments from signals that feed back from motor neurons. One way that plasticity occurs is through satellite cells. These cells reside next to the extrafusal fibers of the muscle belly (Anderson; Bruton) and even the slightest disturbance to a muscle cell can activate a satellite cell. Activation of a satellite cell is evidenced as cellular swelling, expanded organelles, and lower chromatin density (Anderson). Satellite cells may serve as connectors or communicators of signals to other cells, other fibers, the bloodstream, and to muscle fibers. Release of growth factors such as FGF-1, VEGF, and IGF-1 are seen once satellite cells are activated (Anderson). Also, it has been observed that a stretch stimulus during exercise may cause satellite cells to have a function as physical or mechanical connectors. Evidence of this includes nitrous oxide signaling molecules being released once the cells are stretched (Anderson).

Repeated passive stretch is well documented to cause hypertrophy (Rennie, Wackerage, Spangenburg, & Booth, 2004) and may cause adaptive remodeling of skeletal muscle by increasing fiber length and/or increasing the number of sarcomeres in series (Anderson, 2006). Magnusson, Simonsen, Aagaard, Sorensen, et al. (1996) differentiated that tissue added in parallel increases muscle strength and stiffness,

whereas tissue added in series lowers muscle stiffness while muscle strength remains the same. The researchers further proposed that stiffer tendons will deform less to applied external force. The more structures deform under given loads, the higher the hysteresis. Magnusson, Simonsen, Aagaard, Sorensen, et al. insinuated that the long-term adaptations of increasing flexibility would increase hysteresis. However, Kubo et al. (2001) found that static stretching lowered hysteresis, a finding that contradicts previous conclusions. Some researchers submit that increased flexibility could result in decreased performance capabilities (Shrier, 2004). These suggestions are based upon the notion that increased flexibility decreases muscle stiffness and could therefore influence force production because of an altered muscle-tendon length. However, this point of view is not supported nor refuted by research. Some research has been directed towards the effects of increasing flexibility on performance capabilities and a summary is presented in the following paragraphs.

Flexibility and Sports Performance

The effects of increasing flexibility on several key performance parameters have been investigated including muscle strength, running speed, economy of exercise, and vertical jump. However, questions still linger as to whether increasing flexibility provides any benefit to performance.

Muscle strength. As discussed in earlier paragraphs, several studies have shown that acute stretching has a negative effect on athletic or muscular performance. However, several researchers have shown that the long-term effect of stretching (increased flexibility) has a positive effect on performance. Worrell et al. (1994) studied the effects of hamstring stretching on hamstring muscle performance. In this study, 19 participants

with tight hamstrings performed either static or PNF stretching 5 days a week for 3-weeks. It was found that 3-weeks of flexibility training using both PNF and static stretching increased peak torque of hamstrings eccentrically and concentrically. Handel et al. (1997) investigated the effects of contract-relax stretching on muscle performance in athletes. The participants included 16 male athletes. The protocol included contract-relax PNF training for 8-weeks. Increases in maximal torque of the knee flexors and extensors were seen after the intervention at all velocities. The knee flexors showed the greatest increase in muscle strength. However, the authors suggested that gains could not be completely attributed to increases in flexibility because of possible strength gains as a result of isometric training during PNF stretch training. The results of both studies show an increase in muscular strength from chronic stretching and indicate that chronic stretching may have an ergogenic effect on strength.

Running speed. Dintiman (1964) performed a study to examine the chronic effects of weight training and flexibility training on running speed. Static flexibility training did not improve running speed significantly more than sprint training alone (Dintiman). Also, weight training, used as a supplement to sprint training, did not improve running speed. However, when flexibility and weight training programs were combined, they improved running speed significantly more than sprint training alone (Dintiman). The results of this study have been a basis for including flexibility training as a component of training programs for sprinters. Another often studied principle of performance that is affected by increased flexibility is economy of locomotion.

Economy of locomotion. Flexibility is believed to be a key element of economy of movement by facilitating the use of elastic potential energy. More compliant muscle-

tendon complexes require greater contractile force and create a longer delay in external force production. On the other hand, a stiffer muscle would provide more efficient transmission of contractile force production, but this contradicts the aim of stretching, which leads to increased muscle-tendon unit compliance (Gleim & McHugh, 1997).

Craib et al. (1996) investigated the relationship between flexibility and running economy in male distance runners. The participants included 19 male endurance runners (age = 32 years \pm 1 year). They found that less flexible runners had a reduced aerobic demand (better running economy) during running. The positive and significant correlation between range of motion and the aerobic demand of running presented in only two movements (external hip rotation and dorsiflexion) and accounted for 47% of the variance observed in running economy. However, the training regimen of the runners was not controlled and other factors that might have influenced running economy such as kinematics, anthropometric, physiological, and cellular variables were not considered.

In contrast to these findings, Godges et al. (1993) found that flexibility training of hip flexors (3-weeks) resulted in increased range of motion, but had no effect on running economy. Nelson, Kokkonen, Eldredge, Cornwell, Glickman-Weis (2001) investigated the effect of a 10-week quadriceps, hamstrings, and triceps surae stretching program on running economy. The researchers found that chronic stretching significantly increased flexibility but had no effect on running economy. The findings of Godges et al. and Nelson et al. contradict the results presented by Craib et al. (1996). It should be noted that none of the researchers in the studies examined the effects of flexibility on running time, stride length, stride frequency, or the perception of fatigue. Future research should

be directed towards finding optimal levels of flexibility that coincides with optimal running performance.

Vertical jump. Another sports performance parameter that has been proposed to be affected by increased flexibility is the vertical jump. Finni et al. (2000) used optic fibers to measure the function of triceps surae (TS) and quadriceps femoris (QF) in the squat jump (SJ) and the counter movement jump in vivo. Jumping performance was observed to examine how the output of the triceps surae and the quadriceps femoris was modulated to achieve greater jumping height. The study included 4 healthy volunteers (3 females and 1 male). In the CMJ, the quadriceps femoris demonstrated force increases predominately during the eccentric action that were maintained during the concentric action. Early lengthening of the QF muscle during the CMJ resulted in lower EMG activity. Muscle activity was the greatest at longer muscle lengths in both the SJ and the CMJ. The force increase of the TS muscle occurred at a continuous length and corresponded with EMG activity in both the SJ and the CMJ. Mean concentric power output was greater in the CMJ than in the SJ for the muscle groups even though muscle activity was similar in both jumping situations. The cause of the difference in power output between the CMJ and the SJ is likely attributed to added power from elastic recoil. If elastic recoil is an attributing factor to increased power output as suggested by Finni et al. then modalities that increase elastic recoil should increase power output during countermovement jumps. Although controversial, a modality proposed to increase elastic recoil is increased flexibility (Wilson et al., 1992).

Static stretching is a modality that is often used to increase flexibility. Knudson, Bennett, Corn, Leik, and Smith (2001) looked at the effect of static stretching on jump

height. The participants (10 males and 10 females) performed 3 sets of static stretches that lasted 15 seconds for the quadriceps, hamstrings, and plantar flexors. They found that acute static stretching reduced jump height by 3%. Findings such as these are important because static stretching has been historically used as a part of warm-up routines for exercises or sports that use jumping. Because of findings such as these and the popularity of dynamic stretching, Faigenbaum et al. (2006) compared the acute effects of static and dynamic stretching on vertical jump. The participants (31 males and 4 females) performed both static and dynamic warm-up protocols on nonconsecutive days. The static stretching protocol consisted of 2 sets of stretches lasting 30 seconds and the dynamic stretching protocol consisted 2 sets of dynamic warm-up movements for 10 yards. Vertical jump was significantly improved after dynamic stretching as compared with static stretching. The authors conclude the lack of improvement from acute static stretching could be due to a decrease in muscle activation and/or a reduction in passive or active muscle stiffness. Improvements in vertical jump from dynamic stretching were proposed to be a result of excitation of neuromuscular function. Even though research is lacking, the authors propose that the increased neuromuscular excitation would only linger for 20 minutes after dynamic stretching. Overall, research is lacking on the effect of increasing flexibility on vertical jump. Further research should be directed at determining whether increasing flexibility has an effect on vertical jump height and whether increased flexibility through static and dynamic stretching have different outcomes on vertical jump.

Conclusions

Flexibility is the capacity to move a joint through a complete range of motion and can be categorized into static and dynamic components. Dynamic flexibility should be assessed in a manner that replicates movements used in sport and activities.

Unfortunately, traditional methods of assessing range of motion make it difficult to obtain accurate measurements with movement. The isokinetic dynamometer is an attractive instrument for assessing dynamic flexibility because it allows the assessment of flexibility without end of ROM pauses and because it controls compensatory movements.

Static stretching has been shown to generate the greatest gains in flexibility when compared with ballistic stretching and PNF stretching. However, studies using widely accepted descriptions of dynamic stretching are lacking. Improved performance during movements, such as the countermovement jump, has been attributed to increased elastic recoil. Increasing flexibility has been proposed to enhance elastic recoil. Because of its recent popularity and the lack of research literature, research examining the effects of dynamic stretching on dynamic-delay and dynamic-movement flexibility is needed.

Also, research on the long-term effects of dynamic stretching on performance parameters is necessary. Therefore, the purpose of this study was to examine the effects of 4-week static stretching and dynamic stretching programs on lower body flexibility and vertical jump performance in high school volleyball players.

CHAPTER III

METHODOLOGY

Participants

Participants included 25 high school female volleyball players (13 years to 19 years of age) from two local high schools. Parents/legal guardians of participants read and signed an informed consent form prior to participation (see Appendix A).

Participants ($N = 25$) under 18 years of age read and signed an assent form (see Appendix B).

Instrumentation

Demographic information. Participants completed a demographic questionnaire created by the primary investigator and supplied information on injury history, injury status, menstrual cycle regularity, age, and playing history (see Appendix C).

Height. Height was measured with a SECA stadiometer (SECA; Hanover, MD) to the nearest millimeter. The same stadiometer was used throughout the study to reduce error. Participants stood with feet together and parallel to one another to ensure proper weight distribution during the measurement. Shoes and headwear were taken off during this measurement and socks were allowed.

Weight. Weight was measured to the nearest 0.1 kilograms using a SECA scale (SECA; Hanover, MD). The same scale was used throughout the study to reduce error. Participants were asked to wear shorts, underwear, and a shirt during the measure.

Dominant leg status. Dominant leg status was determined as the leg used to kick a ball (McCurdy & Langford, 2005). The procedure consisted of placing a ball in front of the participants and asking them to kick a ball. The participants were not aware of the motivations of this test during the procedure.

Dynamic-delay and dynamic-movement flexibility. Prior to measuring flexibility, participants performed a 5 minute warm-up on a cycle ergometer. Dynamic-delay and dynamic-movement flexibility were measured with a Biodex System 3 dynamometer (Biodex Medical Systems; Shirley, NY). The participant was in a supine position in the adjustable seat apparatus. The pelvis was constrained to the adjustable seat apparatus with straps to prevent compensatory movements from joints other than the hip. An immobilization device that prevents knee flexion was placed on the limb that was measured. The hip of the participant was placed in a neutral position prior to measuring range of motion. The neutral position was confirmed by a goniometer and the isokinetic dynamometer was zeroed. For the dynamic-delay flexibility assessment, the participant was asked to raise the limb as far as she could actively move it and then hold the limb for 5-seconds at the end range of motion. Measurement of dynamic-movement flexibility began by zeroing the isokinetic dynamometer in the neutral position, which was confirmed by a goniometer. The participant was then asked to raise the limb in a manner that is similar to a kicking motion as far as the limb could be actively moved. The number of degrees of hip flexion from neutral was recorded for both dynamic-delay flexibility and dynamic-movement flexibility. The participants performed 3 attempts for both dynamic-delay flexibility and dynamic-movement flexibility of which the highest degrees of hip flexion was used for analysis. The participants were asked to wear

clothing that allowed visual inspection and palpation of limb anatomy and position. This procedure was performed on both legs and order was altered.

Reach. Reach was measured in inches with a tape measure, to the nearest 1/8 inch. The same tape was used throughout the study to reduce error. The tape measure was affixed to a wall in a manner that was level plum. The participant was asked to stand next to the affixed tape measure with her right arm abducted and flexed maximally. There were three measures taken from the distal point of the third phalange and the highest value was used (Burkett et al., 2005).

Vertical jump height. Vertical jump height was obtained through the use of a Vertec (Sports Imports; Columbus, OH). The Vertec is a vertical apparatus that has adjustable horizontal panes that can be used to measure vertical jump height. The same Vertec was used throughout the study to reduce error. The participant was asked to stand with her right shoulder under and 2 to 4 inches behind the horizontal panes of the Vertec with feet 1 to 2 inches wider than shoulder width. A countermovement jump was performed and the participant moved the horizontal panes of the Vertec at maximal jump height. Prior to recording vertical jump, participants were given a practice jump. Vertical jump measures were taken 3 times and the highest value was recorded (Burkett et al., 2005). Vertical jump height was calculated by subtracting the reach measure from the vertical jump measure.

Procedures

The County School Boards (see Appendices D and E) were contacted for permission to conduct the study. Once approval was received, permission was sought from the principals of the individual schools (see Appendices F and G), the University

Institutional Review Board (see Appendix H), the parents and/or guardians of the participants, and the participants. Athletes were notified of the testing 3 to 7 days prior to the test date at their respective school. Testing was performed between the hours of 8 am and 3 pm. Participants were randomly assigned to either static or dynamic stretching groups. Random assignment was accomplished by drawing from a deck of cards that was marked dynamic or static. An equal number of static and dynamic cards was placed in the deck. A data collection form was coded for each participant. The principal investigator collected pre-test and post-test vertical jump and range of motion data and implemented the static and dynamic stretching programs during the study. The stretching programs were performed 3 times a week for 4 weeks and were directed by the principal investigator. The static and dynamic stretching programs were identical in amount of time at stretch. Participants were instructed on proper procedures of the stretches by the principal investigator and performed the stretches prior to commencement of the study. Compliance of the stretching protocols was directly monitored by the principal investigator. All of the participants attended 80% of the training sessions. If any participant had less than 80% attendance they would have been dropped from the study (Bandy & Irion, 1994).

Static stretching program. The participants targeted the hamstrings of both legs during the static stretches. The participants performed 2 repetitions of slow and careful static active modified hurdler stretches. The participants held each stretch for 30 seconds at the point of maximal stretch with mild discomfort (Yamaguchi & Ishii, 2005). The procedure was performed on the left leg and then on the right leg after a 20 second rest

period (Yamaguchi & Ishii). The length of the static stretching program was 4 weeks (Chan et al., 2001).

Dynamic stretching program. For the dynamic stretching program, the participants stretched the hamstrings of both legs. The participants performed 4 sets of dynamic stretches on each leg by standing in an upright position and contracting the hip flexors with the knee extended so the leg was swung up to the anterior aspect of the body. This procedure was performed once every 2 seconds so that the target muscle was stretched. A metronome was used for timing of stretches. Stretching was performed 5 times, slowly at first, and then 10 times as quickly and as powerfully as possible without bouncing (Yamaguchi & Ishii, 2005). Stretching was first carried out on the left leg and then, after a 20 second rest period, performed on the right leg (Yamaguchi & Ishii). The dynamic stretching program lasted for 4 weeks (Chan et al., 2001). The flexibility program began within 3 days of the pre-test and the post-test was performed within 3 days of the last day of the flexibility program.

Data Analysis

A one-way multivariate analysis of variance (MANOVA) was utilized to test the difference between the 4-week static stretching program and the 4-week dynamic stretching program on the combination of dominant leg hamstring dynamic-delay flexibility, non-dominant leg hamstring dynamic-delay flexibility, dominant leg hamstring dynamic-movement flexibility, non-dominant leg hamstring dynamic-movement flexibility, and vertical jump. In addition, as a post hoc test, five univariate analysis of variance (ANOVA) were utilized to test the group difference between the 4-week static stretching program and the 4-week dynamic stretching program on each of

the dependent variables (dominant and non-dominant dynamic-delay flexibility, dominant and non-dominant dynamic-movement flexibility, and vertical jump).

Statistical significance was set at an alpha of .05 for each of the dependent variables.

CHAPTER IV

RESULTS

The participants in the study included 25 female high school volleyball players (13 static stretching group, 12 dynamic stretching group). The average age of the sample was 15.1 years ($SD = 1.2$ years). Among the participants, 5 participants (20%) reported significant injuries in the past year and 5 participants (29%) reported not having regular menstrual cycles. None of the participants were in an injured state during the study. Other demographic characteristics (height, weight, and years of experience playing volleyball) are presented in Table 1.

A one-way MANOVA, with an alpha of .05, was run to test the difference between the 4-week static stretching program and the 4-week dynamic stretching program on the combination of dominant leg hamstring dynamic-delay flexibility, non-dominant leg hamstring dynamic-delay flexibility, dominant leg hamstring dynamic-movement flexibility, non-dominant leg hamstring dynamic-movement flexibility, and vertical jump. Age, regular menstrual status, injury history, and years of playing volleyball were dropped from the original analyses because of lack of significance. Descriptive statistics for the variables included in the final model are shown in Table 2.

There was a significant difference between the 4-week static stretching program and the 4-week dynamic stretching program on the combination of dominant leg hamstring dynamic-delay flexibility, non-dominant leg hamstring dynamic-delay flexibility, dominant leg hamstring dynamic-movement flexibility, non-dominant leg

hamstring dynamic-movement flexibility, and vertical jump, $F(10, 38) = 3.89, p = .001$, Wilk's Lambda = .24. The observed power for the multivariate model was .99.

For the post-hoc analyses, five univariate ANOVA's, with an alpha of .05, were used to evaluate the between-subjects effects of pre-test to post-test measures in the 4-week static stretching group and the 4-week dynamic stretching group. Gains in non-dominant leg dynamic-delay hamstring flexibility were significantly higher in the static stretching group than in the dynamic stretching group, $F(2, 23) = 3.68, p = .041$. The observed power for this univariate ANOVA was .62. Gains in dominant leg dynamic-delay hamstring flexibility were significantly higher in the dynamic stretching group than in the static stretching group, $F(2, 23) = 5.48, p = .011$, observed power = .80. Gains in non-dominant leg dynamic-movement hamstring flexibility were significantly higher in the static stretching group than in the dynamic stretching group, $F(2, 23) = 5.81, p = .009$. The observed power for this univariate ANOVA was .82. Gains in dominant leg dynamic-movement hamstring flexibility were not significantly different between the static stretching group and the dynamic stretching group, $F(2, 23) = 3.12, p = .06$. The observed power was .54. Gains in vertical jump were significantly higher in the static stretching group than in the dynamic stretching group, $F(2, 23) = 9.16, p = .001$. The observed power for the univariate ANOVA was .96.

Table 1

Demographic Characteristics of Participants ($N = 25$)

| Variable | <i>M</i> | <i>SD</i> |
|---------------------------------------|----------|-----------|
| Height (in.) | 65.1 | 2.1 |
| Weight (lbs) | 130.4 | 13.4 |
| Experience playing volleyball (years) | 4.5 | 1.2 |

Table 2

Descriptive Statistics for Final Model ($N = 25$)

| Variable | Static ($n = 13$) | | Dynamic ($n = 12$) | |
|------------------------------|---------------------|---------------|----------------------|---------------|
| | <i>M</i> | (<i>SD</i>) | <i>M</i> | (<i>SD</i>) |
| Gains in NDL DD ROM (deg) | 6.9 * | (12.8) | 5.2 | (9.4) |
| Gains in DL DD ROM (deg) | 6.3 | (10.8) | 6.6 * | (8.4) |
| Gains in NDL DM ROM (deg) | 4.4 ** | (6.6) | 4.3 | (6.1) |
| Gains in DL DM ROM (deg) | 4.4 | (7.8) | -0.2 | (4.2) |
| Gains in vertical jump (in.) | 2.1 *** | (2.2) | 1.8 | (2.3) |

Note. DL = Dominant leg. NDL = Non-Dominant leg. DD = Dynamic-delay. DM = Dynamic-movement. ROM = Range of motion.

* $p < .05$. ** $p < .01$. *** $p < .001$.

CHAPTER V

DISCUSSION AND CONCLUSIONS

The purpose of this study was to investigate the effects of a 4-week static stretching and a 4-week dynamic stretching program on dynamic-delay hamstring flexibility, dynamic-movement hamstring flexibility, and vertical jump performance in female high school volleyball players. Either a static stretching program or a dynamic stretching program was introduced to the participants ranging in age from 13 years to 17 years. Pre-test and post-test dynamic-delay and dynamic-movement range of motion were obtained from an isokinetic dynamometer. Vertical jump height measures were obtained from a Vertec before and after the stretching programs. Flexibility data were analyzed by leg dominance to determine changes following the intervention while vertical jump was assessed by overall change.

Background of the Problem

Static stretching has traditionally been used to increase or maintain levels of flexibility and has been shown to be the most effective stretching method for increasing flexibility when compared to ballistic and proprioceptive neuromuscular facilitation (Davis et al., 2005; LaRoche & Connolly, 2006). Further, Bandy et al. (1998) determined that static stretching was more effective than dynamic stretching at increasing hamstring flexibility. However, these findings are limited because the procedure used for dynamic stretching did not parallel recognized methods of dynamic stretching. In general, research on the long-term effects of dynamic stretching on flexibility is lacking.

Dynamic flexibility is the degree to which a joint can be moved to end points in range of motion by active muscle contraction (Prentice, 1999). This definition does not provide for differentiation between flexibility that is measured with a pause at the end of the range of motion and flexibility that is measured without a pause at the end of the range of motion. It would be beneficial for measurements of flexibility to mimic movements in sports and physical activity which do not pause at the end of the range of motion. However, for the purposes of practicality and comparison to other studies, measurement of flexibility should also be performed with a pause at the end of the range of motion so as to mimic traditional static testing techniques. As such, dynamic flexibility was measured under both conditions during the current study.

Muscle strength and running speed have been shown to be enhanced by increased flexibility (Dintimann, 1964; Handel et al., 1997; Worrell et al., 1994). In addition, researchers suggested that gains in rebound bench press (plyometric bench press) among male weight lifters could be from increases in elastic recoil attained from static flexibility training (Wilson et al., 1992). Furthermore, it has been proposed that increasing elastic recoil may enhance vertical jump (Finni et al., 2000). Therefore, the purpose of this study was to investigate the effects of static and dynamic stretching on dynamic-delay hamstring flexibility, dynamic-movement hamstring flexibility, and vertical jump performance in high school volleyball players.

Characteristics of the Sample

This study included female volleyball players with a mean age of 15.1 years and no previous history of lower extremity pathology that may have adversely affected hamstring length. The participants in a study by Bandy et al. (1998) were both male and

female with a mean age of 26.2 years who were not allowed to participate if they had any history of pathology to the lower extremity. Davis et al. (2005) performed a study on flexibility that included participants with a mean age of 23.1 years that did not have a history of illness or injury that would affect the integrity of the hamstrings. The current study is similar to other studies in that participants were required not to have an injury history that would compromise the hamstrings. By comparison, this study used exclusively female participants and included participants that were younger than participants in previous work.

Unlike this study, most authors of flexibility studies combined the results of both dominant and non-dominant legs and presented an overall change in range of motion for both legs. Dividing the lower extremity into dominant and non-dominant legs was incorporated into the study because over 1/3 of the participants had increases in flexibility in one leg while showing decreases in the other leg after 4-weeks of the flexibility program. Separating the legs by dominant leg status was further warranted because of its inclusion in previous strength studies (McCurdy & Langford, 2005), a lack of inclusion in previous flexibility studies (Chan et al., 2001; Davis et al. 2005; Bandy et al., 1998), and differing biomechanical requirements of the dominant and non-dominant legs during volleyball. Although not reported, the combined leg range of motion gain for dynamic-delay flexibility in the current study was $13.2^{\circ} (\pm 19.1^{\circ})$ for the static group and $11.8^{\circ} (\pm 14.6^{\circ})$ for the dynamic group. Davis et al. (2005) found gains in their PNF stretching group to be 13.1° and gains in their active-static stretch group to be 11.5° . It should be noted that there were different methods of assessing hamstring range of motion between the Davis et al. and the current study. Davis et al. assessed hamstring flexibility

through knee extension angle by placing the hip at 90° and measuring the knee angle as it was extended. This technique was not used in this study because the measure of dynamic-movement flexibility would have been difficult and because this technique would not be valid because most female athletes have hamstring range of motion that extends beyond 90° hip flexion. Despite the differing methods of assessing ROM, the results of these two studies are similar. Of interest, if combined leg analyses had been presented, static stretching changes in range of motion would have been statistically greater than dynamic stretching changes in range of motion.

The mean difference between pretest and posttest hamstring flexibility after 6-weeks of intervention, in a study performed by Bandy et al. (1998), was 11.4° for the static group and 4.3° for the dynamic group. While the gains in range of motion for the static group are comparable to this study, the gains in range of motion in the dynamic group are less. A possible reason for the lower gains in range of motion from the dynamic group could be the differing protocols used between the studies. The protocol used by Bandy et al. included a 5-second delay at the end of the stretch. This would prevent rhythmic movements at the end ranges of motion and not allow for inhibition by the golgi tendon organs. Because dynamic stretching likely relies on neurological mechanisms to increase range of motion, it is conceivable that the smaller gains in ROM seen by Bandy et al. were due to the protocol used. This opinion is further supported by the results of this study.

Discussion of Results

Dynamic-delay flexibility. Static stretching produced significantly greater gains in dynamic-delay flexibility than dynamic stretching in the non-dominant leg. However, the

results also indicated that dynamic stretching produced significantly greater gains than static stretching in dynamic-delay hamstring flexibility in the dominant leg.

Consequently, the hypothesis that there would be a significant difference between the 4-week static stretching program and the 4-week dynamic stretching program on dynamic-delay hamstring flexibility was supported.

The different findings between dominant and non-dominant legs indicate leg dominance could be a factor in determining increases in dynamic-delay flexibility. It should be noted that while the power for the dynamic group was strong (.80), the power for the static group was moderate (.62). A possible reason for the power differences between the analyses is the small sums of squares of the static group in the non-dominant leg analysis. Larger group sizes could increase the power of both analyses.

Due to lack of research comparing dominant leg status and various stretching programs, a physiological explanation of the results is difficult. A possible reason for the differing results between dominant leg and non-dominant leg could be exposure to training. The specificity of training principle indicates that adaptations of muscles and tendons are specific to the type of physical stress. Volleyball is a sport that requires the conversion of horizontal velocity to vertical velocity (run to jump). During this process, the non-dominant leg is typically the lead leg for jumping. In this scenario, the lead leg would be placed in maximal eccentric range of motion which would mimic dynamic stretching. The dominant leg would be more involved in the concentric follow through and is not exposed to movements that mimic dynamic stretching. Therefore, dominant and non-dominant legs are exposed to different movements while training for volleyball. The mean number of years of volleyball playing experience for the current participants

was 4.5 years. This length of time would seem to give ample time for players to adapt to movements in the non-dominant leg that mimic dynamic stretching. Therefore, a possible explanation for static stretching resulting in greater gains in the non-dominant leg is that adaptation to the dynamic-like movements seen in the run-to-jump maneuver had occurred during the playing history. Also, due to lower exposure to similar dynamic stretching movements, the dominant leg was more likely to adapt to dynamic stretching.

Dynamic-movement flexibility. Dynamic-movement flexibility was measured because it has been suggested that flexibility measurements should be carried out while a person performs controlled functional movements (Sexton & Chambers, 2006).

Traditional flexibility measurements require a pause at the end of the range of motion. This pause would negate functional motions from occurring. Also, Anderson (2006) suggested that range of motion needs in sports are dependent upon the movements required in the sport. The motion used to assess dynamic-movement flexibility mimics the motion of the lead leg during the transfer of horizontal velocity to vertical velocity. Based on this, dynamic-movement flexibility relates better to volleyball than dynamic-delay flexibility. Dynamic-delay flexibility was included in this study to make comparisons to other studies and to dynamic-movement flexibility.

Static stretching was found to result in significantly greater gains in dynamic-movement flexibility than dynamic stretching in the non-dominant leg. Conversely, neither static nor dynamic stretching was shown to produce significantly greater gains in dynamic-movement flexibility in the dominant leg. Therefore, the hypothesis that there would be a significant difference between the 4-week static stretching program and the 4-week dynamic stretching program on dynamic-hamstring flexibility was also supported.

Even though a significant difference between the static and dynamic groups was not found for the dominant leg, there was a significant difference in the non-dominant leg. This finding indicates that leg dominance also plays a role in dynamic-movement hamstring flexibility. The potential physiological rationalization for the findings in the non-dominant leg is similar between dynamic-delay and dynamic-movement flexibility. Comparisons between dynamic-delay and dynamic-movement flexibility in the dominant leg are hampered by lack of significant findings in dynamic-movement flexibility. Obvious differences can be seen between the group means for the dominant leg (see Table 2). The lower power (.54) of the dominant leg analysis could have played a role in not finding this difference to be significant. The lack of statistical significance may also be attributed to the low sums of squares for the post hoc analysis (248.4). Increasing sample size could possibly increase power and sums of squares and subsequently increase significance.

Vertical jump. The static stretching group had significantly greater gains in vertical jump than the dynamic stretching group. The static stretching group had an increase in vertical jump of 13.1% and the dynamic group had an increase in vertical jump of 11.6%. The analysis showed high observed power (.96). Therefore, the hypothesis that there would be a significant difference between static and dynamic stretching program was supported.

The different findings between static and dynamic groups are difficult to explain in physiological terms. A possible physiological explanation for the different findings could be that the static stretching program promoted increased ability to store elastic energy. Wilson et al. (1992) suggested that increases in rebound bench press were a

result of increases in elastic recoil attained through static stretching. Recoil of elastic tissue during the vertical jump is a result of mechanical properties within the muscle. Static stretching employs both mechanical (Magnusson, Simonsen, Aagaard, Kjaer, 1996) and neurological (Avela et al., 1999; Vujnovich & Dawson, 1994) resources to increase range of motion. Research is lacking concerning the mechanisms by which dynamic stretching increases range of motion. However, due to similarities with ballistic stretching, it is reasonable to suggest that dynamic stretching mainly impacts neurological properties in increasing flexibility. The specificity of training principle recognizes that adaptations to training are specific to the type of exercise (Heyward, 2006). If static stretching stresses the mechanical properties of the muscular-tendon complex and dynamic stretching does not, it is plausible that static stretching is more likely to cause adaptations in elastic recoil. Therefore, by this line of reasoning, it is conceivable that static stretching resulted in greater gains in vertical jump because of more specific stresses to the mechanical properties of the muscle-tendon complex.

Hunter and Marshall (2002) showed that static stretching could result in gains in a countermovement jump. However, these gains were shown to be greater when static stretching was combined with power training. It should be noted that both groups in the current study were involved in the same pre-season plyometric program during the study. Therefore, the amount of contribution that both the static and dynamic stretching programs yielded to increases in vertical jump is unclear. However, the results do infer that static stretching will produce greater results in vertical jump height than dynamic stretching when both are included in a plyometric program. Kokkanen, Nelson, Eldridge, and Winchester (2007) showed a significant improvement in vertical jump height (6.7%)

following 10 weeks of static stretching. According to Kokkanen et al., the improvements seen in vertical jump could have been the result of increased strength due to muscle hypertrophy. Coutinho, Gomes, Franca, Oishi, and Salvini (2004) found that statically stretching muscles 3 days a week for 3 weeks increased muscle length 5% ($\pm 2\%$), serial sarcomere number 4% ($\pm 4\%$), and fiber area 16% ($\pm 44\%$) in the soleus muscle of rats. These studies indicate that chronic static stretching could lead to an increase in strength. Research on the effects of dynamic stretching on strength is lacking. However, based on the different mechanisms used for static and dynamic stretching and the results of this study it is possible that static stretching will result in greater gains in strength than dynamic stretching.

Overall Conclusions and Future Considerations

Several researchers have suggested that static stretching is superior at increasing ROM when compared to other methods of stretching (Bandy et al., 1998; Davis et al., 2005; LaRoche & Connolly, 2006). However, no researcher has examined the role of dominant leg status and type of stretching. The results from this study clearly identify different responses to static and dynamic stretching in the dominant and non-dominant legs. A possible reason for different responses could be different physiological adaptations in dominant and non-dominant legs during volleyball training and competition.

Bandy et al. (1998) found that dynamic stretching was inferior to static stretching in producing gains in ROM. The description of dynamic stretching used in the study by Bandy et al. was a supine position with a 5-second pause at the end range of motion. Dynamic stretching is described as stretching that “utilizes speed of movement that

avoids bouncing and includes sport specific movements” (Baechle & Earle, 2000, p. 325). This description used by Bandy et al. appears to be a hybrid of static and dynamic stretching. The current study used a protocol of dynamic stretching that is more similar to Baechle and Earle’s description and it was shown that dynamic stretching produced significantly greater increases in flexibility in the dominant leg. This indicates that dynamic stretching performed in the manner described by Baechle and Earle is effective. It should be noted that Bandy et al. did not show effects on dominant versus non-dominant legs.

The current results indicate that static stretching is the better method of stretching to be included in a conditioning program when working to improve vertical jump. However, while this study fails to determine whether static or dynamic stretching actually played a direct role in the increase in vertical jump, it does show that including static stretching in a conditioning program results in greater increases in vertical jump than dynamic stretching. Future studies should be performed that compare the effects of both static and dynamic stretching on vertical jump while excluding forms of training that may influence vertical jump.

Leg dominance was determined by the leg each participant used to kick a ball. The reason for using this definition was its common use in other studies (Guette, Gondin, & Martin, 2005; McCurdy & Langford, 2005). It should be noted that using the kicking leg as the test for dominance is not specific to volleyball. Volleyball is a sport that includes several skills, but kicking is not one of them. Future studies similar to this one should use a leg dominance test that is more specific to volleyball.

The results of this study suggest that including both static and dynamic stretching would be the best approach to increasing flexibility in both the dominant and non-dominant legs. Strength coaches, athletic trainers, and other professionals involved with the conditioning of volleyball players should consider these findings when incorporating flexibility training into overall conditioning programs. Future research should compare the effects of static and dynamic stretching on flexibility by leg dominance in sports other than volleyball. Also, further studies should be implemented that examine muscle groups other than the hamstrings. Overall, this study shows that both static and dynamic stretching are effective at increasing dynamic-delay flexibility, static stretching is more effective at increasing dynamic-movement flexibility in the dominant leg, and that including static stretching in a conditioning program will increase vertical jump more than including dynamic stretching in a conditioning program.

REFERENCES

- American College of Sports Medicine. (2006). *ACSM's guidelines for exercise testing and prescription (7th ed.)*. Philadelphia: Lippincott, Williams & Wilkins.
- Andersen, J. (2006). Flexibility in performance: Foundational concepts and practical issues. *Athletic Therapy Today, 11*, 9-12.
- Anderson, J. (2006). The satellite cell as a companion in skeletal muscle plasticity: Currency, conveyance, clue, connector, and colander. *The Journal of Experimental Biology, 209*, 2276-2292.
- Avela, J., Kyrolainen, H., & Komi, P. (1999). Altered reflex sensitivity after repeated and prolonged passive muscle stretching. *Journal of Applied Physiology, 86*, 1283-1291.
- Baechle, T., & Earle, R. (2000). *Essentials of strength training and conditioning (2nd ed.)*. Champagne, IL: Human Kinetics.
- Bandy, W., & Irion, J. (1994). The effect of time on static stretch on the flexibility of the hamstring muscles. *Physical Therapy, 74*, 845-850.
- Bandy, W., Irion, D., & Briggler, M. (1998). The effect of static stretch and dynamic range of motion training on the flexibility of the hamstring muscles. *Journal of Orthopedic and Sports Physical Therapy, 27*, 295-300.
- Beckenham, M., & Rosemond, D. (2006). Establishing an ideal stride pattern for a potential elite female 400m hurdler. *Athlete and Coach, 44*, 3-11.
- Bixler, B., & Jones, R. (1992). High-school football injuries: Effects of a post-halftime warm-up and stretching routine. *Family Practice Research Journal, 12*, 131-139.

- Bruton, A. (2002). Muscle plasticity: Response to training and detraining. *Physiotherapy, 88*, 398-408.
- Burkett, L., Phillips, W., & Ziuratis, J. (2005). The best warm-up for the vertical jump in college-age athletic men. *Journal of Strength and Conditioning Research, 19*, 673-676.
- Chan, S., Hong, Y., & Robinson, P. (2001). Flexibility and passive resistance of the hamstrings of young adults using two different static protocols. *Scandinavian Journal of Medicine and Science in Sports, 11*, 81-86.
- Cornelius, W., Jensen, R., & Odell, M. (1995). Effects of PNF stretching phases on acute arterial blood pressure. *Canadian Journal of Applied Physiology, 20*, 222-229.
- Cornwell, A., & Nelson, A. (1997). The acute effects of passive stretching on active musculotendinous stiffness. *Medicine and Science in Sport and Exercise, 29*, s281.
- Coutinho, E., Gomes, A., Franca, C., Oishi, J., & Salvini, T. (2004). Effect of passive stretching on immobilized soleus fibermorphology. *Brazilian Journal of Medical and Biological Research, 37*, 1853-1861.
- Craib, M., Mitchell, V., Fields, K., Cooper, T., Hopewell, R., & Morgan, D. (1996). The association between flexibility and running economy in sub-elite male distance runners. *Medicine and Science in Sport and Exercise, 28*, 737-743.
- Davis, D., Ashby, P., McCale, K., McQuain, J., & Wine, J. (2005). The effectiveness of 3 stretching techniques on hamstring flexibility using consistent stretching parameters. *Journal of Strength and Conditioning Research, 19*, 27-32.

- Dintiman, G. (1964). Effects of various training programs on running speed. *Research Quarterly*, 35, 456-463.
- Faigenbaum, A., Kang, J., McFarland, J., Bloom, J., Magnatta, J., Ratamess, N., et al. (2006). Acute effects of different warm-up protocols on anaerobic performance in teenage athletes. *Pediatric Exercise Science*, 17, 64-75.
- Finni, T., Komi, P., & Lepola, V. (2000). In vivo human triceps surae and quadriceps femoris muscle function in a squat jump and counter movement jump. *European Journal of Physiology*, 83, 416-426.
- Fletcher, I., & 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.
- Ford, G., Mazzone, M., & Taylor, K. (2005). The effect of 4 different durations of static hamstring stretching on passive knee-extension range of motion. *Journal of Sport Rehabilitation*, 14, 95-107.
- Gleim, G., & McHugh, M. (1997). Flexibility and its effects on sports injury and performance. *Sports Medicine*, 24, 289-299.
- Godges, J., MacRae, P., & Engelke, K. (1993). Effects of exercise on hip range of motion, trunk muscle performance, and gait economy. *Physical Therapy*, 73, 468-477.
- Gollhofer, A., Schopp, A., Rapp, W., & Stroinik, V. (1998). Changes in reflex excitability following isometric contraction in humans. *European Journal of Physiology*, 77, 89-97.

- Guette, M., Gondin, J., & Martin, A. (2005). Time-of-day effect on the torque and neuromuscular properties of dominant and non-dominant quadriceps femoris. *Chronobiology International*, 22, 541-558.
- Handel, M., Horstmann, T., Dickhuth, H., & Gulch, R. (1997). Effects of contract-relax stretching training on muscle performance in athletes. *European Journal of Applied Physiology*, 76, 400-408.
- Hartig, D., & Henderson, J. (1999). Increasing hamstring flexibility decreases lower extremity overuse injuries in military basic trainees. *American Journal of Sports Medicine*, 27, 173-176.
- Henricson, A., Fredriksson, K., Persson, I., Pereira, R., Rostedt, Y., & Westlin, N. (1984). The effect of heat and stretching on the range of hip motion. *Journal of Orthopaedic & Sports Physical Therapy*, 6, 110-115.
- Heyward, V. (2006). *Advanced fitness assessment and exercise prescription (4th ed.)*. Champagne, IL: Human Kinetics.
- Hunter, J. P., & Marshall, R. N. (2002). Effects of power and flexibility training on vertical jump technique. *Medicine and Science in Sports and Exercise*, 34, 478-486.
- Knudson, J., Bennett, K., Corn, R., Leick, D., & Smith, C. (2001). Acute effects of stretching are not evident in the kinematics of the vertical jump. *Journal of Strength and Conditional Research*, 15, 98-101.
- Kokkonen, J., Nelson, A.G., Eldridge, C., & Winchester, J.B. (2007). Chronic static stretching improves exercise performance. *Medicine and Science in Sport and Exercise*, 39, 1825-1831.

- Kovanen, V., Suominen, H., & Heikkinen, E. (1984). Mechanical properties of fast and slow skeletal muscle with special reference to collagen and endurance training. *Journal of Biomechanics*, *17*, 725-735.
- Kubo, K., Kanehisa, H., & Fukunaga, T. (2002). Effects of transient muscle contractions and stretching on the tendon structures in vivo. *Acta Physiologica Scandinavica*, *175*, 157-164.
- Kubo, K., Kanehisa, H., Kawakami, Y., & Fukunaga, T. (2001). Influence of static stretching on viscoelastic properties of human tendon structures in vivo. *Journal of Applied Physiology*, *90*, 520-527.
- LaRoche, D., & Connolly, D. (2006). Effects of stretching on passive muscle tension and response to eccentric exercise. *The American Journal of Sports Medicine*, *34*, 1000-1007.
- Little, T., & Williams, A. (2006). Effects of differential stretching protocols during warm-ups on high-speed motor capacities in professional soccer players. *Journal of Strength and Conditioning Research*, *20*, 203-207.
- Madding, S., Wong, J., Hallum, A., & Medeiros, J. (1987). Effect of duration of passive stretch on hip abduction range of motion. *The Journal of Orthopaedic and Sports Physical Therapy*, *8*, 409-416.
- Magnusson, S., Simonsen, E., Aagaard, P., Sorensen, H., & Kjaer, M. (1996). A mechanism for altered flexibility in human skeletal muscle. *The Journal of Physiology*, *497*, 291-298.

- Magnusson, S. Simonsen, S., Aagaard, P., & Kjaer, M. (1996). Biomechanical responses to repeated stretches in human hamstring in vivo. *American Journal of Sports Medicine, 24*, 622-628.
- McCurdy, K., & Langford, G. (2005). Comparison of unilateral squat strength between the dominant and non-dominant leg between men and women. *Journal of Sport Science and Medicine, 4*, 153-159.
- McHugh, M., Connolly, D., Eston, R., Kremenec, I., Nicholas, S., & Gleim, G. (1999). The role of passive muscle stiffness in symptoms of exercise-induced muscle damage. *American Journal of Sport Medicine, 27*, 594-598.
- McNeal, J., & Sands, W. (2003). Acute static stretching reduces lower extremity power in trained children. *Pediatric Exercise Science, 15*, 139-145.
- Nelson, A., Kokkonen, J., & Arnall, D. (2005). Acute muscle stretching inhibits muscle strength endurance performance. *Journal of Strength and Conditioning Research, 19*, 338-343.
- Nelson, A., Kokkonen, J., Eldredge, C., Cornwell, A., & Glickman-Weis, E. (2001). Chronic stretching and running economy. *Scandinavian Journal of Medicine and Science in Sports, 11*, 260-265.
- Nelson, R., & Bandy, W. (2004). Eccentric training and static stretching improve hamstring flexibility of high school males. *The Journal of Athletic Training, 39*, 254-258.
- Osternig, L., Robertson, R., Troxel, R., & Hansen, P. (1997). Muscle activation during proprioceptive neuromuscular facilitation (PNF) stretching techniques. *American Journal of Physical Medicine and Rehabilitation, 66*, 298-307.

- Papadopoulos, G., Siatras, T., & Kellis, S. (2005). The effect of static and dynamic stretching exercise on the maximal isokinetic strength of the knee extensors and flexors. *Isokinetics and Exercise Science, 13*, 285-291.
- Petit, J., Fillipi, G., Emonet-Denand, F., Hunt, C., & Laporte, Y (1990). Changes in muscle stiffness produced by motor units of different types in peroneus longus muscle of cat. *Journal of Neurophysiology, 63*, 190-197
- Pope, R., Herbert, R., Kirwan, J., & Graham, B. (2000). A randomized trial of preexercise stretching for prevention of lower limb injury. *Medicine and Science in Sports and Exercise, 32*, 271-277.
- Pousson, M., Hoecke, J., & Goubel, F. (1990). Changes in elastic characteristics in human muscle induced by eccentric exercise. *Journal of Biomechanics, 23*, 343-348.
- Pousson, M., Perot, C., & Goubel, F. (1991). Stiffness changes and fiber type transitions in rat soleus muscle produced by jumping training. *European Journal of Physiology, 419*, 127-130.
- Prentice, W. (1999). *Rehabilitation techniques in sports medicine (3rd ed.)*. Philadelphia: McGraw-Hill.
- Rennie, M., Wackerhage, H., Spangenburg, E., & Booth, F. (2004). Control of the size of human mass. *Annual Reviews in Physiology, 66*, 799-828.
- Rosenbaum, D., & Henning, E. (1995). The influence of stretching and warm-up exercises on Achilles-reflex activity. *Journal of Sport Science, 13*, 481-490.
- Sexton, P., & Chambers, J. (2006) The importance of flexibility for functional range of motion. *Athletic Therapy Today, 11*, 13-17.

- Shellock, F., & Prentice, W. (1985). Warming-up and stretching for improved physical performance and prevention of sports related injuries. *Sports Medicine*, 2, 267-278.
- Shrier, I. (1999). Does stretching improve performance? A systematic and critical review of the literature. *Clinical Journal of Sports Medicine*, 14, 276-273.
- Siatras, T., Papadopoulos, G., Mameletzi, D., Gerodimos, V., & Kellis, S. (2003). Static and dynamic acute stretching effect on gymnasts speed in vaulting. *Pediatric Exercise Science*, 15, 383-391.
- Vujnovich, A., & Dawson, N. (1994). The effects of therapeutic muscle stretch on neural processing. *Journal of Orthopedic and Sports Physical Therapy*, 20, 145-153.
- Wallmann, H., Mercer, J., & McWhorter, J. (2005). Surface electromyographic assessment of the effect of static stretching of the gastrocnemius on vertical jump performance. *Journal of Strength and Conditioning Research*, 19, 684-688.
- Weerapong, P., Hume, P., & Kolt, G. (2004). Stretching: Mechanisms and benefits for sports performance and injury prevention. *Physical Therapy Reviews*, 9, 189-206.
- Wiemann, K., & Hahn, K. (1997). Influences of strength, stretching, and circulatory exercises on flexibility parameters of the hamstrings. *International Journal of Sports Medicine*, 18, 340-346.
- Wilson, G., Elliot, B., & Wood, G. (1992). Stretch-shorten cycle performance enhancement through flexibility training. *Medicine and Science in Sport and Exercise*, 21, 116-123.

Witvrouw, E., Mahieu, N., Daneels, L., & McNair, P. (2004). Stretching and injury prevention: an obscure relationship. *Sports Medicine*, 34, 443-449.

Worrell, T., Smith, T., & Winegardner, J. (1994). Effects of hamstring stretching on hamstring muscle performance. *Journal of Orthopaedic and Sports Physical Therapy*, 20, 154-159.

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

APPENDICES

APPENDIX A

Informed Consent Form

**Middle Tennessee State University Institutional Review Board
Informed Consent Document for Research**

MTSU
IRB Approved
Date 7/11/07
Exp. 7/11/08

Principal Investigators: John M. Coons and Colleen E. Mahoney
Study Title: The Effects of Static and Dynamic Stretching on Flexibility, Agility, and Vertical Jump
Institution: Middle Tennessee State University

Name of participant: _____ Age: _____

The following information is provided to inform you about the research project and your participation in it. Please read this form carefully and feel free to ask any questions you may have about this study and the information given below. You will be given an opportunity to ask questions, and your questions will be answered. Also, you will be given a copy of this consent form.

Your participation in this research study is voluntary. You are also free to withdraw from this study at any time. In the event new information becomes available that may affect the risks or benefits associated with this research study or your willingness to participate in it, you will be notified so that you can make an informed decision whether or not to continue your participation in this study.

For additional information about giving consent or your rights as a participant in this study, please feel free to contact Tara Prairie at the Office of Compliance at (615) 494-8918.

1. Purpose of the study:

The purpose of this study is to examine the effects of two types of stretching on hamstring flexibility, agility, and vertical jump performance in high school volleyball players.

2. Description of procedures to be followed and approximate duration of the study:

Height will be measured with a stadiometer and weight will be measured with a scale. For dynamic-delay flexibility assessment you will be asked to raise the limb as far as you can actively move it and then hold the limb for 5-seconds at the end range of motion. For dynamic-movement flexibility, you will be asked to raise the limb in a manner that is similar to a kicking motion as far as can be actively moved. You will perform 3 attempts for both dynamic-delay flexibility and dynamic-movement flexibility. These procedures will be performed on both legs.

Reach will be measured in inches with a tape measure that is affixed to a wall. You will be asked to stand next to the affixed tape measure with your right arm abducted and flexed maximally and three measures will be taken. Vertical jump height will be obtained through the use of a Vertec. You will be asked to stand under the Vertec and perform countermovement jump. At the highest point in the jump, you will move the horizontal panes of the Vertec. You will be given a practice jump prior to performing 3 jumps. Agility will be measured through a T-test. During the T-test, you will run as quickly as possible in a T-pattern course. The T-pattern course will be marked with cones and will be time with a single light sensor time gate. You will run 3 T-tests and the best time will be used.

You will be assigned to either static or dynamic stretching groups which will be a part of team training. The stretching programs will be performed 4 times a week for 4 weeks under the direction of John Coons and Colleen Mahoney. The stretches will target the hamstrings of both legs in both types of stretching. For static stretching, you will perform 2 sets of slow and careful static active modified hurdler stretches that will be held for 30 seconds in each stretch. The procedure will be performed on the left leg and then on the right leg after a 20 second rest period. The dynamic stretching program will involve 4 sets of dynamic stretches on each leg, standing in an upright position and contracting the hip flexors with the knee extended so the leg will be swung up to the front of the body. This procedure will be performed once every 2 seconds using a metronome to time the stretches. Stretching is to be performed 5 times, slowly at first, and then 10 times as quickly and powerfully as possible without bouncing. Stretching will first be carried out on the left leg and then after a 20 second rest period, be performed on the right leg.

**Middle Tennessee State University Institutional Review Board
Informed Consent Document for Research**

3. Expected costs:

There are no expected costs during the study.

4. Description of the discomforts, inconveniences, and/or risks that can be reasonably expected as a result of participation in this study:

Slight soreness may occur as a result of participating in the study. No inconveniences and/or risks are expected from participating in this study.

5. Compensation in case of study-related injury:

No compensation will be given in case of study-related injuries.

6. Anticipated benefits from this study:

You are being asked to participate in a study because increased flexibility has been shown to enhance sports performance. Traditionally, static stretching has been used for achieving flexibility, but results of recent studies have shown that static stretching may hinder performance. This has prompted some strength coaches to use other forms of stretching such as dynamic (drills) stretching. However, studies have not been performed on the long term results of dynamic stretching on flexibility. Also, dynamic stretching has been shown to be good for increasing jump height. Unfortunately, studies have not been done looking at the long-term results of dynamic stretching on jumping. Results from this research will reveal the long-term effects of static and dynamic stretching on jumping and hamstring flexibility.

7. Alternative treatments available:

No alternative treatments are available.

8. Compensation for participation:

No compensation for participation in this study will be given.

9. Circumstances under which the Principal Investigator may withdraw you from study participation:

You may be withdrawn from the study for attending less than 80% of the stretching sessions.

10. What happens if you choose to withdraw from study participation:

No penalties will result from withdrawing from this study.

11. Contact information. If you should have any questions about this research study or possibly injury, please feel free to contact **John Coons** and/or **Colleen Mahoney** at **615-898-5545** or my Faculty Advisor, **Jennifer Caputo, Ph.D.** at 615-898-5547.

13. Confidentiality. All efforts, within reason, will be made to keep the personal information in your research record private but total privacy cannot be promised. Your information may be shared with the MTSU University Institutional Review Board or if you or someone else is in danger or if we are required to do so by law.

Middle Tennessee State University Institutional Review Board
Informed Consent Document for Research

STATEMENT BY PERSON AGREEING TO PARTICIPATE IN THIS STUDY

I have read this informed consent document and the material contained in it has been explained to me verbally. I understand each part of the document, all my questions have been answered, and I freely and voluntarily choose to participate in this study.

Date

Signature of volunteer

Consent obtained by:

Date

Signature

Printed Name and Title

APPENDIX B

Assent Form

Middle Tennessee State University Institutional Review Board
 Proposal for Research Using Human Participants
Assent Document for Research Study

MTSU
 IRB Approved
 Date 7/11/07
 Exp. 7/11/08

PI: **John M. Coons and Colleen E. Mahoney**

Version Date:

Title of Study: **The Effects of Static and Dynamic Stretching on Flexibility, Agility, and Vertical Jump**

Institution/Hospital: **Middle Tennessee State University**

This assent document applies to: High School Students

(Examples: children ages 7 – 12, or adults that are unable to legally give informed consent.)

Name of participant _____ Age _____

Below are the answers to some of the questions you may have. If you have any questions about what is written below or have any other questions about this research, please ask them. You will be given a copy of this consent form.

1. Why are you doing this research?

To see if dynamic stretching is good at increasing flexibility, agility, and jumping.

2. What will I do and how long will it take?

Your height, weight, and length from your middle finger to your feet will be measured. How far you can stretch your legs, how high you can jump, and how fast you can run in a "T" pattern" will be measured before and after starting a stretching program that will last four weeks. You will either stretch by holding a stretching or by kicking.

3. Do I have to be in this research study and can I stop if I want to?

You do not have to be in this study and you can stop at any time during the study.

4. Could it make me sick [or sicker]?

Being in this study should not make you sick.

5. Will anyone know that I am in this research study?

Only John Coons, Colleen Mahoney, Richard Farley, and Jennifer Caputo will know you are in this study.

6. How will this research help me or other people?

This study will help coaches know whether or not kick stretching will increase flexibility.

7. Can I do something else instead of this research?

No other participation is needed of you in this study.

8. Who do I talk to if I have questions?

If you should have any questions about this study or possibly injury, please feel free to contact **John Coons and/or Colleen Mahoney** at 615-898-5545 or my Faculty Advisor, **Jennifer Caputo, Ph.D.** at 615-898-5547.

 Date

 Signature of patient/volunteer

Consent obtained by:

 Signature

 Printed Name and Title

APPENDIX C

Demographic Questionnaire/Data Collection Form

DEMOGRAPHIC QUESTIONNAIRE

Age _____

Date of Birth ____/____/____

Have you had a significant injury? (circle one) Yes No N/A

If yes, how many times? _____

If yes, did your injury require surgery? (circle one) Yes No N/A

Are you presently injured? (circle one) Yes No N/A

How many years have you been playing volleyball? _____

Do you have a regular menstrual cycle (every 28 days)? Yes No N/A

DATA COLLECTION FORM

Height _____ in.

Weight _____ lbs.

Dominant leg

L _____ R _____

_____ Pre-Test Dynamic-Delay ROM

L _____ R _____

_____ Pre-Test Dynamic-Movement ROM

L _____ R _____

_____ Pre-Test Reach

1 _____ 2 _____ 3 _____

_____ Pre-Test Vertical Jump

1 _____ 2 _____ 3 _____

_____ Pre-Test T-test

1 _____ 2 _____ 3 _____

_____ Posttest Dynamic-Delay ROM

L _____ R _____

_____ Posttest Dynamic-Movement ROM

L _____ R _____

_____ Posttest Reach

1 _____ 2 _____ 3 _____

_____ Posttest Vertical Jump

1 _____ 2 _____ 3 _____

_____ Posttest T-test

1 _____ 2 _____ 3 _____

APPENDIX D

Rutherford County School Board Approval Letter



RUTHERFORD COUNTY BOARD OF EDUCATION

Harry Gill, Jr., Director of Schools

2240 Southpark Boulevard
 Murfreesboro, Tennessee 37128
 Phone (615) 893-5812 Fax (615) 898-7940

July 10, 2007

John M. Coons
 2315 Mercury Blvd. Apt. F77
 Murfreesboro, TN 37127

Dear Mr. Coons,

The request for your and Colleen E. Mahoney to conduct the study, "The Effect of Static and Dynamic Stretching on Flexibility and Vertical Jump" at Riverdale High School has been approved. For your review, I have also included a link to the Rutherford County of Board of Education Policy 6-26 relative to student testing and surveys used while completing the study.

http://www.rcs.k12.tn.us/rc/policy/policy_manual/chap_6/policy_6_26.htm

When research is conducted in the Rutherford County School System, it is standard procedure for the researcher to request the principal's approval, and if approved, data collection will also be subject to the time frame and conditions that the principal specifies. I emphasize that the research should not interfere with regular instructional program and that other school staff members' involvement be subject to his/her willingness to participate and the demands upon his/her time.

Please contact me again if the Instruction Department can be of assistance.

Sincerely,

Don Odom
 Assistant Superintendent
 Curriculum and Instruction

APPENDIX E

Williamson County School Board Approval Letter

Fwd: Research Proposal

08-003

Subject: Fwd: Research Proposal
From: "Colleen Mahoney" <cemahone@loyno.edu>
Date: Tue, 09 Oct 2007 08:54:18 -0600
To: tprairie@mtsu.edu

Here is the forwarded version--

----- Message Forwarded on Tue, 09 Oct 2007 08:53:43 -0600

From: "David Heath" <davidh@wcs.edu>
To: <cemahone@loyno.edu>
Subject: Research Proposal
Date: Mon, 8 Oct 2007 13:53:01 -0500

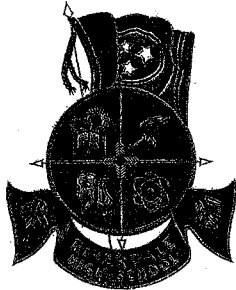
Your request to conduct a research study with students who are members of the Franklin HS volleyball team is approved with the provided the following conditions are met:

1. Each student participating in the study must have a permission slip, signed by their parent or guardian, prior to any participation in the study
2. The original signed permission slip from each student will be submitted to Todd Campbell, assistant principal of Franklin HS, who will maintain the signatures for a period of 1 year after the study is completed.

David Heath, EdD
Deputy Superintendent
Williamson County Schools

APPENDIX F

Permission from Riverdale High School Principal



Tom Nolan, Principal

Riverdale High School

802 Warrior Drive
Murfreesboro, Tennessee 37128
Phone 615-890-6450
Fax 615-890-9790

Bill Spurlock, Assistant Principal
Robert James, Assistant Principal
Karon Robinson, Assistant Principal
Tom Ridley, Assistant Principal

May 11, 2007

I give my permission to John Coons to perform the study "The Effect of Static and Dynamic Stretching on Flexibility and Vertical Jump".

This will be performed for the Riverdale High School volleyball team.

A handwritten signature in black ink, appearing to read "T. V. Nolan".

Thomas V. Nolan

APPENDIX G

Permission from Franklin High School Principal

Franklin High School

810 Hillsboro Road,
Phone: (615) 472-4450

Executive Principal: Willie Dickerson

Assistant Principals: Todd Campbell,
Pamela Lankford, Lily Leffler,
Christian Niemeyer



An International Baccalaureate School

Franklin, TN 37064
Fax: (615) 472-4478

Guidance Counselors: Lee Motyka,
Vicki Crowell, Angela Sawyers,
Leticia Varela, Susan Womack
Guidance Fax: (615) 472-4479

July 17, 2007

To Whom It May Concern:

As the athletic principal of Franklin High School, I am very excited about Colleen Mahoney and John Coons from your university using our kids in their study. Not only will they make our student-athletes better, but it will set the bar for students who will benefit from this study in the future.

We welcome the study and hope that our student-athletes set the bar at a high level for others to match. If you have any further questions or concerns please feel free to contact me at todde@wes.edu or 615-472-4460.

Sincerely,

Todd E. Campbell, Ed.D.
Assistant Principal
Franklin High School

APPENDIX H

University Institutional Review Board Approval

Office of Compliance

P.O. Box 134
 Middle Tennessee State University
 Murfreesboro, Tennessee 37132
 Office: (615) 494-8918 • Fax: (615) 898-5028
www.mtsu.edu/~research/compliance.html

**MIDDLE
 TENNESSEE**
 STATE UNIVERSITY

July 11, 2007

John M. Coons, Colleen E. Mahoney, Dr. Jennifer Caputo, & Dr. Richard Farley
 Department of Health and Human Performance
jmc4k@mtsu.edu, cem4b@mtsu.edu, jcaputo@mtsu.edu, rfarley@mtsu.edu

RE: Protocol Title: "The Effects of Static and Dynamic Stretching on Flexibility, Agility..."
 Protocol Number: 08-003

Dear Investigator(s),

I have reviewed the research proposal identified above and determined that the study poses minimal risk to participants and qualifies for an expedited review under 45 CFR 46.110 Category 4& 7.

Approval is granted for one (1) year from the date of the original letter for **60** participants.

According to MTSU Policy, a researcher is defined as anyone who works with data or has contact with participants. Anyone meeting this definition needs to be listed on the protocol and needs to provide a certificate of training to the Office of Compliance. **If you add researchers to an approved project, please forward an updated list of researchers and their certificates of training to the Office of Compliance before they begin to work on the project. Any changes to the protocol must be submitted to the IRB before implementing this change.**

Any unanticipated harms to participants or adverse events must be reported to the Office of Compliance at (615) 494-8918 as soon as possible.

You will need to submit an end-of-project report to the Office of Compliance upon completion of your research. Complete research means that you have finished collecting and analyzing data. **Should you not finish your research within the one (1) year period, you must submit a Progress Report and request a continuation prior to the expiration date.** Please allow time for review and requested revisions.

Please note, **all research materials must be retained** by the PI or faculty advisor (if the PI is a student) for at least **three (3) years after study completion**. Should you have any questions or need additional information, please do not hesitate to contact me.

Sincerely,


 Tara M. Prairie
 Research Compliance Officer

