THE RELATIONSHIP BETWEEN AGE AND RANGE OF MOTION ON POWER OUTPUT IN CYCLISTS

A Thesis

Presented to the faculty of the Department of Kinesiology

California State University, Sacramento

Submitted in partial satisfaction of the requirements for the degree of

MASTER OF SCIENCE

in

Kinesiology

(Exercise Science)

by

Lauren Michelle Green

FALL
2012
THE RELATIONSHIP BETWEEN AGE AND RANGE OF MOTION ON POWER OUTPUT IN CYCLISTS

A Thesis

by

Lauren Michelle Green

Approved by:

__________________________, Committee Chair
Daryl Parker

__________________________, Second Reader
Roberto Quintana

__________________________
Date

iii
Student:  Lauren Michelle Green

I certify that this student has met the requirements for format contained in the University format manual, and that this thesis is suitable for shelving in the Library and credit is to be awarded for the thesis.

__________________________, Graduate Coordinator  _______________________
Michael Wright                     Date

Department of Kinesiology
Abstract

of

THE RELATIONSHIP BETWEEN AGE AND RANGE OF MOTION ON POWER OUTPUT
IN CYCLISTS

by

Lauren Michelle Green

Introduction

Increasing age is accompanied by a decrease in muscle mass, muscle fiber size and type and a decrease in muscular power, max strength, explosive force and explosive strength. Flexibility has been promoted as a means to increase performance and reduce injury. However, recent studies have associated acute pre-exercise stretching with reductions in measurements of athletic performance such as power, force and strength. Although many studies show the inhibitory effects of acute stretching and flexibility it has been speculated that chronic flexibility may enhance these same athletic variables. Thus this study aimed to ascertain whether long-term stretching coincides with decrements to athletic performance, specifically power, in cyclists.
Methods

We evaluated the relationship between range of motion (ROM) and peak anaerobic power (\(P_{\text{an,peak}}\), peak aerobic power (\(P_{\text{aer,peak}}\)) and age in two classes of cyclists; young cyclists (YC, age: <35 years old) and master’s cyclists (MC, age: >35 years old). 10 healthy male and female participants; 5 MC and 5 YC who had been cycling consistently for at least one year in a competitive setting were tested in the CSUS Human Performance Laboratory. Testing consisted of a graded exercise test (GXT), Wingate cycle ergometry and ROM measurements of the knee within a two-hour time window at least 24-hours after their last bout of exercise.

Results

There was no significant correlation between age and quadriceps ROM. The correlation coefficient was -0.017 for ROM and age (p= 0.963). There was no significant correlation between age and either anaerobic or aerobic power. The correlation coefficients were 0.34 for \(P_{\text{an,peak}}\) (p= 0.333) and 0.58 for \(P_{\text{aer,peak}}\) (p= 0.081). There was no significant relationship between quadriceps ROM and either anaerobic or aerobic power.

Conclusion

The results of this study suggest that increased ROM has neither a beneficial or detrimental relationship on aerobic or anaerobic power as the subject ages. Our observations support previous research, showing no changes to performance and
therefore recommend stretching must be based on the activity type and level of activity of
the individual in question.

_______________________, Committee Chair
Dr. Daryl Parker

_______________________
Date
ACKNOWLEDGMENTS

Dr. Parker – Thank you for your time and guidance. I appreciate your willingness to push me in the right direction and am grateful for your knowledge and dedication.

Dr. Quintana - Thank you for always lending an ear. Your enthusiasm for our field is contagious and you inspire your students to reach further.

I could not have asked for better support than that received my friends and colleagues. Without the unwavering support of Heather and Max, I do not know how I could have completed this project. You are a delight to collaborate with and brilliant in so many ways. With my deepest gratitude, I cannot thank you enough.

To my family, you were my internal voice pushing me harder each day. Mom and Dad, I never once said, “I can’t.” Thank you for instilling me with strength and reason. Ryan, Sean and Christa, your support and not-so-gentle nudging have driven me to be stronger.

To Blake, my eternal support and strength. You are the best friend I could ever ask for and the love of my life. Thank you for believing in me, supporting me, helping me and sacrificing for me. Your devotion and selflessness make me work harder and dream bigger. I cherish your knowledge and ambition and am eternally grateful for the journey we are on.
# TABLE OF CONTENTS

<table>
<thead>
<tr>
<th>Acknowledgements</th>
<th>viii</th>
</tr>
</thead>
<tbody>
<tr>
<td>List of Tables</td>
<td>xi</td>
</tr>
<tr>
<td>List of Figures</td>
<td>xii</td>
</tr>
<tr>
<td>Chapter</td>
<td></td>
</tr>
<tr>
<td>1. INTRODUCTION</td>
<td>1</td>
</tr>
<tr>
<td>Statement of Purpose</td>
<td>4</td>
</tr>
<tr>
<td>Significance of Thesis</td>
<td>4</td>
</tr>
<tr>
<td>Limitations</td>
<td>5</td>
</tr>
<tr>
<td>Delimitations</td>
<td>5</td>
</tr>
<tr>
<td>Assumptions</td>
<td>5</td>
</tr>
<tr>
<td>Definition of Terms</td>
<td>5</td>
</tr>
<tr>
<td>Hypotheses</td>
<td>7</td>
</tr>
<tr>
<td>2. REVIEW OF LITERATURE</td>
<td>8</td>
</tr>
<tr>
<td>Physiology of Aging</td>
<td>8</td>
</tr>
<tr>
<td>The Measurement of Power Output</td>
<td>13</td>
</tr>
<tr>
<td>Physiology of Acute Stretching</td>
<td>14</td>
</tr>
<tr>
<td>Physiology of Chronic Stretching</td>
<td>16</td>
</tr>
<tr>
<td>Chronic Stretching and Performance</td>
<td>23</td>
</tr>
<tr>
<td>Summary</td>
<td>29</td>
</tr>
<tr>
<td>3. METHODOLOGY</td>
<td>31</td>
</tr>
<tr>
<td>Subjects</td>
<td>31</td>
</tr>
<tr>
<td>Experimental Design</td>
<td>32</td>
</tr>
<tr>
<td>Procedures</td>
<td>32</td>
</tr>
<tr>
<td>Graded Exercise Test</td>
<td>33</td>
</tr>
<tr>
<td>Range of Motion</td>
<td>33</td>
</tr>
<tr>
<td>Quadriceps</td>
<td>34</td>
</tr>
<tr>
<td>Wingate Test</td>
<td>34</td>
</tr>
<tr>
<td>Data Analysis</td>
<td>34</td>
</tr>
</tbody>
</table>
4. RESULTS .................................................................................................................. 36
   Age and Power Output............................................................................................. 36
   Range of Motion and Power Output ................................................................. 37
   Range of Motion and Age..................................................................................... 39
5. DISCUSSION ......................................................................................................... 40
   Conclusion............................................................................................................. 45
Appendix A. Informed Consent .................................................................................. 47
Appendix B. Subject Information and Medical History .......................................... 50
Appendix C. Data Collection Sheet ......................................................................... 53
References.............................................................................................................. 55
<table>
<thead>
<tr>
<th>Tables</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Subject Characteristics</td>
<td>32</td>
</tr>
</tbody>
</table>
# LIST OF FIGURES

<table>
<thead>
<tr>
<th>Figures</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.</td>
<td>4.1 Peak anaerobic power and age</td>
</tr>
<tr>
<td>2.</td>
<td>4.2 Peak aerobic power and age</td>
</tr>
<tr>
<td>3.</td>
<td>4.3 Peak anaerobic power output and quadricep ROM</td>
</tr>
<tr>
<td>4.</td>
<td>4.4 Peak aerobic power output and quadricep ROM</td>
</tr>
<tr>
<td>5.</td>
<td>4.5 Age and quadricep ROM</td>
</tr>
</tbody>
</table>
Between the years of 1990 and 2030 the number of people older than 60 years old is expected to more than double and the average life expectancy of Americans was estimated to climb to 79.7 and 84.3 (for men and women, respectively) (Behm, Bambury, Cahill, & Power, 2004). With increasing age comes a decrease in muscle mass, muscle fiber size and type and a decrease in muscular power, max strength, explosive force and explosive strength (Houmard et al., 1998; Izquierdo et al., 1999; Korhonen et al., 2006; Runge, Rittweger, Russo, Schiessl, & Felsenberg, 2004). A decrease in muscle mass and strength can be predicated with an increased prevalence of disability provoked by a loss of locomotor competence, decreasing independence and increasing risk of fall (Izquierdo et al., 1999; Runge et al., 2004). The loss of muscle mass, or sarcopenia and resulting effects on the body contribute to the increasing health care costs among the elderly.

Research has connected sarcopenia with an increased risk of osteoporosis, insulin resistance, obesity and arthritis. Despite this loss of muscle mass, older adults are urged to participate in muscle strengthening activities only as much as they are urged to participate in activities to increase range of motion; two days per week (Thompson & American College of Sports Medicine, 2010).

Flexibility is a measure of range of motion (ROM) about a joint and is specific to the joint in question. Increased ROM (increased flexibility) is often recognized in being important to general fitness and wellness. In general, ROM is determined by joint structure, muscle elasticity and, and nervous system activity (Brooks, Fahey, & Baldwin,
2005). Joint health, injury prevention, reduction of delayed-onset muscle soreness, relief of aches and pains, improved body position and strength for sports and maintenance of posture contribute to an individual’s ROM.

The type of stretching (static vs. dynamic) and type of muscular activity (eccentric vs. concentric) can predict the effects that stretching will have on performance (Thompson & American College of Sports Medicine, 2010; Yamaguchi & Ishii, 2005). Static flexibility exercises pertain to reaching a point within a joint’s range of motion and holding this position whereas dynamic flexibility refers to moving throughout a joint’s range of motion quickly without resistance. Traditionally, stretching has been used during warm-up phase to increase ROM in an attempt to reduce injury and advance athletic performance (Marek et al., 2005; Thompson & American College of Sports Medicine, 2010). According to the American College of Sports Medicine, healthy adults including older adults should perform flexibility exercises 2-3 days per week, after the conditioning phase. Whereas all types of stretching activities are recommended for normal healthy adults, older adults are recommended to limit their stretching to be of the static variety (Behm et al., 2004). Chronic stretching is often recommended across all age groups to increase active ROM (Thompson & American College of Sports Medicine, 2010).

Recent studies have associated an acute bout of pre-performance stretching (especially that of the static variety) with reductions in measurements of athletic performance, such as power, force and strength (Behm et al., 2004). For instance, pre-performance stretching has been demonstrated an inhibitory effect on running speed, vertical jump performance (Power, Behm, Cahill, Carroll, & Young, 2004; Young &
Behm, 2003), and maximal force or torque production (Avela, Kyröläinen, & Komi, 1999; Fowles, Sale, & MacDougall, 2000; Nelson, Guillory, Cornwell, & Kokkonen, 2001). Power and his associates (2004) have shown that following a routine of static stretching torque of the quadriceps for maximum voluntary contraction decreased by 9.5% (Power et al., 2004). In addition, in a review looking at the effects of acute stretching and maximum voluntary contraction, power, jump height, force and velocity, Shrier found 20 out of 23 acute stretching studies reported diminished performance attributes (Shrier, 2004).

Although many studies show the inhibitory effects of acute stretching and flexibility it has been speculated that inflexibility in certain areas of the musculoskeletal system may enhance power output in several sports (Craib et al., 1996). In addition, the effects of chronic stretching are still widely unknown. Seven of the studies reviewed by Shrier suggest that chronic stretching might prove to have the opposite effect to that of an acute bout of stretching, increasing performance variables while only two articles showed neither a deficit nor gain in any variable (Shrier, 2004). The mechanism for these proposed increases is still widely unaccounted for however, it has been proposed that chronic stretching imparts changes to mechanoreceptors, dampening muscle signal transmission and subsequently muscle activation (J Kokkonen, Nelson, & Cornwell, 1998). In addition, the positive outcomes of chronic stretching are hypothesized to be a result of muscular hypertrophy (Joke Kokkonen, Nelson, Eldredge, & Winchester, 2007). Whether these changes can be accounted for amongst all age and athletic groups is invariably unknown. A majority of past research has solely looked at the effects on a
population younger than 40 years of age and limited array of athletic performance
variables such as 50-yard dash, maximal velocity of contraction (MVC), contraction
velocity, eccentric and concentric contraction force and counter movement jump height
(Shrier, 2004). If decreases or delays in muscle activation occur, movements could take
more time as the elongated state could account for a decreased contraction speed
(Rosenbaum & Hennig, 1995). The effect of a decreased contraction speed could amount
to a greater incidence for falling for someone who is already experiencing abatements to
performance.

**Statement of Purpose**

The purpose of this study was to ascertain whether the changes in range of motion
that occur with age correlate to a decrease in athletic performance in trained cyclists.

**Significance of the Thesis**

Research such as this can help us better identify the underlying nervous, tendon
and mechanical variables contributing to range of motion and to what extent these
variables alter performance in terms of power output and endurance capabilities. In terms
of an aging society, this information will better help us prescribe more suitable stretching
and exercise protocols to those who may be already seeing declines in strength and
power.
Limitations

1. The study was limited to analyzing those tests performed at certain times during the year and their individual training regime.
2. Subject’s prior experience with laboratory testing and the Wingate protocol was not assessed.
3. Exposure to flexibility training was not assessed.

Delimitations

1. All subjects were healthy, trained cyclists.
2. All data was collected in a controlled environment.
3. Subjects limited exercise a day prior to testing to limit fatigue.

Assumptions

1. Subjects adhered to exercise testing protocol and provide honest assessment of fatigue and stretching.
2. Peak power and VO$_{2\text{max}}$ corresponded to actual ability to produce power in a competitive setting.
3. Range of motion measurements were representative of subject’s flexibility.
4. All subjects were healthy, trained cyclists.

Definition of Terms

- Musculotendinous Stiffness – the relationship between a force and the deformation that force has on the object in question (Eiling, Bryant, Petersen, Murphy, & Hohmann, 2007).
- Musculotendinous Unit (MTU) – Combination of the muscle, tendon and bone working together as one functional unit (Hersche & Gerber, 1998).
- Maximal Voluntary Contraction (MVC) – the maximal force produced by a contracting muscle as it pulls against an object (Hortobágyi, Faludi, Tihanyi, & Merkely, 1985).
- Muscle Activation – upon receiving a neural impulse, neurotransmitters are released, creating an electrical charge, allowing sodium to enter (depolarization) and allowing an action potential to be generated (Wilmore, Costill, & Kenney, 2008).
- Peak Anaerobic Power ($P_{an,peak}$) – a measure of performance looking at the body’s ability to produce all-out peak anaerobic power and anaerobic capacity (H, G, & H, 1987).
- Peak Aerobic Power ($P_{aer,peak}$) – the power that corresponds to maximal oxygen uptake (Chamari, Ahmaidi, Fabre, Massé-Biron, & Préfaut, 1995).
- Range of Motion – amount of movement about a joint, determined by joint structure, muscle elasticity and, and nervous system activity (Brooks et al., 2005)
- Static Stretching – a slow gradual stretch lasting 10-30 seconds that puts the muscle into a position of pull but not to the point of pain (Brooks et al., 2005).
- Surface Electromyography (EMG) – a technique to record and evaluate skeletal muscle electrical activity (Robertson, 2004).
- **VO$_{2\text{max}}$** – the maximum capacity of an individual’s body to transport and consume oxygen (Brooks et al., 2005).

- **Warm-up** – a pre-exercise period intended to prepare one for the efficient and safe functioning of the cardiovascular, pulmonary and muscular systems by increasing breathing, blood flow and heart rate etc. (Wilmore et al., 2008).

- **Wingate Cycle Ergometry** – a test performed on a cycle ergometer aimed at measuring peak anaerobic performance (H et al., 1987).

**Hypotheses**

1. There will be no significant relationship between range of motion and either anaerobic or aerobic peak power.

2. There will be a significant relationship between age and range of motion.

3. There will be a significant relationship between age and peak power.
Chapter 2

REVIEW OF LITERATURE

This chapter will review current topics pertaining to the effects of flexibility on both aging and performance variables. Material presented in this chapter includes: changes to muscular and connective tissue, performance and flexibility as a result of aging; differences between acute and chronic flexibility and the physiological determinants that account for these changes. Additional material will discuss the differences between chronic flexibility and stiffness and the effects on athletic variables as a result of both and, measurements of power output and past usage of Wingate testing.

Physiology of Aging

Muscle Fiber Type and Aging

The aging process can be detrimental to the musculoskeletal system, as it has a discernible impact on both the functional and structural components. Performance deficits such as decreases in explosive force and maximal strength can first become evident in the fourth decade of life with losses in power being evident more so than losses in strength (Izquierdo et al., 1999; Metter, Conwit, Tobin, & Fozard, 1997). These losses occur as a result of a loss of both muscle size and amount of muscle fibers (muscle mass), specifically fast twitch motor units (type II fibers) which are responsible mostly for power output. In assessing losses of individual fiber type using whole muscle cross-sectional studies, Lexell et al. (1986) found an equally evident loss of both type I and type II fibers with increasing age (Lexell, Downham, & Sjöström, 1986; Lexell, Henriksson-Larsén, Winblad, & Sjöström, 1983; Lexell, Taylor, & Sjöström, 1988).
Although Lexell found fiber number loss to occur consistently between Type I and Type II fibers, it was also found that fast-twitch fiber cross-sectional area atrophies at a higher rate. Whereas size difference in type I fibers did not differ with increasing age, there was a 26% loss amongst cross-sectional area with type II fibers (Lexell et al., 1988). In a study evaluating the fiber-type distribution, cross-sectional area and myosin heavy chain (MHC) isoform content in 18-84 year-old male sprinters, biopsy samples were taken from the vastus lateralis. It was determined that the cross-sectional area of type II fibers was reduced with age while that of type I fibers remained the same. In addition MHC IIx isoform content decreases while MHC I increased, which may mirror the atrophy of the type II fibers (Korhonen et al., 2006).

**Soft Tissue Properties and Aging**

Soft tissues of the body, such as tendons, ligaments and cartilage are associated with tensile properties involved in human movement; specifically load-bearing capabilities, load-distribution, compression, force-production and muscle damage prevention (Humphrey, 2003). In addition to physiological changes such as muscle atrophy, losses in strength, force and power, degradation of dense fibrous tissues resulting in increased muscle and joint stiffness have also been reported to occur with aging (Buckwalter et al., 1993). Degradation of soft tissues that are responsible for tensile strength, like those surrounding the joint capsule, have been shown to cause restriction of motion, pain with movement and weakness (Jette, Branch, & Berlin, 1990). In some ligament-bone complexes, tensile properties have been reported to noticeably decrease with age (Buckwalter et al., 1993). In a study of 27 pairs of human cadaver
knees, Woo found linear stiffness, ultimate load, and energy absorbed decreased significantly with increasing specimen age (Woo, Hollis, Adams, Lyon, & Takai, 1991).

**Aging and Flexibility**

Although there are thought to be many benefits to stretching, many of the studies that have shown the potential positive influences have been done using a younger population, usually between the ages of 18 and 39 years. As a result, the improvements suggested may not translate to all age groups (Feland, Myrer, Schulthies, Fellingham, & Measom, 2001). One of the major changes that occurs in dealing with flexibility and range of motion is an increase of muscle and joint stiffness with increased amounts of fibrous connective tissue (Spence, 1989). Additionally, research has shown declines in both passive and active ROM between 70-92 years of age in the lower-limb joints (B & Aw, 1989).

Feland et al. compared the effects of 6 weeks of repeated hamstring stretches that lasted 15, 30, or 60 seconds to determine whether ROM gains were correlated with longer stretch durations. Sixty-two apparently healthy older adults (range= 65-97, mean age= 84.7) without prior hip or knee replacements and without lower back injuries participated. Subjects were placed in 1 of 4 groups and were assessed for physical activity level. Group 1 the control group performed no stretching. Groups 2 (mean age 85.5), 3 (mean age 85.2) and 4 (mean age 83.2) were stretched 5 times a week for 6 weeks for 15, 30 and 60 seconds (respectively) on a randomly selected right or left limb. Range of motion tests were taken once a week via goniometer at the knee joint to measure knee extension. The authors found that a 60-second stretch (group 4) produced greater ROM gains than 30
and 15-second stretches (group 3 and group 2, respectively). The gains made by group 4 persisted longer than the gains made by groups 2 and 3.

_Aging and Performance_

In addition to the decreased flexibility, locomotor capacity, stability, bone density, muscle mass and strength, joint stability and mobility (Brooks, 2007), research has also shown that anaerobic power reduces with age. 12 young athletes (YA, ages 18-33) and 12 master athletes (MA, ages 59-72) with similar heights, mass and endurance training schedules underwent two exercise tests; a VO\textsubscript{2max} test and a force-velocity (F-v) test via both using a cycle ergometer. The VO\textsubscript{2max} test consisted of a 3-min, 30 W warm-up at an rpm of 60 and then was followed by incremental increases of 30 W min\textsuperscript{-1}. VO\textsubscript{2} was considered maximal if at least 3 of the following were attained: 1) a plateau in VO\textsubscript{2} despite an increase in load; 2) an RER of greater than 1.10; 3) theoretical HR\textsubscript{max} was attained within 5%; 4) subject was unable to continue pedaling at 60 RPM. Power developed by the subject at VO\textsubscript{2max} was considered peak aerobic power (P\textsubscript{aer,peak}). The F-v test determined the peak anaerobic power (P\textsubscript{anaer,peak}). A 4-min warm-up at 30% of P\textsubscript{aer,peak}, with a short, 6-second acceleration at the end of each minute preceded the test. 5 minutes of passive recovery immediately followed the warm-up. The F-v test consisted of repetitive, 6-second sprints against increasing breaking forces, followed by a 5-minute fixed recovery period. The test began against a force of 15 N for MA and 20 N for YA and was thereafter increased by 15 N and 20 N for MA and YA respectively. The authors found peak anaerobic power output was 42.7% lower in the older subjects. However, peak aerobic power was 35% lower for YA than for MA (Chamari et al., 1995).
Izquierdo et al. (1999) studied the relationship between age and maximal strength and power in middle-aged and older men. Twenty-six middle-aged men (M40) (mean age 42, range 35-46) and 21 elderly men (M65) (mean age 65, range 60-74) participated in the study. The authors found the muscle cross sectional area, maximal bilateral concentric strength and unilateral knee extension strength to be higher in M40 than in M65 (P < 0.001). They found that the heights of the squat and counter-movement jumps were between 27-29% lower (P < 0.001) and, the maximal rate of force development of the knee extensors and flexors was lower (P < 0.01-0.001) in M65. Additionally, M65 showed lower (P < 0.001) concentric power values for lower and upper extremity tests than those performed by M40. The authors related the declines in performance variable to the normal declines that occur to maximal strength and muscle mass with aging. They suggested that due to the lower force and cross sectional area of the leg extensors, there might be decreases in voluntary drive to the muscles may account for some of these decrements. Additionally, explosive strength and power showed the largest deficits in comparison to maximal isometric strength. The authors suggest that losses in strength are expected to vary depending on the type of action and which extremities are used (Izquierdo et al., 1999).

In a study of 258 apparently healthy men and women (n= 169 women) between the ages of 18 and 88 years, calf muscle cross-sectional (CSA) and jumping mechanography was measured to assess the relationship between CSA and power. CSA was measured with Quantitative Computed Tomography (pQCT) to indicate muscle mass. Jumping mechanography was used to measure peak force. The subject was asked
to perform three one-legged jumps on their dominant leg and the best value was taken as peak force. There were no significant correlations found between muscle cross section and age for either men or women. There were close correlations with age found for peak power and peak force for both men and women ($P < 0.001$). In fact, all parameters of muscle performance were negatively correlated with age ($P < 0.001$). The authors related the age-related declines in power output to several factors including changes in body composition, loss of muscle mass, a greater percentage of slow twitch muscle fibers or even a reduction in central nervous excitability but could not pinpoint which was the primary cause of the age-related declines in physical performance (Runge et al., 2004).

**The Measurement of Power Output**

Power, the product of velocity and force, is also the quantification of explosive ability in regards to strength. The ability to generate power by the body depends on muscle mass, the ability of quick acting energy systems, muscle fiber type and neurological factors. Although strength is an important component of sport, power is more important as it is the practical application of both speed and strength and is responsible for short, intense bouts of activity that are common in many sports.

**Wingate**

The Wingate Cycle Ergometer uses 30-second all out burst of exercise against a predetermined workload to measure power through challenging the nonoxidative energy systems (phosphagen and glycolytic). The Wingate test is the most commonly used testing method for assessing Peak Power (Del Coso & Mora-Rodriguez, 2006) and has been shown to generate 2-4 times the power of a VO2max test. Wingate cycle ergometer testing is commonly used to test Peak Power (PP), Mean Power (MP) and Fatigue Index
(FI) in competitive cycling performance. Evidence strongly suggests that PP is a useful indicator and predictor of cycling performance (Bentley, McNaughton, Thompson, Vleck, & Batterham, 2001).

**Physiology of Acute Stretching**

Stretching has been conventionally recommended in rehabilitation, physical fitness and athletic events with the intent to increase the range of motion, reduce the risk of injury and/or improve performance (Handel, Horstmann, Dickhuth, & Gülch, 1997; D. Casey Kerrigan, Xenopoulous-Oddsson, Sullivan, Lelas, & Riley, 2003; Joke Kokkonen et al., 2007; Magnusson, Simonsen, Aagaard, Sørensen, & Kjaer, 1996). However, recent reviews (Rubini, Costa, & Gomes, 2007; Shrier, 2004) and many previous studies (Behm et al., 2004; J. T. Cramer et al., 2004; Evetovich, Nauman, Conley, & Todd, 2003) have advocated that pre-exercise stretching may have a detrimental effect on the muscles ability to produce torque, power and maximal force. The term “stretching-induced force deficit” (J. T. Cramer et al., 2004) to describe the detrimental performance effects that an acute bout of stretching can have. Detrimental effects include but aren’t limited to: decreases in isometric and isokinetic peak torque (Joel T. Cramer et al., 2004; Fowles et al., 2000); sprinting speed (Winchester, Nelson, Landin, Young, & Schexnayder, 2008); vertical jump performance (Behm & Kibele, 2007); and balance, reaction time and movement time (Behm et al., 2004). Although the precise mechanisms underlying the detrimental effect of acute stretching remain unclear, previous studies have hypothesized that it may be attributed to either “neural” or “mechanical” factors or a combination of both.
Mechanical Adaptations to Acute Stretching

Alterations in the contractile and/or mechanical properties of the musculotendinous unit (MTU) are linked to the stretching-induced force deficit. Nelson et al. (2001) suggested that stretching may alter the muscle’s length-tension relationship by increasing the resting length of the sarcomeres. A more slack parallel and series elastic component could in turn, decreases MTU stiffness and affects the transmission of forces, rate of force transmission, and the rate at which changes in muscle length or tension are detected by reducing the electromechanical delay (Behm et al., 2004). Decreased muscle stiffness can affect induced muscle twitch amplitude because of the increased time to “take up slack” in in-series sarcomeres (Caldwell, 1995). Increased muscle length may alter the ability to produce force at a given angle by altering the combined effort of the muscle properties and joint kinematics (Fowles et al., 2000). Cramer et al. (2004) hypothesized that static stretching decreased peak torque (PT), through alteration of the length tension relationship and torque/ROM relationship, as the joint angle at PT is velocity dependent and occurs closer to full extension with increasing velocity. Fowles et al. (2000) hypothesized that due to a persistent reduced MVC after recovery of activation, other factors affecting force-generating abilities after stretch were due to changes in the length-tension relationship and/or plastic deformation of connective tissue (Fowles et al., 2000). In addition it is thought (Behm et al., 2004) that alteration of the MTU may also alter the ability of the Golgi tendon organ (GTO), found in the musculotendinous junction, to detect and monitor the muscle tension, delaying transmission slower than that of a stiffer MTU.
Neurological Adaptations to Acute Stretching

Several studies have reported post-stretching neural observed as decreases in muscle activation using both surface electromyography (EMG) and the twitch interpolation technique (Behm, Button, & Butt, 2001; Fowles et al., 2000). Fowles et al. (2000) was one of the first to demonstrate the temporary decrease in muscle activation after 30 min of plantar flexor stretching. The authors (Fowles et al., 2000) showed that maximal muscle activation was diminished after the stretching, and this factor accounted for 60%, 68%, 26%, 1%, 13%, and 13% of the stretching-induced force deficit at post, 5, 15, 30, 45, and 60 min, respectively, after stretching. However, the specific causes of the neural deficit were not identified. Behm et al. (2001) also suspected decreases in muscle activation to be responsible for the stretching-induced decreases in maximal force output of leg extensors (Behm et al., 2001).

In addition, Cramer et al. (2004) reported decreases in PT and EMG amplitude after stretching for both the stretched and control (contralateral) leg extensor muscles, which they hypothesized to be partially attributed to an unidentified neural inhibitory mechanism (J. T. Cramer et al., 2004).

Physiology of Chronic Stretching

Although many studies have reported the detrimental effects of acute stretching on performance variables such as force, strength, peak torque and mean power output (J. T. Cramer et al., 2004; Joel T. Cramer et al., 2004; Fowles et al., 2000), a recent review by Shrier (2004) suggest that studies of chronic stretching reported improvements or no change to performance. Out of 9 studies reviewed by Shrier (2004), 7 studies reported
regular stretching to improve performance variables while two studies reported no changes. In addition to an increased ROM, chronic stretching programs have been shown to reduce musculotendinous stiffness (Guissard & Duchateau, 2004) and improve isokinetic peak torque (Worrell, Smith, & Winegardner, 1994), maximal strength (Joke Kokkonen et al., 2007), and concentric bench press work (Wilson, Elliot, & Wood, 1992). The mechanism(s) behind muscle alteration from chronic flexibility is still somewhat limited. Changes to the MTU (Gajdosik, 1991; Magnusson et al., 1996; Reid & McNair, 2004), increased stretch tolerance (LaRoche & Connolly, 2006; Magnusson et al., 1996) and reflex activities have been speculated to be the underlying chronic stretch-induced changes. In addition to the lack of information on the exact mechanism of stretching, experimental methods of previous studies have lacked uniformity in methods, stretching regimens, treatment duration and outcome measures.

**Mechanical Adaptations to Chronic Stretching**

In a study testing the effects of static stretching of the hamstring muscles on the maximal length and resistance to passive stretch, twenty-four healthy men (18-37 years) with an initial straight leg raise (SLR) ≤ 70º, not currently engaged in exercise programs, were randomly assigned to a control group (N=12) or a stretching group (N=12). The stretch training program lasted 21 days and consisted of slow, static stretches lasting 15 seconds. Each stretch was completed 10 times daily with a 15-second in between. Subjects participated in a mock testing session to determine if hamstring EMG activity was within acceptable limits. Prior to beginning the stretch program each subject was tested to determine SLR, maximal resistance to passive stretch (MRPS) and maximal
hamstring length (MHL). With the pelvis stabilized, subjects were positioned on their left sides and right thigh fixed at 90° on a horizontal platform. The right knee was passively extended until amplified EMG activity (>50 μV) from the hamstrings was observed. The angle of the knee (A-Max) represented MHL, and torque, representing MRPS was calculated in Nm. Following the three-week stretching protocol, all testing procedures, including SLR were repeated for each subject. Results showed that SLR and MHL increased (P<0.001) for the stretching group when compared to the control group. Increased MHL occurred with an associated increase in the MRPS for the stretching group (P<0.05) when compared to the control group. The author (Gajdosik, 1991) concluded that due to the concomitant increase in MHL and MRPS, the muscles of the hamstring had undergone passive strengthening adaptations. Such adaptations could be explained by length changes in skeletal muscles of animal models who showed length and passive resistance adaptations (increasing sarcomeres), when immobilized in the lengthened position (Tabary, Tabary, Tardieu, Tardieu, & Goldspink, 1972).

Furthermore, Reid and McNair (2004) suggested that the results of a six-week periodic hamstring-stretching program assessing knee range of motion, passive resistive forces, and muscle stiffness, were additional evidence supporting structural changes to chronic stretching. Forty-three male school-age subjects (mean age, 15.8 ± 1.0 years old) volunteered for the study and were randomly assigned via coin toss to either the control group (no stretching) or the intervention group. The hamstring-stretching program consisted of one stretch, performed for three repetitions each lasting 30 s, once a day for five consecutive days each week. Passive knee extension measuring hamstring
extensibility was tested using a dynamometer, surface EMG was used to find maximal isometric voluntary contraction and maximum tolerable stretch. Variables of interest were the maximal passive resistive force, maximum range of motion and stiffness that was calculated using a computer-based program using the mean stiffness in the final 10% of the maximum range of motion. Four total trials were performed; one trial acted as the familiarization trial and the subsequent three were used for testing, taking the average for data analysis. Following the intervention, Reid and McNair (2004) found a significant increase (P<0.05) in knee extension range of motion, passive resistive force and stiffness when compared to the control group. The authors (Reid & McNair, 2004) hypothesized the findings to be concurrent with those of Magnusson (1996) in terms of passive resistive force; an increase in joint angle accompanied an increase in force. However unlike Magnusson (1996) these increases were also accompanied by an increase in stiffness, providing further evidence for changes to the structural characteristics of the tissues, most likely the increase of sarcomeres in series (Magnusson et al., 1996; Reid & McNair, 2004).

Whereas many human model studies have aimed to provide a rationale behind the structural changes many have referenced the changes of animal models where such changes were actually identified. Coutinho et al. (2004) used eighteen 16-week old rats, and divided them into three groups of 6 each: a) left soleus immobilized in the shortened position for three weeks; b) left soleus immobilized but removed and stretched for 40 minutes every three days; and c) left soleus non-immobilized and passively stretched every three days. The right soleus was left intact and used for comparison. Following
three weeks, anesthetization occurred and both soleus (right and left) were weighed and dissected; medial soleus was used for histology and the lateral portion was used for sarcomere measurements. The cross-sectional area of 100 muscle fibers randomly chosen from the central region of one cross-section of each soleus was measured under microscope. When compared to the contralateral muscles, immobilized muscles showed a significant (P<0.05) decrease in muscle weight, muscle length, fiber area, and serial sarcomere number. Group B (immobilized and stretched) showed milder muscle atrophy compared to immobilized group (P<0.001). Those muscles only submitted to stretching (Group C) significantly (P<0.05) increased length, serial sarcomere number and fiber area when compared to contralateral muscles (Coutinho, Gomes, França, Oishi, & Salvini, 2004).

*Neurological Adaptations to Chronic Stretching*

When changes in torque and range of motion occur however, changes to passive resistance go unchanged, authors typically argue that the viscoelastic parameters have been unaltered and any changes seen are due to stretch tolerance or decreased reflex activity (Mahieu et al., 2007). Guissard and Duchateau (2004) studied the effects of 30 sessions of static stretching in order to determine the contributions of neural and mechanical mechanisms influenced by chronic stretching to alter ROM. Twelve subjects (n=8 men) volunteered for the study. The training program lasted for 30 sessions, five times per week for 6 weeks. Each session consisted of 5 alternating repetitions of four different passive, static calf stretches. Each stretch was performed on the right leg and was held for 30 s with a 30 s rest period in between. The mechanical and electrical
properties of the right plantar-flexors were tested at 90º before, after 10, 20, and 30 sessions and again, 30 days after commencement of the training program. Each testing session began with a graded stimulation (reflex EMG) of the right tibial nerve to determine the maximal direct motor response (Mmax) and Hoffman (Hmax) reflex. The tendon (T) reflex was provoked by a rotating clinical hammer dropped onto the Achilles tendon from a constant height. Each subject performed five unloaded plantar-flexions as quickly as possible (maximal), followed by five voluntary, ballistic isometric contractions at ±70% of MVC (submaximal), and finally, a maximal ankle dorsiflexion test. The maximal and submaximal MVCs were used to determine maximal peak torque and rate of torque development (respectively), while the maximal dorsiflexion test was used to measure ROM and passive stiffness (via the passive torque-angle curve). Stretch training produced a 30.8% increase in ankle dorsiflexion one day after training ceased (P<0.05), with 56% of this gain still observed after 10 sessions. Between the 10th and 20th sessions, a 23% gain (P<0.05) was still visible and similarly, 21% (P<0.05) was still observed during the last 10 sessions. One month after the training session a 74% gain in ankle dorsiflexion was still present in comparison to the untrained leg. A positive relationship was found after 30 training session, for all the subjects between the gain in ankle dorsiflexion and the reduction in passive stiffness (r²= 0.88; P<0.001) and muscle passive stiffness was shown to be decreased by 33% (P<0.001). After 30 sessions there were no significant changes (P>0.05) in peak isometric MVC torque or rate of torque development. In addition, although Mmax was not modified by training (P>0.05) Hmax/Mmax (P<0.01) showed a significant decrease after 30 sessions yet returned to
baseline 30 days following training. The T reflex was decreased 18.2% (P>0.05) following 10 sessions and 36% (P<0.05) following 20 sessions however no further changes were seen in the last 10 sessions. The results suggest that 30 session of static stretching of the plantar flexor muscles reduce passive stiffness of the calf muscles and simultaneously increase dorsiflexion range of motion. The decreases to tendon and Hoffman reflexes strongly suggest that neural changes contribute to muscle lengthening and that the increases in flexibility are attributed to reductions in passive stiffness and tonic reflex activity (Guissard & Duchateau, 2004).

While Guissard and Duchateau (2004) proposed alterations in reflex activity to be the mechanism behind chronic stretching adaptions, other authors propose it to be an increase to stretch tolerance. Magnussen et al. (1996) examined the effects of long-term stretching on both stretch tolerance and the tissue properties of skeletal muscle. Seven female participants (mean ± SD: age=26±6) who were inactive or recreationally active volunteered. The stretch-training program consisted of five 45-s stretches with 15-30 s of rest in between. Two daily sessions, morning and afternoon, were performed for 20 consecutive days. Every participant completed two protocols before and after three weeks of a stretching program. Protocol 1 consisted of a slow stretch to a pre-determined angle, which was then held for 90 s for both the contralateral (control) leg and stretched (experimental) leg. A maximal voluntary contraction (MVC) to normalize the passive peak torque value and electromographic activity (EMG) data was performed following the holding phase. EMG (μV), passive energy (area under the curve) and stiffness (Nm·rad⁻¹) were calculated during the slow stretch maneuver. Initial peak torque, rate of
torque decline and EMG amplitude were calculated during the holding phase. During protocol 2, all else remained the same as in protocol 1 however the stretch was continued to stretch tolerance (the point of pain). Following 3 weeks of stretch training, results for protocol 1 showed that there were no significant differences in EMG amplitude (P=0.24), passive energy (P=0.61), or stiffness (P=0.86) when compared to the control phase. Results for protocol 2 however, indicated significant changes in the stretched leg only for passive energy (P=0.018), peak torque (P=0.018) and maximal joint angle (P=0.018). EMG remained unchanged for both the stretched and control legs. The authors (Magnusson et al., 1996) conclude that there was no observable change in the tissue properties following three weeks of stretch training and that the increases to joint ROM and passive torque suggest that the underlying mechanism allowing a change in range of motion is increased stretch tolerance rather than changes to the viscoelastic properties of the musculature.

**Chronic Stretching and Performance**

While many studies have been performed to assess the value a bout of acute stretching on performance, fewer studies have been directed to answer the same question in regards to chronic stretching or increased ROM.

In a study to determine the influence of chronic stretch training on muscular power, strength and endurance of 38 inactive or recreationally active college students, Kokkonen et al. (2007), subjected each subject to a series of exercise tests during two, three-day visits held 10 weeks apart. During visit one, a sit and reach, standing long jump, 20-m sprint, and one repetition maximum (1RM) leg flexion and leg extension
tests were performed. Visit two consisted of a leg extension and flexion muscle strength-endurance test and a vertical jump test. Finally, visit 3 included a treadmill VO2peak test. Thirty-eight subjects were evenly and randomly assigned (18 per group) to either the control (CON, n=11 females) or the stretching (STR, n=11 females) group. The 10-week stretching (STR) protocol was performed 3 days per week and consisted of 15 passive (assisted) and active (unassisted) static stretches, targeting the lower-extremity musculature. Each stretch was held for 15 s, and repeated three times with a 15-s rest period in between. The results indicated an 18.1% increase (P<0.05) in sit and reach performance for the STR group with no change (P>0.05) in the CON group, showing gains in flexibility. The STR group improved in standing long jump distance (2.3%, P<0.017), vertical jump height (6.7%, P<0.017), and 20-m sprint time (1.3%, P<0.017) when compared to the CON group, showing improvements in power. Lastly for muscular strength and endurance the 1RM for the STR group improved for both knee flexion (15.3 %, P<0.025) and extension (32.4%, P<0.025) as did the STR endurance for knee flexion (30.4%, P<0.025) and extension (28.5%, P<0.025) when compared to the CON group. The findings suggested that an intensive, regular stretching program could improve several aspects of performance including flexibility, endurance, strength and power in the lower extremity. The authors suggested that the improvements in power and endurance were related to strength improvements caused by muscular hypertrophy and/or increases in muscle length (Joke Kokkonen et al., 2007).

Additionally, Hortobagyi et al. (1985) found that seven weeks of stretch-training improved sprinting stride frequency, velocity-specific features of isometric and
concentric muscle contractions and increased flexibility. The authors attributed this change to stretch-induced adaptations to increasing numbers of sarcomeres in series. The authors examined the effects of lower body stretching program on ROM and muscular performance by subjecting subjects to maximal voluntary contraction (MVC), torque development, sprinting and flexibility testing. Twelve healthy male secondary school students who were active, but not trained specifically (mean ± SD: age=15±0.5 years) participated. Each participant performed three isometric MVCs, six to eight fast isometric contractions, and five maximal concentric contractions at 25, 50, 75, 100 and 125 kg of the leg extensors on two occasions, seven weeks apart. Calculations during the fast isometric contractions were used to determine the rate of torque development and half-relaxation time and a sprinting test was used to determine maximal stride frequency. Flexibility tests included a supine hamstring stretch, front-to-rear split and a side split while supine. The stretch training program lasted seven weeks and was performed three times per week; each participant performed two sets of six stretches that were held for 10 s each. As a result, there were increases (P<0.05) in flexibility from pre-to post-stretch training across all flexibility tests. Although rate of torque development, half relaxation time, and maximal stride frequency improved (P<0.01) following training, there were no changes in isometric MVC peak torque. In addition, peak concentric velocity increased (P<0.01) for the three lowest loads (25, 50 and 75 kg).

In addition to the aforementioned stretching-induced performance variable improvements, other authors have shown gains in lower and upper body muscle performance, range of motion and running stride frequency after stretch training
programs. Worrell et al. (1994) examined the effects of flexibility on isokinetic peak torque in 19 healthy participants (no mention of specific training). Each subject (n=9 females) performed isokinetic strength testing and flexibility assessments prior to and after three weeks of static stretch training. An active leg extension test was used to test flexibility and an isokinetic dynamometer was used to perform all concentric muscle actions. Concentric and eccentric peak torque values for each leg were recorded at 60 and 120°•s\(^{-1}\). Both legs were stretch; each randomly assigned to either static or contract-relax proprioceptive neuromuscular facilitation (PNF). Stretch training was performed five days per week for three weeks. Static stretching was held for 15-20 s stretches with 15 s rest for four repetitions. PNF included four, 20 s bouts consisting of a 5-s maximal isometric hamstring contraction, 5-s rest period and, a 5-s maximal isometric quadriceps contraction followed by 5-s rest. Although stretch training did not significantly improve range of motion, the authors credited the improvement of maximal isokinetic eccentric and concentric peak torque to a greater stored potential energy caused by a more compliant series elastic component.

Still, some others showed no influence to any other component other than improvements to range of motion (Bazett-Jones, Gibson, & McBride, 2008; Nelson, Kokkonen, Eldredge, Cornwell, & Glickman-Weiss, 2001). Following ten weeks of chronic stretching targeting all the lower body musculature, Nelson et al. (2001) showed and improvement to flexibility but no changes or influence in submaximal running economy. Thirty-two trained participants (16 males, 16 females) performed a VO\(_{2}\)\(_{\text{max}}\) test, running economy test and a sit-and-reach test on two separate occasions 10 weeks
apart. Participants had been vigorously running (>70% maximum heart rate) for 30 minutes, 3-5 days per week for at least six months prior to the study. Each participant was randomly assigned to wither a stretching (STR) or non-stretching (CON) group following the pre-testing measures. Stretch training was performed for 10 weeks, three days per week. The stretching protocol consisted of 15 assisted and unassisted static stretches targeting lower body musculature. Stretches were repeated three times and held for 15 s with a 15-s rest period in between. The significant (P<0.05) increase (9%) in sit-and-reach performance for the STR group when compared to the CON group (P>0.05) coupled with insignificant changes in VO$_{2\text{max}}$ test and running economy led the authors to propose that there were no alteration to musculotendinous stiffness.

Additionally, Bazett-Jones et al. (2008) examined chronic stretching on hamstring flexibility, sprint performance and vertical jump height in 21 division III women’s track and field athletes. Each participant performed a vertical jump, a 55-m sprint and an active leg extension test on three occasions separated by three weeks. Participants were randomly assigned to a stretching (n=10) or control (n=11) group. Stretch training lasted six weeks and consisted of one static hamstring stretch that was performed on each leg four times per day, four days per week for 45 s, with a 45-60-s break. The authors found that the chronic stretching had little influence on ROM, vertical jump height, 55-m sprint speed or flexibility and proposed that stretching may not be beneficial for highly trained athletes.

Hunter and Marshall (2001) assessed the effects of flexibility and power on drop jump (DJ) and countermovement jump (CMJ) techniques and found that 10-week
stretching protocol did not change the level of lower-limb stiffness (eccentric) in the CMJ. Fifty trained subjects (basketball and volleyball) were randomly assigned to a group: power training group (P), stretching group (S), combined power and stretching (PS) and control group (C). Training lasted for 10 weeks. Power training was performed twice a week and was comprised of resistance and plyometric training exercises, stretching was performed four times per week (1 supervised session), and included a multitude of stretches for the lower limbs. Each stretch was held to the point of mild discomfort and from week four onward, some PNF type exercises were performed. The PS group performed both power and stretch training. Testing was performed pre and post 10-week intervention. The investigators concluded that stretching did not appear to offer any significant benefit to CMJ technique or DJ height or technique. There was however a slight increase in CMJ height and, although no increase in eccentric lower-limb stiffness was not observed, they speculated that the benefits in stretching to CMJ might have come from a decrease in series elastic component stiffness which allowed greater storage of elastic energy increasing the stretch-shortening cycle performance, but could not be certain.

Twenty-nine males (ages 18-60 years) participated in a study to examine the effects of chronic stretching on the rate of torque development (RTD), peak torque (PT), the angle at peak torque (PTA) and work (W) of thigh extension. Subjects were randomly assigned to a static stretching (n=9), ballistic stretching (n=10) or control (n=10) group. The static stretch group held the stretch position for the duration while the ballistic group moved in and out of the stretch each second. The stretching protocol
consisted of 10 sets of single hamstring stretch, performed three times per week for four
weeks. Each set was held for 30 s with 30 s of rest in between. Four maximal thigh
extensions at 60°·s⁻¹, on an extensor torque apparatus connected to an isokinetic
dynamometer were performed on two occasions, four weeks apart. The highest torque
generated was noted as PT, the slope the linear region of the torque vs. time curve was
noted as RTD, the area under the angle-torque curve was calculated for W, and the angle
at which PT occurred was PTA. Following the four-week protocol, no significant
(P>0.05) differences for PT, RTD, W, or PTA were observed when comparing the static
and ballistic groups to the control. The authors (LaRoche, Lussier, & Roy, 2008)
suggested, based on these results, that four-weeks of chronic stretching have little
influence on hamstring strength and, in addition, the lack of changes to PTA indicated
that the length-tension relationship and the length were unaltered.

Summary

While we are aware of the age-induced deficits to flexibility, power and
performance, there still lies a gap piecing together the role of flexibility in performance
as aging occurs. Chronic stretching and thus and increased ROM has been shown to have
either positive or no effect on performance (Bazett-Jones et al., 2008; Hortobágyi et al.,
1985; Joke Kokkonen et al., 2007; Nelson, Kokkonen, et al., 2001; Wilson et al., 1992;
Worrell et al., 1994). While there are several proposed theories behind chronic stretch-
induced musculoskeletal changes and the subsequent alterations to performance, research
has yet to agree the exact mechanism behind these changes. It is hypothesized that there
are both mechanical and neurological factors at play and they type of activity and the
stimulus will predicate which adaptation will be made (Chamari et al., 1995; Izquierdo et al., 1999; Runge et al., 2004). While we may be able to predict the effects of ROM on performance and we may be able to predict effects of aging on performance we are still unclear as to what effect an increase (or decrease) in ROM will have on an aging person’s athletic ability and performance.
Chapter 3

METHODOLOGY

This study included male and female cyclists from two age classifications: Master’s cyclists (MC) (35+ years old), and young cyclists (YC) (age= 18-34). The study was approved by The California State University, Sacramento Human Subjects Ethics Committee. Informed consent was obtained on the day of the procedure. Subject’s baseline measurements were gathered prior to the testing start date. The actual testing day occurred 24-hours following the last bout of exercise. The tests included VO$_{2\text{max}}$ testing, range of motion (ROM) measurements of the knee using a Leighton Flexometer, and a Wingate cycle ergometer test. Wingate testing was chosen, as it is a common method of testing power output. The performance goal for subjects was to obtain maximum power output. Testing protocol took place over a 2-hour period.

Subjects

Ten healthy male and female participants from two cycling age classes volunteered to participate (see descriptive data in Table 1). Subjects were recruited from cycling clubs located in and around the Sacramento, CA metropolitan area. Participants were trained cyclists, and were without physical limitations (subjects were pre-screened and deemed acceptable according to their number of risk factors as determined by the ACSM). Each subject trained at least 5 hours per week for a period $\geq$ 1 year prior to participation. It was hypothesized that power output and any subsequent deficits due to age or flexibility would be more apparent in trained athletes as their musculotendinous unit (MTU) has more exposure to training and therefore a better opportunity to adapt to
the demands. In addition, because of the physiological adaptation to training, trained athletes often give more of an all-out effort and are able to recognize internal queues signaling fatigue and maximal effort thus making a better research model.

Table 1:  
*Subject Characteristics*

<p>| | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Age (years)</td>
<td>33.4 ± 8</td>
</tr>
<tr>
<td>Height (cm)</td>
<td>171.5 ± 12</td>
</tr>
<tr>
<td>Weight (kg)</td>
<td>70.7 ± 9.52</td>
</tr>
<tr>
<td>VO$_{2\text{max}}$ (mL/kg/min)</td>
<td>60.8 ± 7.04</td>
</tr>
<tr>
<td>BMI</td>
<td>24.3 ± 4.62</td>
</tr>
<tr>
<td>ROM, Quadriceps (degrees)</td>
<td>139.3 ± 34</td>
</tr>
<tr>
<td>Peak Power, Aerobic, Relative (W/kg)</td>
<td>5.4 ± .55</td>
</tr>
<tr>
<td>Peak Power, Anaerobic, Relative (W/kg)</td>
<td>13.53 ± 1.28</td>
</tr>
</tbody>
</table>

**Experimental Design**

Testing consisted of one session. The test occurred in the following sequence for each participant: 1) GXT 2) ROM measurement and 3) Wingate. There was a minimum of 24 hours between the subject’s last bout of exercise and exercise testing.

**Procedures**

All subjects received in-depth instructions prior to starting testing protocol to ensure reliability. Upon arrival, a 24-hour activity recall was collected to ensure subject’s adherence to protocol. Subjects performed both GXT and Wingate on an electronically
braked stationary bicycle (Lode Excalibur). Heart rate was tracked with a Polar Heart Rate monitor and was measured throughout the test duration. Heart rate was recorded the last 10 seconds of each stage. The Borg RPE scale was explained and utilized throughout each visit to measure rate of perceived exertion and heart rate. RPE was collected at the end of every other stage. Gas collection was measured via a Parvo Medics TrueOne 2400 metabolic cart (Sandy, Utah USA).

**Graded Exercise Test (GXT).** Prior to the test starting, subjects set the cycle to meet their personal measurement; the seat was measured and set to the appropriate height and distance from the handle bars and if needed, personal pedals were attached. The test was comprised of a one-minute stage protocol. The testing procedure began at 70 Watts (50Watts for females) and thereafter increased by 25 W for females and 35 W for males with each stage and was terminated when 70 rpm could no longer be maintained. Expired air was collected the entire length of the protocol and was discontinued when the subject reached VO$_{2\text{max}}$ (previously identified as an increase in oxygen consumption $< 2\text{mL/kg/min}$, an RER $\geq 1.1$ and an RPE $> 17$). Gas volume and analysis calibrations were taken each day of use, prior to subject arrival. Gas volume calibration was performed with a 3L syringe and calibrated against known barometric pressure, % humidity and temperature. Gas analysis calibration was performed against known concentrations of O$_2$ and CO$_2$. Expired gas testing was performed automatically with the subject connected to a two-way valve connected to the metabolic cart.

**Range of motion.** Following the cool-down phase of the GXT, ROM measurements were collected using a Leighton Flexometer at the knee. Leighton
Flexometer has been shown to have the reliability of hip flexion at 0.995 for the left leg and 0.978 for the right leg (Leighton, 1942). Measurement was taken at the following site:

Quadriceps. While in a prone position with a fully flexed knee, the subject brought the heel to the gluteus (with the aid of the instructor). If needed the knee was helped into a lifted position to guarantee maximal stretch.

Wingate Test. Following the ROM measurements subjects remounted the cycle and performed an all-out bout of exercise to assess power. Selection of workload (flywheel resistance) for the Wingate test was chosen electronically based on the client’s bodyweight. A standard torque factor of 0.7 Nm was used for all tests. Correct seat height was selected so the participant’s knee was slightly bent when the pedal was in the 6 o’clock position. During the last 30 seconds of the subject’s warm-up, the subject was asked to increase their RPM to the highest that could be achieved. The workload was then added to the bike and the subject attempted to maintain the highest rpm possible for 30 seconds, giving an all-out effort. Following 30 seconds, the load was removed from the bike ergometer and the subject continued to cycle at a slow rpm until recovered. Peak power was calculated and recorded by the Lode Ergometer Manager Wingate software.

Data Analysis

Variables analyzed were quadriceps ROM, age, relative aerobic power (P_{aer,peak}) and, relative anaerobic power (P_{an,peak}). Conventional statistical methods were used for calculating means and standard deviations. Data was analyzed using Pearson’s
Correlation Coefficients. Correlation was assessed for each of the following: ROM/age, ROM/$P_{an,peak}$, ROM/$P_{aer,peak}$, age/$P_{an,peak}$, and age/ $P_{aer,peak}$. Significance was set at $P<0.05$ for all analyses.
Chapter 4

RESULTS

The purpose of this study was to examine the relationship between age, ROM and power output in trained cyclists. Ten subjects (n=1 female) underwent GXT, ROM testing and a Wingate test. Data collected included HR, RPE, VO2 and P_{an,peak} and P_{aer,peak}. All procedures were performed in the Human Performance Research Laboratory at California State University, Sacramento.

**Age and Power Output**

$P_{an,peak}$ and $P_{aer,peak}$ were measured. There was no significant correlation between age and either $P_{an,peak}$ or $P_{aer,peak}$. The correlation coefficients were -0.0149 for $P_{an,peak}$ ($p=0.6812$) and 0.0324 for $P_{aer,peak}$ ($p=0.9293$). Data for power output (both aerobic and anaerobic) and age can be seen in Figures 4.1 and 4.2.

![Figure 4.1](image)

**Figure 4.1** Peak anaerobic power and age. Peak anaerobic power ($P_{an,peak}$) was assessed via Wingate test. No significant correlation was found between ($P_{an,peak}$) and age.
Figure 4.2 Peak aerobic power and age. Peak aerobic power ($P_{aer,peak}$) was assessed via GXT test. No significant correlation was found between ($P_{aer,peak}$) and age.

Range of Motion (ROM) and Power Output

Quadriceps flexibility was assessed using a Leighton Flexometer. Pearson Correlation Coefficients revealed that there was no significant correlation between quadriceps ROM and either $P_{an,peak}$ or $P_{aer,peak}$. The correlation coefficients were 0.0606 for $P_{an,peak}$ ($p = 0.8674$) and 0.1191 for $P_{aer,peak}$ ($p = 0.7431$). Data for power output (both aerobic and anaerobic) and quadriceps ROM can be seen in Figures 4.3 and 4.4.
Figure 4.3 Peak anaerobic power output and quadricep ROM. Peak anaerobic power ($P_{\text{an,peak}}$) was assessed via Wingate test. No significant correlation was found between ($P_{\text{an,peak}}$) and quadricep ROM.

Figure 4.4 Peak aerobic power output and quadricep ROM. Peak aerobic power ($P_{\text{aer,peak}}$) was assessed via Wingate test. No significant correlation was found between ($P_{\text{aer,peak}}$) and quadricep ROM.
Range of Motion (ROM) and Age

Pearson Correlation Coefficients revealed that there was no significant correlation between quadriceps ROM and age. The correlation coefficient was -0.0169 for ROM and age (p= 0.9631). Data for age and quadriceps ROM can be seen in Figures 4.5.

Figure 4.5 Age and quadricep ROM. Peak anaerobic power ($P_{an,peak}$) was assessed via Wingate test. No significant correlation was found between ($P_{an,peak}$) and quadricep ROM.
Chapter 5
DISCUSSION

The study population is described in Table 1. It is important to note the level of fitness and training of this subject pool, as the subjects were highly physically competent and thus not representative of a general population. In this case, it was believed that subject selection was representative of aging-induced physical declines in healthy, physically fit persons without disabilities and diseases. Healthy athletes however, were the best-fit model to study age-related decrements of maximal physical performance as they are already following a regular training program and heredity factors are difficult to control for. The two groups of YC and MC had similar endurance training backgrounds and thus could be assumed to have had similar relative fitness levels for their respective age levels. Motivation and ability to exert maximal effort were also assumed to be comparable as their theoretical HR max in respect to age were similar.

It has widely been acknowledged that with an increase in age, declines in physical performance occur as a result of different functions of aging such as muscle atrophy, heredity factors and reductions of physical activity, health, and body mass (Buckwalter et al., 1993; Chamari et al., 1995; Kamel, 2003). The present study examined the relationships amongst age, peak power output and range of motion about the knee in competitive cyclists with a very long history of systematic training.

The main findings were as follows: 1) There was no significant correlation between age and quadriceps ROM. 2) There was no significant correlation between age and either anaerobic or aerobic power. 3) There was no significant relationship between
quadriceps ROM and either anaerobic or aerobic power. Although there is limited research documenting the benefits derived from regular stretching programs (which increase ROM) previous studies looking at the effects of chronic stretching including those assessing strength, speed, power and endurance have mainly found improvements in performance (Hortobágyi et al., 1985; Hunter & Marshall, 2002; Worrell et al., 1994). Stretching programs are typically recommended to a lesser extent than those that have been used to achieve the aforementioned strength gains (Joke Kokkonen et al., 2007).

Although this study was not designed to investigate the underlying mechanism behind increased ROM and increased power, other studies have speculated the performance gains in some studies to be from “neural” or “mechanical” factors or a combination of both. Changes to the musculotendinous unit (MTU) (Hortobágyi et al., 1985; Joke Kokkonen et al., 2007), increased stretch tolerance (Magnusson et al., 1996) and reflex activities have been speculated to be the underlying chronic stretch-induced changes. In a 10-week stretching protocol of 40 physically inactive and recreationally active college students, Kokkonen et al. (2007) found improvements in power (P<0.017) and muscular strength and endurance (P<0.025) when compared to a non-stretching group. The author attributed these strength improvements to muscular hypertrophy and or/ increases in muscle length (Joke Kokkonen et al., 2007). Hortobagyi et al. (1985) found that seven weeks of stretch-training on active, but not specifically trained secondary school students improved sprinting stride frequency, velocity-specific features of isometric and concentric muscle contractions and increased ROM. Because both ROM and velocity-specific characteristics of concentric and isometric muscle actions
changed, the authors attributed this change to stretch-induced adaptations to increasing numbers of sarcomeres in series (Hortobágyi et al., 1985).

Conversely, other studies have examined the influence of chronic stretching on vertical jump height, sprint performance, peak torque, rate of torque development and running economy and have reported insignificant changes in these measures of athletic performance (Bazett-Jones et al., 2008; Godges, MacRae, & Engelke, 1993; LaRoche et al., 2008; Nelson, Kokkonen, et al., 2001). Godges et al. found that although three weeks of passive stretching were adequate in increasing hip extensor range of motion, walking economy and running economy were not improved in the 25 healthy, athletic, male college students. The authors attribute the lack of change in running and walking economy to stretching protocol being too short, and possible lack of motor stimulation from passive stretching (Godges et al., 1993). Nelson et al. (2001), reported that while a 10-week stretching program altered range of motion in 32 trained college runners, there was no significant effect on running economy. Although there were increases in joint range of motion, the authors concluded that this might not necessarily alter stiffness (and thus alterations of the MTU) of a joint. Bazett-Jones et al. (2008) attributed the lack of changes in vertical jump height and 55-m spring speed to the training level of their subject pool and hypothesized that competitive athletes with normal ROM may not benefit from stretching. Lastly, LaRoche et al. (2008) reported insignificant changes between their control and stretch groups for peak torque and rate of torque development and suggested that the lack of change may indicate that there were no alterations to the length-tension relationship or muscle length itself. In support of the aforementioned
research, the current study found no significant correlation between quadriceps ROM and either $P_{an,peak}$ ($p=0.980$) or $P_{aer,peak}$ ($p=0.892$). This suggests that changes in range of motion may not have a large effect on performance as other variables.

While there have been several studies to look at the alterations in performance from chronic stretching (and therefore increased ROM), few if any have looked at the relationship between power, ROM and, age. Kerrigan et al. (2003) examined the relationship between a 10-week flexibility program and alterations in walking speed in healthy elderly persons. The authors hypothesized that there would be a correlation between the degree to which static peak hip extension improved and the degree of improvement in dynamic peak hip extension during gait. A decrease in hip extension (from poor ROM in the hip) could account for age-related gait differences in walking speeds (mainly slower walking speeds). Kerrigan et al. (2003) found that the treatment group, who stretched their hip flexors twice daily for 10-weeks had increased both static and dynamic peak hip extension. Dynamic extension was improved in both fast and comfortable walking speeds, thus supporting the authors’ hypotheses that increased ROM could increase functionality. In another study by Kerrigan et al. (2001), the gait differences between healthy young adults and elderly fallers and non-fallers were studied. The authors found that elderly fallers and non-fallers had only one kinematic gait difference that was more exaggerated than that of the young adults; peak hip extension. They attributed this reduction in peak hip extension to declining functionality, as poor hip extension could prevent full range of motion during walking (D C Kerrigan, Lee, Collins, Riley, & Lipsitz, 2001). In comparison to the work of Kerrigan et al. (2001, 2003), the
current research found no significant correlation between any of the variables studied. Most importantly, there were no negative correlations between age and ROM or age and performance (in the form of peak power output). Therefore, decrements to ROM and some performance variables most commonly seen with increasing age may not be entirely normal, especially in those with a more active lifestyle. The physiological changes observed in many aging persons most closely mirror that of younger sedentary individuals; decreased muscle mass, muscle fiber size and type and decreases in muscular power, max strength, explosive force and explosive strength (Houmard et al., 1998; Izquierdo et al., 1999; Korhonen et al., 2006; Runge, Rittelweger, Russo, Schiessl, & Felsenberg, 2004). Thus, with more training and more activity, age-induced deficits to functional abilities and performance may possibly be diminished or delayed.

Chronic stretching is often recommended across all age groups to increase active ROM (Thompson & American College of Sports Medicine., 2010). Although current stretching recommendations consist of at least two days per week of a variety of stretching types for normal healthy adults and at least two to three days per week, limited to static stretching for older adults (Behm et al., 2004), the current work is unable to support these views. A more conditioned population might not need the prolonged or additional advised stretching that is recommended with aging. In fact, because there were no significant correlations between any of the variables, an untrained or sedentary aging person most closely mirror the characteristics of a younger sedentary individual; decreased power, force and strength, and increased incidence of a number of metabolic diseases (Driss et al., 2001; Healy et al., 2008).
Future research in this area will need to observe ROM measurements about different joints as well as different activity level types. It is possible that the results observed were due to the physiological adaptations that occur due to consistent training. To address this, future research would benefit from observing different age populations with different training statuses. In addition, because there is limited range of motion on the bicycle, observing other performance variables and their correlation with ROM and age might give us a better understanding of exercise and stretching prescription for all age groups and activity levels. Furthermore, due to these ROM limitations from the cycle other performance variables might better depict the age-related declines seen more commonly in activities like walking and may offer a better representation of an average aging adult. Additionally, further research showing a statistically significant correlation however, might help show the importance, or lack thereof for an increased need in stretching programs for the elderly however; our study did not show any significant decrements to max power output from either age or range of motion.

Conclusion

The current research supports previous studies of trained athletes, showing no improvements to performance from increases in range of motion (Bazett-Jones et al., 2008; Godges et al., 1993; Hunter & Marshall, 2002; Nelson, Kokkonen, et al., 2001). There however, will still be a debate on whether or not increases in range of motion contributes to or detracts from the functionality of an aging population and whether this population benefits from additional range of motion exercises. This conflict will only be subdued when further research is able to repeatedly show that range of motion enhances
or limits performance as we age, and whether or not these changes can be quelled by further increasing range of motion or, an alternative type of exercise.
APPENDIX A

Informed Consent

Informed Consent
Effect of Stretching and Flexibility on Performance

Purpose of Study

In recent years the importance of pre-exercise stretching has been questioned. Previous research examining weight lifting and sprinting has found that pre-exercise stretching has decreased performance. However, very little data has examined endurance performance. This study will examine the effects of pre-exercise stretching on an endurance cycling performance. This investigation is being conducted by Daryl Parker, PhD in the department of Kinesiology at CSUS, and is the lead investigator. Dr. Parker will be assisted in the laboratory by graduate students completing their education at CSUS. Any questions regarding the study can be directed to Dr. Parker, (916) 278-6902 or parkerd@csus.edu.

Testing Procedures

Flexibility Assessment will be assessed following any exercise tests. Hip and knee flexibility will be assessed with an Leighton Flexometer while you flex the knee, hip, and ankle.

Maximal stress testing will be completed on an electronically braked bicycle. The testing procedure will begin at 70 Watts (50 Watts for females). Every minute thereafter the load will increase 35 Watts (25 Watts for females) and will be terminated when 70 rpm can no longer be maintained. During the testing procedure you will have to breathe through a two-way valve while wearing a headgear and nose clip. During the test heart rate will be monitored continuously. Heart rate will be monitored with a heart rate monitor strapped around your torso.

Wingate Cycle Testing will be carried out 30 minutes after the maximal stress test. Following a 10 minute warm-up you will spin the bike ergometer up to highest rpm you can achieve. The workload will then be added to the bike and you will attempt to maintain the highest rpm possible for 30 seconds. Following the 30 seconds the load will be removed from the bike ergometer and you will cycle at a slow rpm until recovered.

*Total time commitment for the study is approximately two hours.
Risks and Discomforts

Vigorous exercise, such as graded exercise testing and time trialing, involves a certain amount of risk. The associated death rate with vigorous exercise is very low in low risk individuals. During the testing procedures you will experience increased blood pressure, rapid breathing, increased heart rate, increased exertion, sweating, muscular discomfort, and fatigue. Also during this procedure it is possible that you will experience an alteration in heart rhythm, and in rare cases a heart attack or stroke. However, risks of these events taking place will be minimized by pre-health screening and monitoring during the tests.

In the event of an emergency, we will activate the emergency medical response process for the university. Any medical treatment or response that incurs a charge will be the responsibility of the research participant and not the university. The investigators of this study are trained in CPR and basic first aid.

Responsibilities of the Participant

Knowledge of your current health status and any abnormalities associated with it could profoundly affect the outcomes of your test, as well as your safety during the testing procedure. It is your responsibility to disseminate accurate and complete information regarding your health and condition prior to undergoing the test procedures. During the procedure it is your responsibility to provide the technicians with accurate information regarding how you feel during the test. It is also your responsibility to report any chest pain, tightness, or other abnormal discomfort during the testing procedures.

Benefits of the Testing Procedure

The exercise test may provide you with information regarding your current state of health and physical fitness. These tests can be used as a baseline beginning assessment to determine changes in physical state over time as well as various states of conditioning. Further, depending on the testing procedure this information may be beneficial in developing an exercise program for the enhancement of your current physical fitness.

Use of Medical Records

The data collected during this study will be treated as confidential. No one may view your results without your expressed written consent. This data will be coded with a random ID number and used for statistical analysis with your right to privacy maintained.

Consent to Participate
This testing procedure is voluntary and you are free to withdraw from the procedure at any time. Please feel free to ask questions regarding the procedure at any time. This may include clarification on the consent form, instructions on the procedure, or any part of the testing process that you are not comfortable with. You may also feel free to contact Daryl Parker PhD, the primary investigator, at any time regarding questions that you have 916-278-6902 or parkerd@csus.edu.

I have read this consent form, and understand the procedure, risks involved and my responsibilities during the testing process. Knowing the risks involved and having had my questions answered to my satisfaction I hereby consent to participate in this study.

______________________________
Date

______________________________
Print Name

______________________________
Signature

______________________________
Date

______________________________
Print Name of Witness

______________________________
Signature of Witness
APPENDIX B

SUBJECT INFORMATION AND MEDICAL HISTORY

SAC STATE HUMAN PERFORMANCE RESEARCH LABORATORY

NAME:____________________________________ DATE____________________________

ADDRESS:________________________________ PHONE:___________________________

EMAIL:___________________________________

OCCUPATION:____________________________________________________________________

GENDER:   M__ F___ AGE________yrs DATE OF BIRTH____________________

TOTAL CHOLESTEROL________ mg/dL   HDL_______ mg/dL   LDL________ mg/dL

TG___________mg/dL

FASTING BLOOD GLUCOSE ________________mg/dL   Other blood results:_____________

We will take the following 4 measurements (do not answer):

WEIGHT__________kg   HEIGHT_________cm   BP_____/____mmHg   HR_______beats/min

MEDICAL HISTORY: (Please Circle your Answer/s)

Are you currently taking any medications: Yes or No:

If yes, please list:_______________________________________________________________

Please list all medical conditions (e.g. ulcers, arthritis, mono, hepatitis, HIV, musculoskeletal injury)?_______________________________________________________________

Please list any hospitalizations and/or surgeries?___________________________________________

Have you ever been diagnosed with a breathing problem such as asthma? Yes or No:

If yes, please explain:________________________________________________________________

Have you ever been diagnosed with a heart problem or condition? Yes or No:

If yes, please explain:________________________________________________________________

Do you have any of the following symptoms at rest or with low to moderate physical activity? Yes or No:

Lightheadedness   Shortness of Breath   Chest Pain   Numbness

Fatigue   Coughing   Wheezing

Other_________________

If yes, please explain:________________________________________________________________

Do you have any of following cardiovascular disease risk factors?  Yes or No

Family History of Heart Attacks   Hypertension   High Cholesterol
Sedentary Lifestyle (refer to next page)  Diabetes  Current cigarette smoker

Obesity  (Calculate BMI=________kg/m²)
If yes, please explain:__________________________________________________________

Do you have an immediate family member with any of the following diseases? Yes or No
Diabetes  Hypertension  High Cholesterol  Obesity
If yes, please explain:________________________________________________________________

Are there any other conditions that might affect your health/exercise ability? Yes or No:
If yes, please explain:_________________________________________________________________

Training History

What type of athlete are you? Please circle the best answer:
A) Professional-National class  B) Competitive at Regional-Local level  C) Age or Class Competitor
D) Well Trained  E) Other:___________________________________________________________

How many years have you been training competitively?____________________________________

Over the last year, what has been your weekly mileage?_____________________________________

Over the last year, what percentage of your overall training is at a pace faster than “somewhat hard” or >70% of VO2max?___

What are your 3 best performances and include date and event/course?
1:_____________________________________________________________________________________
2:_____________________________________________________________________________________
3:_____________________________________________________________________________________

Please give your best performance over the last 18 months include date, time and course?

These questions concern your training over the 20 weeks:
What is the average number of exercise sessions per week?_____________________________
What is the average duration of your exercise sessions?_______________________________
What is the average intensity of your exercise bouts?_______________________________

Could you give us the respective volume of easy, moderate (="somewhat hard" or 70% VO2max) and hard workouts (>“Hard” or 85% VO2max) per week (miles per week)?Easy =___ Moderate___ Hard_____
What is the total volume of your workouts per week (miles per week)?_____________________
Any recent significant injuries which have limited your training?______________________________

Additional Information:

How have you ever performed a fitness or maximal exercise test? Yes or No:
If yes, what were the results of your tests?  Protocol_________VO2 max___________ Speed/Power_______ Lactate Threshold_______
Overall Interpretation:__________________________________________________________________
COMMENTS & OBSERVATIONS:____________________________________________________________________

OVERALL RISK STRATIFICATION:____________________________________________________________________

EXERCISE & EXERCISE TEST RECOMMENDATIONS:________________________________________________________

APPROVED BY: __________________________ Dr. Daryl Parker, Ph.D.

________________________ Lauren Green
### Data Collection Sheet

**Stretching Study**

**APPENDIX C**

<table>
<thead>
<tr>
<th>Date</th>
</tr>
</thead>
</table>

<table>
<thead>
<tr>
<th>Name/#</th>
<th>DOB/age</th>
<th>Gender</th>
</tr>
</thead>
</table>

<table>
<thead>
<tr>
<th>Phone #</th>
<th>Email</th>
</tr>
</thead>
</table>

<table>
<thead>
<tr>
<th>Height</th>
<th>Weight</th>
<th>Experience</th>
</tr>
</thead>
</table>

<table>
<thead>
<tr>
<th>Resting HR</th>
<th>Linear Factor</th>
</tr>
</thead>
</table>

<table>
<thead>
<tr>
<th>Bicycle measurements</th>
<th>Vertical</th>
<th>Horizontal</th>
</tr>
</thead>
<tbody>
<tr>
<td>Seat</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Handlebars</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>VO2 max</th>
<th>Values at Max</th>
</tr>
</thead>
<tbody>
<tr>
<td>VO2 (L/min)</td>
<td></td>
</tr>
<tr>
<td>VO2 (ml/kg/min)</td>
<td></td>
</tr>
<tr>
<td>Heart Rate</td>
<td></td>
</tr>
<tr>
<td>RPE</td>
<td></td>
</tr>
<tr>
<td>Max W @ 70%</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Wingate</th>
<th>Values</th>
</tr>
</thead>
<tbody>
<tr>
<td>Min Power / Fi</td>
<td></td>
</tr>
<tr>
<td>Peak Power</td>
<td></td>
</tr>
<tr>
<td>Time to PP</td>
<td></td>
</tr>
<tr>
<td>Mean Power</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Stretches</th>
<th>After (degrees)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hamstrings</td>
<td></td>
</tr>
<tr>
<td>Quadriceps</td>
<td></td>
</tr>
<tr>
<td>Hip Flexors</td>
<td></td>
</tr>
<tr>
<td>Hip Extensors</td>
<td></td>
</tr>
<tr>
<td>Plantar Flexors</td>
<td></td>
</tr>
</tbody>
</table>
Protocol

1. 60 minutes prior to test time warm up the cart.

2. Calibrate prior to the subjects arrival.

3. Set the Lode to the proper vertical and horizontal seat and handlebar settings.

4. Have clients begin a short warm up. Begin VO2max test.

5. Wait 30 Min

6. Wingate Test

<table>
<thead>
<tr>
<th>Stage</th>
<th>Heart Rate</th>
<th>RPE</th>
<th>VO2</th>
</tr>
</thead>
<tbody>
<tr>
<td>Resting</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>1</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>2</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>3</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>4</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>5</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>6</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>7</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>8</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>9</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>10</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>11</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>12</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>13</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
REFERENCES


