5-16-2008

An Optimal Interset Rest Period For Strength Recovery During A Common Isokinetic Test

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A Thesis

Submitted to the Graduate Faculty
of the University of New Orleans
in partial fulfillment of the
requirements for the degree of

Master of Arts
in
Human Performance and Health Promotion
Exercise Physiology

by Ivan Blazquez

B.S. University of New Orleans, 2003

May 2008

Acknowledgements

The author would like to first give thanks to God for allowing completion of this thesis despite the odds. First there was Hurricane Katrina, the budget cuts and the termination of the Human Performance & Health Promotion Department, the seizure of the department building by the athletic department, the 2-year ultimatum for continuing students to finish or a loss of degree, the endless revisions partly attributed to the author's perfectionism, the eventual breakdown of the Cybex NORM on-campus and the 2-3 month time period of having to make a decision whether to settle for an independent study or try to finish the study by hoping to find another Cybex NORM in the city. Fortunately, Metairie Orthopedic Sport Therapy clinic provided a great opportunity. The author wishes to thank Dr. Barbara Warren for her diligent and continual support via corresponding through email while in the state of Washington. The author would also like to thank his family and friends, particularly his mom for her support and encouragement and his dad for his support. The author would also like to thank all the study participants, Dr. O'Hanlon, Dr. Silvestri and Dr. Bonis for being present for the defense. Lastly, thanks to David Ware and Craig Goodwin of Metairie Orthopedic Sport Therapy for permitting usage of the Cybex NORM despite the hectic daily operation.

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Abstract

Introduction: Isokinetic testing is used in rehabilitation settings on a regular basis, yet there is a lack of consistency in rest period usage among protocols. **Purpose:** The purpose of this study was to establish an optimal rest period that would allow reproducibility of strength during a common isokinetic strength-test. **Methods:** Twenty-seven healthy college-aged males underwent isokinetic strength testing to determine peak torque at 60, 180 and 300 deg/sec, respectively. Work:rest ratios of 1:3, 1:8 and 1:12 were counterbalanced between sets. A 3 X 3 repeated measures ANOVA was used to analyze the data. The $p < .05$ level of significance was used for all tests. **Results:** There was no significant difference in either knee extension or knee flexion peak torque when comparing work:rest ratios. **Conclusion:** These findings suggest that a 1:3 work:rest ratio is sufficient during a common isokinetic strength test.

Key words: isokinetic strength test, rest period, work:rest ratio, knee extension, knee flexion, peak torque.

Chapter 1

Introduction

Isokinetic testing has been a favorable method in acquiring new insight into biomechanics and greatly expanding the possibilities for studying various physiological principles of muscle function such as the force-velocity relationship (Foss & Keteyian, 1998; Hill, 1938), the power-velocity relationship (Osternig, 1986; Perrine & Edgerton, 1978), and the strength curve (Kulig, Andrews, & Hay, 1984; Stone & O'Bryant, 1987). Isokinetic testing has also demonstrated versatility by offering a convenient way to predict 1-repetition maximum (1-RM) in dynamic leg extensions (Gulick, Chiappa, Crowley, Schade, & Wescott, 1998), while also offering a noninvasive way to predict muscle fiber-type composition (Adams, 2002).

Since its introduction in the scientific literature (Hislop & Perrine, 1967; Thistle, Hislop, Moffroid, & Lowman, 1967), isokinetic testing has become a common method of evaluating human muscle performance in athletes and functional capacity in patients. In the same time period that isokinetic exercise was introduced, many of the published papers that followed were based on knee testing (Dvir, 2004). Although knee testing does not enjoy the same degree of exclusivity today, it still remains as one of the most commonly used isokinetic protocols among clinicians (Dvir, 2004).

In isokinetic evaluation, the types of tests commonly performed include muscular strength (Tourny-Chollet, Leroy, Leger, & Beuret-Blanquart, 2000), endurance (Colliander, Strigard, Westblad, Rolf, & Nordenstrom, 1998), power (Liebermann, Maitland, & Katz, 2002), and bilateral and ipsilateral strength (Adams, 2002). Although some have been skeptical of isokinetic testing due to the claim of a lack of functionality (Siff, 2003; Stone 2000), it has continued to be commonly utilized among researchers, athletic trainers, and physical therapists due to its quantitative capability and the precision of measurement it provides (Baltzopoulos & Brodie, 1989; Davies, 1992; Elliott, 1978; Rothstein, Lamb, & Mayhew, 1987). The expansive capability to standardize testing procedures in isokinetic testing compared to other strength testing modes gives isokinetic testing an advantage in terms of test validity (Sale, 1991). Even with the high cost of an isokinetic device, these devices have become more prevalent in many athletic training facilities on college campuses and in sophisticated fitness and rehabilitation clinics (Adams, 2002).

Isokinetic strength testing has become more widely used owing to the credibility it conveys through its capacity to identify and quantify clinically relevant muscle performance factors such as explosive strength, fatigue tolerance, or strength imbalance, all of which may be involved in knee pathology (Perrin, 1993). Another reason for the frequent use of isokinetic testing is its capacity to dispense quantifiable data that are useful in monitoring physiological changes in athletes and patients alike. This method of strength evaluation has been useful in describing physiological changes in response to physical training (Brown & Whitehurst, 2003), providing useful biomechanical data for research purposes (Kannus, 1994), and characterizing function in various populations (Melzer, Benjuya, & Kaplanski, 2000). Among these various populations, athletes in many different sports have been plagued with lower leg injuries (Pincivero, Gear, Sterner, & Karaunkara, 2000).

A common problem among athletes following anterior cruciate ligament (ACL) reconstructive surgery is the loss of quadriceps muscle strength. Through isokinetic strength testing, a clearer and more objective view of strength progression and improvement may be observed (Tyler, Nicholas, Hershman, Glace, Mullaney, & McHugh, 2004). The extensive use of isokinetic strength testing as a common modality for baseline data acquisition has paved the way for optimal rehabilitation program design in patients and athletes. However, the validity of the test results regarding strength progression and improvement are heavily dependent on the standardization of testing procedures (Pincivero, Lephart, & Karunakara, 1998; Sale, 1991). Standardization of testing allows findings to be mainly attributed to the success of the rehabilitation program (Pincivero et al., 1998). Furthermore, with the aid of valid and reliable strength findings, clinicians and physical therapists will be able to design a much safer and more effective training program for their patients.

Statement of the Problem

The ability of an isokinetic device to assess muscular function and pathology by way of quantification of torque, work, and power are attributes that are valuable in producing measurable change as well as making advances in the disciplines of exercise science and sports medicine. With objective measures such as these, validity and reliability of strength tests are enhanced, while findings gain practical value (Osternig, 1986). For these reasons, the importance of accurately reproducing isokinetic strength values during testing becomes critical in preventing instrument or testing error when tracking changes during physical training and rehabilitation (Pincivero, Lephart & Karunakara, 1997a). The implication is that when strength values are reliable, other confounding variables have been eliminated, thereby allowing the changes of physical training and rehabilitation to be more clearly seen.

Although many studies have employed isokinetic strength testing to investigate various aspects of muscle performance, interset rest periods have not received as much attention (Bilcheck, Kraemer, Maresh, & Zito, 1993; Parcell, Sawyer, Valmor & Chinevere, 2002; Pincivero, Gear, Moyna, & Robertson, 1999; Stratford, Bruulsema, Maxwell, Black, & Harding, 1990). Even with the inaugural research investigating interset rest periods by Ariki, Davies, Siewart, & Powinski (1985) and Stratford et al. (1990), many researchers have continued to underestimate the impact of interset rest periods on measurement reliability. When rest periods are not standardized, the test may begin to measure other facets of muscular function such as high-intensity muscular endurance (Robinson, Stone, Johnson, Penland, Warren, & Lewis, 1995). As a result, an unnecessary amount of fatigue can occur, thereby preventing full muscle activation in the succeeding sets (Pincivero et al., 1998). The eventual outcome will be one of misleading findings that do not assess muscular strength at its true maximum (Weiss, 1991).

Obtaining an Optimal Interset Rest Period

In attempting to address the problem of lack of standardization of interset rest periods in isokinetic testing, fatigue and recovery specific to strength testing need to be clearly understood. Furthermore, a fundamental comprehension of the historical roots of fatigue and recovery research is essential. In strength testing of any mode, the test is typically of very short duration due to the anaerobic nature of high-intensity muscle contractions lasting 1-15-s as dictated by the adenosine triphosphate phosphocreatine (ATP-PC) energy system (Robergs & Roberts, 1997). The underlying logic to strength is that it is manifested through the ATP-PC energy system with the main energy source being phosphocreatine (PCr) (Robergs & Roberts, 1997). Thus, the relevance of these underlying concepts is paramount in making coherent and logical decisions about rest period establishment.

PCr recovery will be the type of exercise recovery referred to in the following review of literature on exercise recovery. Since PCr is the primary substrate used in energy production during any isokinetic strength test (Robergs & Roberts, 1997), its significance is worthy of further explanation. Hence, basic research on PCr recovery kinetics is of primary interest due to PCr recovery being the underlying physiological mechanism responsible for strength recovery.

Historically, basic research has primarily looked at exercise recovery in controlled laboratory settings using isometric and exhausting dynamic exercise (Bigland-Ritchie, Jones, Hosking, & Edwards, 1978; Bogdanis, Nevill, Boobis, Lakomy, & Nevill, 1995; Boska, Moussavi, Carson, Weiner, & Miller, 1990; Harris, Edwards, Hultman, Nordesjo, Nylind, & Sahlin, 1976; Hultman, Bergstrom & McLennan Anderson, 1967; McCann, Mole, & Caton, 1995; Nassar-Gentina, Passonneau, Vergara & Rapoport, 1978; Nosek, Fender, & Godt, 1987; Spande & Schottelius, 1970; Takahashi, Inaki, Fujimoto, Katsuta, Anno, Niitsu, et al., 1995). Several of these studies looked at recovery of isolated animal (Nassar-Gentina, et al., 1978; Nosek, et al., 1987; Spande & Schottelius, 1970) and human muscles (Bigland-Ritchie et al., 1978; Bogdanis et al., 1995; Boska et al., 1990; Harris et al., 1976; Hultman et al., 1967; McCann et al., 1995; Takahashi et al., 1995) in which the modes of contraction were not specific to the types of contraction typically used in strength training or testing. Many of the earlier findings on exercise recovery were based on various anaerobic exercises such as isometrics (Boska et al., 1990), electrical stimulation (Bigland-Ritchie et al., 1978), over-ground sprinting (Balsom, Seger, Sjodin, & Ekblom, 1992), or cycle sprinting (Bogdanis et al., 1995).

Although many of these aforementioned studies have investigated the causes of fatigue, none have looked at recovery specifically related to strength training or testing. In particular, of the few basic research studies investigating PCr recovery kinetics, several looked at PCr recovery during exhausting cycle ergometer or isometric tests (Bogdanis et al., 1995; Boska et al., 1990; Harris et al., 1976; Hultman et al. 1967). Although many applied research studies have reported differences in recovery times for isokinetic strength testing (Bottaro, Russo, Oliveira & Barbosa, 2005; Parcell et al., 2002; Pincivero et al., 1998; Touey, Sforzo, & McManis, 1994), this cannot replace the clear depiction that basic research can offer into strength recovery based on the underlying mechanisms into PCr recovery kinetics. For example, the reported strength recovery times in applied research were quantified through indirect measures such as peak torque or reproducibility of strength performance (Bottaro et al., 2005; Parcell et al., 2002; Pincivero et al., 1998; Touey et al., 1994). On the contrary, basic research provides a direct measure of the exact underlying physiological processes (e.g. PCr recovery kinetics) that occur during strength recovery through muscle biopsy (Harris et al., 1976; Hultman et al., 1967) or a more recent and noninvasive procedure known as phosphorus nuclear magnetic resonance (P-NMR) spectroscopy (McCann et al., 1995; Takahashi et al., 1995). In applied research, these underlying physiological processes are only implicated based on the indirect measures of peak torque or reproducibility of strength performance. With the applied research results of differences existing in strength recovery time (Bottaro et al., 2005; Parcell et al., 2002; Pincivero et al., 1998; Touey et al., 1994), it gives justification to investigate PCr recovery directly through basic research so that these strength recovery differences can be logically confirmed and understood more precisely.

Although basic research findings have primarily investigated exhausting dynamic exercise (e.g. non-functional isometric contractions, cycle ergometry, over-ground sprinting), which lacks specificity to resistance training, the rest periods recommended from these results have nonetheless been applied in sports, fitness, and rehabilitation settings (Harris et al., 1976; Hultman et al., 1967 McCann et al., 1995; Takahashi et al., 1995). However, the specific effects of PCr recovery kinetics within strength training or testing have yet to be thoroughly investigated in either basic or applied research. This should not negate the tremendous benefit of these basic research findings in exercise recovery, because they do encompass the underlying physiological processes involved in human fatigue and recovery. However, with the lack of consistency in research findings regarding strength recovery (Bottaro et al., 2005; Parcell et al., 2002; Pincivero et al., 1998; Touey et al., 1994) and the genuine importance of having reliable baseline strength data, these are just a few of the many reasons that further investigation into strength recovery is warranted. The relevance is that if fatigue becomes a factor in strength testing, then the results will not reflect the individual's true strength level, thereby negatively affecting the rehabilitation program design and the precision in monitoring strength improvement. The benefits that can be expected from standardizing rest periods are as follows: 1) higher test-retest reproducibility; 2) better test time management and; 3) higher proficiency in strength assessment and strength training program development. Research has demonstrated that sufficient interset rest periods enable greater amounts of isokinetic strength production with a higher reliability of measurement compared to no rest (Stratford et al., 1990) or short rest periods between sets (Ariki et al., 1985).

Although rest periods may vary according to the isokinetic test velocity and the repetition load, there has been a general inconsistency in rest period allotment in the literature (see Table 1). Proper rest periods are important for maximizing tension, thus allowing maximal strength to be reproduced between test trials (Brooks, Fahey, & White, 1996). Inadequate rest between test trials may have a significant impact on the reliability of measurements due to fatigue, which may compromise the reported findings (Parcell et al., 2002; Pincivero, Gear & Sterner, 2001). If rest periods are insufficient, then the specific use of the ATP-PC system and concurrent maximal muscular strength will be lost in addition to fatigue becoming a confounding variable (Weiss, 1991). Unfortunately, an optimal interset rest period has not been determined for strength recovery.

Table 1

Summary of Results

Source	Test Velocities (deg/s)	Reps/ Velocity	Order of Contractions	Contraction Mode	Gender	Rest Period Length	Main Findings
Ariki et al. (1985)	180, 210 240, 270 300	10	Ascending	Reciprocal	Males & Females	30, 60 90-s	90-s was optimal ($p < 0.05$)
Bilcheck et al. (1993)	30, 120	3	Randomized	Discrete & Reciprocal	Females	30-s	2.5 minute rest period preserves strength ($p < 0.05$)
Bottaro et al. (2005)	60, 90 120	4	Randomized	Discrete	Males	30, 60 120-s	No difference among rest periods ($p < 0.05$)
Brown et al. (1998)	60, 120, 180, 240, 300, 360, 400, 450	3	Ascending	Reciprocal	Males & Females	30-s	Men had less acceleration ROM than women ($p < 0.05$)
Caiozzo et al. (1981)	50, 96, 144, 190, 240, 288	4-7	Ascending	Not reported	Males & Females	10-s per rep	Training at 96°/s altered force-velocity relationship ($p < 0.05$)
Gomez et al. (2002)	30, 180, 300	3	Not reported	Reciprocal	Males	Not reported	A 10-kilometer run induces muscle-fiber specific fatigue ($p \leq 0.05$)

Note. Summary of results continued on next page.

Table 1 Continued

Parcell et al. (2002)	60, 120 180, 240 300	4	Ascending	Discrete	Males	15, 60 180, 300-s	A rest period of ≥ 60-s greater led to sufficient recovery ($p < 0.05$)
Pincivero et al. (1998)	90	10	4 sets @ 90º/s	Reciprocal	Males & Females	40 160-s	The 160-s rest period led to greater recovery ($p < 0.05$)
Stratford et al. (1990)	60	5	1 set @ 60º/s	Reciprocal	Females	no rest, 30-s per rep	The 30-s rest led to greater recovery ($p < 0.001$)
Stumbo et al. (2001)	60, 180, 300	3	Ascending	Reciprocal	Males & Females	3-min	Hand-grip stabilization improved performance in men only ($p < 0.007$)
Weir et al. (1996)	60, 180, 300	3	Ascending	Reciprocal	Males & Females	Not reported	Extraneous movement effects peak torque ($p = 0.0196$)
Wyse et al. (1994)	60, 180	4	Randomized	Reciprocal	Males	5-min	Time-of-day has an effect on peak torque ($p < 0.05$)

Note. This summary is a combination of strength testing and rest period studies along with other studies that were derived during the compilation of this investigation. Only the studies with a clear explanation and description of test protocols were used in this summary.

Purpose of Study

While a scant number of studies have investigated interset rest periods in isokinetic testing (Parcell et al., 2002; Pincivero et al., 1999), none have identified a time-cost and consistently effective interset rest period. The purpose of this study was to establish an optimal rest period that would allow consistent reproducibility of strength during a common isokinetic strength-testing protocol. The practical applications were to promote higher test reliability that would ultimately improve precision of strength progress reports and exercise program design.

Significance of the Study

In isokinetic testing, precision of results are increased due to the quantitative capability of the isokinetic apparatus when compared to other modes of strength testing (e.g. free-weights) (Perrin, 1993). While many facets in isokinetic testing have been standardized, rest periods have been inconsistent in many published studies, while some studies have even failed to report rest periods (see Table 1). Although convenience may be a reason for ignoring length of rest periods, this is not an acceptable reason to avoid standardizing rest periods. Therefore, rest periods should be studied more extensively and eventually standardized in retrospect to isokinetic testing being a highly quantitative form of measurement and evaluation.

When true strength change and improvement are the objective among clinicians and researchers, test reliability becomes critical in the fulfillment of attaining reliable data (Pincivero et al., 1997a). Therefore, rest periods need to be further investigated in order to atone for confounding variables and to preserve high test reliability.

Hypotheses

1) There will be significant differences in knee extension peak torque when using different work:rest ratios (rest periods).

2) There will be significant differences in knee flexion peak torque when using different work:rest ratios (rest periods).

Definition of Terms

<u>Applied Research:</u> Type of research that has direct practical application to educational problems, but of which the researcher has limited control of the research setting (e.g. peak torque measurement used to indirectly indicate PCr stores post-exercise based on peak torque and PCr correlation) (Gay & Airasian, 2003; Thomas & Nelson, 2001).

<u>Basic Research:</u> Type of research conducted in laboratory settings in which the researcher has careful control of the conditions and of which theory development is paramount, but of which research findings have limited practical application to educational problems (e.g. muscle biopsy to determine PCr stores post-exercise) (Gay & Airasian, 2003; Thomas & Nelson, 2001).

<u>Discrete Single Contraction</u> – An isokinetic test mode in which movement is non-continuous and is typically in a single direction (e.g. knee extension immediately followed by relaxing and

letting the leg fall back to starting position) (Brown, Whitehurst, Findley, Gilbert, Groo & Jimenez, 1998; Wrigley & Strauss, 2000).

Fatigue – The inability to maintain a given exercise intensity (Robergs & Roberts, 1997).

Interset Rest Period – The allotment of time between sets of resistance exercise (Pincivero & Campy, 2004).

Isokinetic – An accommodating resistance that functions to keep speed of movement at a constant pre-set speed throughout a specific range of motion, regardless of force exertion being maximal or submaximal (Perrin, 1993).

Metabolic Fatigue – Fatigue that arises from the accumulation of metabolic by-products due to energy-producing anaerobic metabolic processes [e.g. excessive build-up of inorganic phosphate (Pi) and lactate] (Boska et al., 1990).

Non-Metabolic Fatigue – Fatigue that arises from neurological origin and could be both of peripheral or central location (e.g. failure of nerve impulses to reach muscles or a neurotransmitter transmission failure) (Moussavi, Carson, Boska, Weiner & Miller,1989).

Peak Torque (Strength) – Maximal amount of force exerted within the isokinetic moment angular curve; usually is the highest point in the torque curve (Perrin, 1993).

Phosphagen System (ATP-PC) – A simple anaerobic energy system involving muscle stores of ATP and the use of PC to sustain ATP production primarily during short-term, high-intensity work (Foss & Keteyian, 1998; Wilmore & Costill, 1999).

Phosphocreatine (PCr) – An energy-rich compound found in skeletal muscle that plays a pivotal role primarily during high-intensity, short duration exercise by providing energy for muscle contraction by maintaining adenosine triphosphate (ATP) concentration (Robergs & Roberts, 1997; Wilmore & Costill, 1999).

Rate of Force Development – The speed with which one can access maximal strength or a specific percentage of his or her maximal strength within a very short period of time (e.g. amount of force generated within the first 0.03-s of muscular contraction) (Behm, 1995; Bell & Jacobs, 1986).

Reciprocal Contraction – An isokinetic test mode in which movement is continuous and typically concentric muscle force is measured in both directions (e.g knee extension immediately followed by knee flexion) (Brown et al., 1998; Wrigley & Strauss, 2000).

Work:Rest Ratio – A proportional relationship between the time spent exercising and the time spent resting (e.g. a 1:3 work:rest ratio would equate to 10 seconds of exercise, followed by 30 seconds of rest) (Foss & Keteyian, 1998).

Limitations

Limitations in this study were as follows:

1) The effects of race: Race was not controlled in this study. Research has shown that

African-American males have a greater proportion of type II muscle fibers compared to Caucasian males, suggesting potentially greater fatigue rates and a slower recovery time (Ama, Simoneau, Boulay, Serresse, Theriault, & Bouchard, 1986).

2) Subject reliability: In regard to subject reliability, this was a difficult variable to control due to the complexities of the human element (Perrin, 1993). For instance, the willingness to exert maximum effort and compliance to test instructions are factors that may confound the reliability of measurement.

3) Measurement of PCr dynamics: Due to equipment and time feasibility, PCr could not be measured. As a result, PCr concentration was premised on the theoretical basis in which it behaves during high-intensity exercise (Harris et al., 1976; Hultman et al., 1967). This basis is that as peak torque declines, so does PCr concentration.

4) Improvement in strength from daily activities: Research has shown that strength changes can occur as a result of the testing itself being a stimulus for strength improvement among novice subjects (Cronin & Henderson, 2004). Although research has shown 5 days between test sessions to be an ideal amount of time in attaining reliable measures (Gleeson & Mercer, 1996), 2 days between test sessions has also shown to be an adequate time period in retaining reliability as well (Bardis, Kalamara, Loucaides, Michaelides, & Tsaklis, 2004; Levene, Hart, Seeds, & Fuhrman, 1991). This interday rest period of 2 days was used in this study due to its time-cost effectiveness.

While learning effects during testing sessions have also been suggested to confound measurements (Kues, Rothstein, & Lamb, 1992), these learning effects can be expected due to normal day-to-day variation in strength (Dvir, 2003). In delineation of whether changes in strength occur as a result of measurement error or real change, Dvir (2003) has suggested that no real change is significant unless a 20% difference is found in retesting. Thus, an arbitrary cut-off point has now been established to distinguish learning effects versus treatment effects. Furthermore, two familiarization sessions took place prior to experimental testing to reduce strength changes due to learning effects.

Delimitations

Delimitations in this study were as follows:

1) <u>Age:</u> Only subjects between the ages of 18-35 participated in the study.

2) <u>Health status:</u> Only subjects in good physical condition participated in this study. Subjects consisted of males at low-risk for cardiovascular disease and who had non-pathologic knees.

3) <u>Fitness status:</u> Only subjects who participated in 30-minutes of accumulated physical activity at least 3 days per week were included in this study.

4) <u>Participant Recruitment:</u> Only university students were recruited for participation in this study.

Assumptions

Assumptions in this investigation were as follows:

1) Subjects were given the same form of consistent verbal encouragement during testing.

2) Peak torque reproducibility represented PCr concentration and subsequent recovery. The assumption was that as peak torque decreases, PCr decreased as well. The logic to this assumption has been substantiated in research showing declines in strength (peak torque) when rest periods are insufficient (Hitchcock, 1989). Other research has positively correlated ($r = 0.80$, $p < 0.05$) PCr concentration with total work production (Casey, Constantin-Teodosiu, Howell, Hultman, & Greenhaff, 1996). Thus, strength (peak torque) was used to understand the effect rest periods had on PCr concentration.

3) The Cybex NORM isokinetic dynanometer provided valid data despite its known inherent problems such as torque overshoot (Sapega, Nicholas, Sokolow, & Saraniti, 1982) and gravity correction estimation based on the cosine curve (Keating & Matyas, 1996).

4) Subjects did not vary dietary patterns and outside physical activities throughout the course of the study. From a performance enhancement perspective, it has been shown that oral creatine and caffeine intake have ergogenic effects on strength performance in isokinetic testing (Greenhaff, Casey, Short, Harris, Soderlund, & Hultman, 1993; Jacobson, Weber, Claypool, & Hunt, 1992). Thus, subjects were asked to refrain from caffeine a minimum of 12 hours before testing and any

other ergogenic aids throughout the course of this study.

5) Subjects did not vary time of day for testing. Time of day can be a confounding factor that has also been shown to affect strength test performance (Wyse, Mercer, & Gleeson, 1994). However, as a result of the busy schedule of college students juggling class time with other commitments such as employment (Buckworth, 2001), time of day and time between test sessions were scheduled judiciously, but within a standardized time scope. Therefore, testing occurred a minimum of 48 hours between test sessions (Bardis et al., 2004; Levene et al., 1991; Weiss, Coney & Clark, 1988) within roughly the same time of day (11 a.m. – 1 p.m.) for each subject.

Chapter 2

Review of Related Literature

In most isokinetic studies, the prevalent method of strength testing has typically been of ascending order in which the test progresses from slow-to-fast speeds (see Table 1). However, the establishment of interset rest periods between sets has been an area of discordance. The problem is that many of these studies have used interset rest periods that do not account for the changing intensity of test sets in this prevalent slow-to-fast speed test design. On the contrary, interset rest periods in isokinetic strength tests should be dependent on the intensity of the sets. The intensity is grounded on the repetition load and the corresponding isokinetic test velocity. The repetition load relates training effects to a specific number of repetitions (Fleck & Kraemer, 1988), but it also implicates the intensity and the bioenergetic pathway involved (Knuttgen, 2003; Kraemer, 2003). The isokinetic velocity relates to the magnitude of motor units active and the force generated as supported by the force-velocity relationship (Hill, 1938). Thus, each test velocity will incur a different workload as determined by the total contraction time. If an isokinetic test is designed to measure muscular strength, then the repetition load should be from 2-6 repetitions (Baltzopoulos & Brodie, 1989; Perrine, 1986; Pincivero & Campy, 2004).

Although the comparison among different protocols of isokinetic testing is difficult due to the differences in contraction mode (i.e., discrete single vs. reciprocal or concentric-only vs.

concentric-eccentric), exercise mode of study (i.e., training vs. testing), and repetition load (i.e., 4 reps vs. 20 reps), they provide the most closely related comparisons in the scientific literature identifying interset rest periods (Woods, Bridge, Nelson, Risse, & Pincivero, 2004). The following review of literature provides an overview of the scant number of published studies on interset rest periods in isokinetic testing. Thereafter, relevant concepts pertaining to the logic in understanding strength recovery were reviewed. Ultimately, a proposed solution in deriving an optimal interset rest period in isokinetic testing was examined. The review of literature and relevant concepts are in the order as follows:

1) Isokinetic strength testing.

2) ATP-PC system supremacy in strength testing.

3) Fatigue specific to a common isokinetic knee strength testing protocol.

4) Recovery in strength testing.

5) Proposed method of identifying strength recovery.

Isokinetic Strength Testing

The primary methods of identifying strength recovery in the research have included a variety of rest periods (Parcell et al., 2002) and work:rest ratios (Pincivero, Lephart & Karunakara, 1997b). The work:rest ratio is a simplistic method of standardizing rest periods more in depth as compared to the allotment of one set rest period. For instance, in two work bouts of 6-s and 12-s of muscular contractions, a standard 60-s rest period would apply to both work bouts. However, a work:rest ratio of 1:10 would be dependent on the duration of the work bout. In this case, the rest periods would be 60-s and 120-s for the 6-s and 12-s work bouts, respectively. The rest periods (60 & 120-s) in this case were based on the ratio (1:10) in which the rest periods are in multiples of each of the work bouts (6-s x 10 & 12-s x 10 = 60 & 120-s). The logic to this method is that it accommodates for the specific magnitude of fatigue induced by each work bout. The premise is that the longer the duration of the exercise bout within the ATP-PC system, the greater the depletion of PCr, thus the need for the rest period to be dependent on the work bout. This is a factor that is missed when allotting a standard and restrictive 60-s rest period (Parcell et al., 2002).

The current data available have indicated conflicting findings in regard to interset rest periods in isokinetic strength testing and training, with some research indicating short rest periods (≤ 60-s) to be adequate (Parcell et al., 2002), while others have shown intermediate (90-s) (Ariki et al., 1985) and long rest periods (≥ 150-s) (Bilcheck et al., 1993) to be adequate. In an inaugural investigation studying the influence of rest periods along the velocity spectrum (180, 210, 240, 270, and 300 deg/s), Ariki et al. (1985) found that in performing 10 repetitions per velocity, a 90-s rest period was optimal in strength performance. Contrary to these early findings by Ariki et al. (1985), Bilcheck et al. (1993) found that a rest period of 150-s was adequate in strength recovery when performing 1 set of 3 repetitions at 30 deg/s and 120 deg/s following a fatigue task consisting of 3 sets of 30 repetitions at 120 deg/s. Interestingly, Pincivero et al. (1999) found that although a 1:8 work:rest ratio (160-s rest period) led to a better preservation of peak torque compared to a work:rest ratio of 1:2 (40-s rest period) when performing 4 sets of 20 repetitions at 180 deg/s (20-s per set), although the longer rest interval still did not allow sufficient recovery. Touey et al., (1994) found that a longer rest period (120-s) allowed adequate strength recovery at 60 deg/s, while a shorter rest period (60-s) was adequate at 180 deg/s in performing 4 sets of 10 repetitions for each test velocity. It was later noted that a rest period of 60-120-s allowed optimization of the work:rest ratio (1:4-1:8), although performance was maximized with 240-s of rest (Touey et al., 1994). Others have found that a rest period of 160-s was sufficient for optimal recovery and strength performance (Pincivero & Campy, 2004; Pincivero et al., 1997b; Pincivero et al., 1998). Specifically, Pincivero & Campy (2004) used a workload of multiple sets of 20 repetitions at 180 deg/s, while Pincivero et al. (1998) and Pincivero et al. (1997b) both used a workload of multiple sets of 10 repetitions at 90 deg/s. Although these studies found similar results of longer rest periods being optimal, each of these studies were looking at completely different aspects of rest period influence on strength (Pincivero & Campy, 2004; Pincivero et al., 1997b; Pincivero et al., 1998). Pincivero et al. (1998) investigated how rest periods effected strength recovery and reliability in testing, while Pincivero et al. (1997b) utilized the long (160-s) and short (40-s) rest periods to observe strength changes over a 4-week training period. Pincivero & Campy (2004) and Pincivero et al. (1997b) both shared a common interest in observing strength changes over a training program, with the only difference in protocol being that the training period by Pincivero & Campy (2004) was extended to 6-weeks.

Contrary to these latter findings, other investigators have found that shorter rest periods were enough to recover during testing. Parcell et al. (2002) found that 60-s of rest was sufficient to generate reproducible maximum efforts when performing 5 sets of 4 repetitions in an ascending order from 60, 120, 180, 240, and 300 deg/s. In an attempt to replicate the findings of Parcell et al. (2002), Warren & Blazquez (2004) used a similar protocol. The major difference in the protocol by Warren & Blazquez (2004), was that a different rest period was distributed after each set throughout the session, as opposed to sustaining the same rest period throughout the entire session (Parcell et al., 2002). In addition, it was later discovered by the researchers (Warren & Blazquez, 2004) that the effects of gravity and overshoot may not have been corrected in every subject. Research has demonstrated that the magnitude of error can be as high as 510% if gravity is unaccounted for during isokinetic testing (Winter, Wells, & Orr, 1981). Not surprisingly, no significant differences or findings were observed in the work of Warren & Blazquez (2004). In a more recent study, Bottaro et al. (2005) found 30-s to be adequate when performing 2 sets of 4 repetitions at 60, 90 and 120 deg/s in randomized order.

In other research, Conroy, Stanley, Fry, & Kraemer (1989) found that a 2-minute rest did not lead to any significant performance differences compared to no rest in 1 set of 3 reciprocal repetitions of leg extension and flexion. However, the 2-minute rest was allotted between repetitions and not sets in addition to there being an overall lack of detail in the methodology. For instance, while participants were tested at four test velocities (60, 180, 240, & 300 deg/s), no details were offered as to the rest interval between sets. In other findings (Harder, Kincade-Schall, Pincivero, Coelho, Lephart & Robertson, 1999; Keller, Pincivero, Coelho, Lephart, & Robertson, 1999), it was found that short interset rest periods (40-s) were conducive for short-term strength development when training at 180 deg/s. Although an attractive finding, it has no relevance since the purpose was to develop strength through training, instead of preserving strength for testing.

In regard to the findings of Parcell et al. (2002) and Bottaro et al. (2005), a possible reason for finding a shorter rest period to be sufficient in sustaining peak torque could be due to the relative intensity of the strength test. The rest periods necessary to optimize strength performance tend to be higher as intensity increases. Such a linear relationship was demonstrated in the results of Touey et al. (1994) who concluded that at 60 deg/s, a 2-minute rest period allowed adequate recovery, while at 180 deg/s, a 1-minute rest period allowed adequate recovery.

The implication from their findings suggests the need for longer rest periods for heavier resistances that are represented isokinetically as slower velocities (force-velocity relationship). Another interesting outcome from the work of Touey et al. (1994) was that they advocated a 240-s rest period for allowing maximal strength recovery. An intriguing similarity was that this 240-s rest period would have equated to a 1:12 work:rest ratio in the testing protocol of Pincivero et al. (1999). In the findings of Pincivero et al. (1999), it was remarked that even with a 160-s rest period, this 1:8 work:rest ratio still did not allow full recovery. Based on these indications, it would seem plausible to have higher work:rest ratios during isokinetic strength testing.

In the testing protocol used by Touey et al. (1994), both testing velocities (60 deg/s & 180 deg/s) consisted of a workload of 4 sets of 10 repetitions. However, the 60 deg/s test velocity set lasted longer, thereby inducing a higher metabolic workload that would presumably have led to a longer needed rest period. Alternatively, Parcell et al. (2002) used 5 sets of 4 repetitions consisting of discrete single concentric-only contractions with each set advancing to a faster velocity, thus leading to less tension time on the working musculature. In similar fashion, Bottaro et al. (2005) used 2 sets of 4 repetitions consisting of discrete single concentric-only contractions. Given that these were discrete single concentric-only contractions with no significant knee flexion work involved, the duration of work was shorter. Furthermore, with the exception of 60 deg/s, all other velocities were ≥ 90-120 deg/s. Hence, the actual amount of work accomplished during subsequent sets was considerably less than other studies using reciprocal concentric knee extensions/flexions (Pincivero & Campy, 2004; Pincivero et al., 1997b; Pincivero et al., 1999; Pincivero et al., 1998; Touey et al., 1994) and single concentric/eccentric knee extensions (Bilcheck et al., 1993).

While it has been well established that the magnitude of fatigue and the duration of the ensuing rest periods undertaken can have a dramatic effect on subsequent exercise performance, there is a lesser known psychological component within strength testing that may also have a significant impact on strength performance. In a study by Tharion, Harman, Kraemer, and Rauch (1991), it was found that shorter interset rest periods led to greater psychological anxiety and fatigue. If rest periods are short (≤ 60-s), the bodily sensations from an inadequate rest period may prevent optimal psychological preparation. This acute response to short interset rest periods can prevent reproduction of maximal effort during subsequent test trials, thereby compromising test validity and reliability. Optimal rest periods between sets are needed to allow adequate recovery and enough time to attain an optimal level of cognitive arousal for the next test trial (Young, 1989).

While the amount of rest will be dependent on the nature of the test, Perrin (1993) has recommended an interset rest period of 30-60-s for strength testing at any velocity. He also suggested that the interset rest period be at least 1-minute or longer if the test consists of 25-30 repetitions (Perrin, 1993). In agreement, Wrigley & Strauss (2000) recommended a 40-60-s rest interval be allowed between sets. Furthermore, they also suggested that shorter rest intervals be used for discrete single concentric-only contractions and tests at high-velocities (Wrigley & Strauss, 2000). Opposing views by Davies (1992) and Davies, Heiderscheit, & Brinks (2000) suggested that 90-s is the optimum rest period, while for power profile testing, a 3-minute rest period is recommended. Sale (1991) suggested that longer rest periods (1-3 minutes) should be administered at slower velocities testing larger muscle groups. Although Davies (1992) advocated a 90-s rest period based on the findings of Ariki et al. (1985), he suggested that this amount of time lacks ecological validity since it would take up too much time in a busy clinical setting. In addition, it should be disclosed that this 90-s rest period was directed towards training rather than testing. Interestingly, the basis for this 90-s rest period was predicated on test velocities ≥ 180 deg/s, which refutes the 30-60-s rest period recommendations for fast test velocities (Perrin, 1993; Wrigley & Strauss, 2000). In reference to the exercise protocol used by Ariki et al. (1985), the work:rest ratios ranged from 1:9-1:15.

In light of these reports and findings, there are several factors that need to be addressed prior to drawing conclusions simply based on these findings. One important factor is how the type of contraction modes within the isokinetic test protocols tended to differ among the studies. For instance, discrete single concentric-only contractions (Parcell et al., 2002) and reciprocal concentric-only contractions (Pincivero et al., 1999; Pincivero et al., 1998; Touey et al., 1994) were employed by some investigators, whereas concentric and eccentric contractions were utilized by Bilcheck et al. (1993). Two potential problems arise with the administration of differing contraction modes. First, the recovery effects would tend to differ due to a dissimilar amount and type of work completed (Fleck & Kraemer, 2004). Reciprocal contractions accomplish twice the amount of work as discrete single contractions, since in reciprocal contractions the muscle group does not relax at any point, whereas in discrete single contractions, the muscle group works half the time while relaxing in the return to the starting position. Thus, whether the contraction mode is reciprocal with concentric-only or concentric-eccentric contractions, the energy requirements will be greater in reciprocal versus discrete single contractions. Moreover, there would be a greater localized diminishment of energy stores when performing concentric and eccentric contractions since the agonist muscle group is being worked on both contractile phases (Bilcheck, Maresh & Kraemer, 1992). Pasquet, Carpentier, Duchateau, & Hainaut (2000) found that a greater loss of force occurred in concentric contractions (31.6%) compared to eccentric contractions (23.8%). However, recall that in concentric-only reciprocal contractions, an agonist-antagonist contraction pattern is achieved. Hence, the total time under tension is evenly distributed across agonist-antagonist muscle groups, whereas in a reciprocal concentric-eccentric contraction, the total time under tension will be sustained by the agonist muscle group the entire time (Bilcheck et al., 1993). Although one could argue either viewpoint, the fact still remains that concentric-only contractions versus concentric-eccentric contractions will elicit different fatigue and recovery patterns as supported by the law of specificity (Fleck & Kraemer, 2004).

In research pertaining to isokinetic testing, the prevalent methodology of isokinetic strength testing has reflected an ascending order across the velocity-spectrum (Parcell et al., 2002). In these prevalent practices, one velocity-spectrum set is typically used in assessing and quantifying muscular strength. Thus, the approach to discovering the optimal rest period must address the current methodology of isokinetic strength testing. Since one velocity-spectrum set is performed, the issue becomes how the fatigue patterns of the previous test velocity sets influence subsequent sets at different test velocities. With ascending order protocols testing at slow velocities first, the effect of fatigue induced by these slower velocity test sets needs to be addressed in regard to how it impacts performance at faster subsequent test velocities. At fast test velocities, the strength expression is limited by the short duration of contraction time. Hence, the rate of force development will be the determinant of the exact percentage of maximal strength that will be displayed as peak torque in these fast velocity sets. Following this logic, if fatigue reduces the rate of force development, then the peak torque at faster velocities should also be depressed (Ewing, 1982; Spendiff, Longford, & Winter, 2002). Therefore, if the objective in isokinetic testing is to obtain the best possible results that can only transpire through maximal efforts, it is important to identify how the previous slower-velocity set may deter the strength response in the following higher-velocity set.

ATP-PC System Supremacy in Strength Testing

Before delving into strength recovery physiology, there is a relevant and rudimentary bioenergetic-time continuum worthy of discussion. In isokinetic strength testing, the primary energy system being used is the ATP-PC system. Providing that strength testing is conducted with a proper repetition load (2-6 reps) (Baltzopoulos & Brodie, 1989) and duration (1-15-s) (Wilmore & Costill, 1999), the ATP-PC system will predominate irrespective of the test velocity. If the intensity is maximal then the duration will be short since the energy pathway will be primarily anaerobic (Adams, 2002; Foss & Keteyian, 1998; Serresse, Lortie, Bouchard, & Boulay, 1988). To illustrate this, Serresse et al. (1988) demonstrated the relationship of the time course of exercise being indicative of the energy system utilized during a 10-s work performance on a cycle ergometer. The major contributors to this 10-s work performance were estimated at 53%, 44%, and 3% for the phosphagenic, glycolytic, and oxidative pathways, respectively (Serresse et al., 1988). In contrast, when performing a 90-s work performance, the major contributors to energy production were estimated at 12%, 42%, and 46% for the phosphagenic, glycolytic, and oxidative pathways, respectively (Serresse et al., 1988). When reviewing the literature, the maximal power of the ATP-PC system has been found to vary from 1-15-s (Conley, 2000; Foss & Keteyian, 1998; McArdle, Katch & Katch, 2001; Wilmore & Costill, 1999). Although the ATP-PC system is still a strong contributor beyond 15-s, substrate utilization shifts more towards anaerobic glycolysis beyond 15-s (Foss & Keteyian, 1998; McArdle et al., 2001; Wilmore & Costill, 1999). Essentially, the ATP-PC system is the primary contributor up to 15-s, afterwards the glycolytic system begins to supersede the energy contribution duties. Therefore, while intensity, as indicated by work bout duration, may vary due to the isokinetic velocity-spectrum, it can logically be deduced from the bioenergetic-time continuum that the ATP-PC system is the primary bioenergetic pathway that is utilized during any common isokinetic strength testing protocol.

Fatigue Specific to a Common Isokinetic Knee Strength Testing Protocol

Understanding fatigue as a physiological phenomenon has been very elusive due to the complexities of the human biological system and the vast array of interrelated factors involved in the fatigue process. Although other definitions are available, fatigue will be operationally defined in this investigation as the inability to maintain a given exercise intensity (Brooks et al., 1996; Robergs & Roberts, 1997). Essentially, fatigue was represented in this investigation by significant declines in peak torque across the velocity-spectrum. Although evidence exists in regard to many factors being associated with fatigue (Boska et al., 1990; Green, 1995; Moussavi et al., 1989), the exact sights and causes of fatigue have been difficult to decipher. Nevertheless, there have been significant factors associated with fatigue that have been found to arise more prominently within the specific energy system being emphasized.

The recovery of strength is dependent upon the rate of ATP regeneration, which relies on the resynthesis of PCr, an oxidative process, and partly to anaerobic glycolysis as well (Bogdanis et al., 1995; Conley, 2000; Harris et al., 1976). In order for maximal voluntary contraction (MVC) to be returned to pre-fatigue levels, certain biochemical events need to occur. Many have come to a consensus toward the relationships between MVC and certain metabolic factors. There are at least three metabolic factors that are associated to a loss in MVC: 1) Inorganic phosphate (Pi) accumulation (Westerblad, Allen, & Lannergren, 2002), 2) Adenosine diphosphate (ADP) accumulation (Robergs & Roberts, 1997), and 3) PCr depletion (Brooks et al., 1996). Each of these factors coexists in the process of metabolic activity in high-intensity exercise of very short duration (1-15-s). When one engages in a high-intensity exercise bout for a period of 1-15-s, stored intramuscular ATP is hydrolyzed up to a certain point, which is followed by PCr hydrolysis and ultimately, eventual PCr depletion (Brooks et al., 1996). During these catabolic reactions, metabolic by-products such as Pi and ADP accumulate due to the breakdown and eventual depletion of PCr (Brooks et al., 1996; Robergs & Roberts, 1997). Westerblad et al. (2002) suggested that the frequently observed relationship between declining pH and decreased muscle performance is more coincidental than causal and that some other consequence of anaerobic metabolism, such as Pi, is a stronger candidate as being a cause for impaired muscle performance in high-intensity exercise. Furthermore, this metabolic by-product pattern of accumulation would seem plausible regarding the bioenergetic time-continuum. When ATP stores begin to diminish, the PCr stores are tapped until depletion, along with a concomitant increase in Pi levels. Once PCr stores are depleted or when catabolic rates exceed anabolic rates, glycolysis commences with a greater accumulation of H+ as excessive quantities of lactate are produced. Hence, it can be recognized that decreases in pH brought on by increases in H+ are not as significant in deterring contractile function during short duration high-intensity exercise (≤ 15-s) as once thought (Brooks et al., 1996). If the rest periods are adequate enough to promote full recovery, then the ATP-PC system will remain the primary supplier of energy. It is when inadequate recovery occurs that lactic acid begins to accumulate due to the inadequate replenishment of PCr stores, thus the natural transition from the ATP-PC energy system to the glycolytic energy system. Therefore, it is important to maintain the correct test duration, repetition loads and rest periods since maximal strength production occurs within 1-15-s as deemed by the ATP-PC system.

Recall that if the objective in isokinetic testing is to obtain the best possible results that can only transpire through maximal efforts, it is important to identify how the previous slower-velocity set may deter the strength response in the following higher velocity set. The main reason for this approach is that ascending order protocols reflect the prevalent methodologies in the literature (see Table 1). Thus, the findings of this investigation may have practical implications to current and future clinicians and physical therapists. In approaching this issue, how torque is developed at higher velocities must be understood. Research on the relationship between muscle-fiber composition and the torque-velocity curve has suggested that the rate of force development is a strong indicator of torque levels at higher velocities (Thorstensson, Grimby, & Karlsson, 1976; Thorstensson & Karlsson, 1976). The implication is that if the rate of force development is the main factor in peak torque development at faster velocities, then the influence of rest periods on rate of force development needs to be investigated.

Interestingly, emerging research has investigated the effects of fatigue on neural manifestations such as rate of force development, which constitutes maximal strength production (Ewing, 1982; Gandevia, 2001; Haff, Stone, O'Bryant, Harman, Dinan, & Johnson et al., 1997; Hakkinen, 1993; Kearney & Stull, 1981; Royce, 1962; Spendiff et al., 2002). It has been suggested that the earliest signs of neuromuscular fatigue tend to occur during intense exercise of at least 30-s or greater (Robergs & Roberts, 1997). However, neuromuscular fatigue has been suggested to occur during intense interval exercise if the rest periods are insufficient (Bompa, 1999b). The line of reasoning is that with short rest periods, an intermittent effect of fatigue (i.e. 3 sets of high-intensity exercise of 10-s) can accrue into having a cumulative effect similar to a continuous exercise bout (i.e. 1 set of high-intensity exercise of 30-s) (Hogan, Ingham & Kurdak, 1998).

In an isokinetic strength test, it is also important to understand how a participant's effort, as dictated by pretest instruction, can influence the rate of energy expenditure of the ATP-PC energy system and the correspondent fatigue patterns of the ATP-PC energy system as well. This chain of events occurs since the participants are required to perform fast and explosive contractions in order to reach the pre-set testing speed. Research has shown that specific neural patterns such as higher firing rates and stronger neural impulses occur in the performance of explosive type movements and exercises (Behm, 1995). In support, Linnamo, Hakkinen, & Komi (1998) compared the effects of maximal versus explosive strength loading and found that explosive strength loading resulted in a significantly greater ($p < 0.05$) decrease in rate of force development in the early contraction phase (0-100 ms). An important aspect of the methodology used was that in the explosive strength loading condition, participants lifted a load of 40% of 10-RM and were told to perform the contractions as explosively as possible (Linnamo et al., 1998). Similarly, these pretest instructions are required in isokinetic testing for optimization of the load range, which will ultimately lead to optimal performance (Sale, 1991; Wrigley &

Strauss, 2000). Furthermore, with the presence of visual feedback and verbal encouragement in many isokinetic testing protocols, fatigue tends to occur even more rapidly than without these social influences (Dvir, 2004). With factors such as test instructions (contracting as hard and as fast as possible), verbal encouragement, and visual feedback being prevalent in isokinetic strength tests (Sale, 1991; Wrigley & Strauss, 2000), the manifestation of fatigue occurs very rapidly whereby neural control becomes impeded as well. In one such study looking at the influence of fatigue across the isokinetic velocity-spectrum in discrete single knee extensions, Spendiff et al. (2002) detected greater reductions in peak and mean torque in all test velocities (30, 60, 120, & 180 deg/s) following fatiguing exercise at low test velocities (30 & 60 deg/s). Therefore, the interference of optimal force production following one slow-velocity set may have an affect on strength performance in subsequent high velocity sets, since rate of force development is a determining factor of peak torque at higher velocities (Thorstensson et al., 1976).

In retrospect to short rest periods (30-60-s) being recommended (Perrin, 1993) and used (see Table 1) in velocity-spectrum isokinetic strength tests, it should be acknowledged that PCr levels may plummet to suboptimal levels which may encourage earlier signs of fatigue in subsequent test speeds in these test protocols due to a lower starting level of PCr (Dawson, Goodman, Lawrence, Preen, Polglaze & Fitzsimmons et al., 1997). Consequently, PCr will gradually decline to lower starting levels after each set as a result of insufficient rest periods. Such an occurrence was the eventual outcome in the findings of Dawson et al. (1997) and Gaitanos, Williams, Boobis, & Brooks (1993). Gaitanos et al. (1993) detected that after a single 6-s maximal cycle sprint, there was a 57% decline (76.5 ± 7.2 to 32.9 ± 2.6 mmol kg^{-1}) in muscle PCr concentrations. Similarly, Dawson et al. (1997) found that after one maximal 6-s cycle sprint, PCr stores were at 55%, 69%, and 90 % of the pre-exercise value at 10-s, 30-s, and 3 minutes post-exercise, respectively. In addition, a comparison was made on the influence of one single maximal cycle sprint (1 x 6-s) vs. a repeated series of cycle sprints (5 x 6-s) on PCr depletion and repletion rates. From these findings, it was later suggested that full repletion of PCr takes longer in repeated cycle sprints due to a greater depletion of PCr stores, whereby repletion must occur from lower PCr levels (Dawson et al., 1997). In essence, while a 30-60-s rest interval may permit performance during one or two test velocities, it is not recommended for multiple set test protocols. Therefore, when testing for strength, it is recommended that the rest period coincide with the specific capacity (substrate maximum attainable power and substrate recovery time) of the energy system (ATP-PC) being utilized.

Recovery in Strength Testing

Now that fatigue pertaining to the ATP-PC system has been described, a better understanding of strength recovery can occur, which can aid in improving the prescription of rest periods in isokinetic strength testing. Typically, the work bouts in strength tests are readily acknowledged and identified while the recovery aspects are not given the same recognition (Matuszak, Fry, Weiss, Ireland, & McKnight, 2003; Parcell et al., 2002; Pinicivero et al., 1997b). Although frequently overlooked, recovery is just as important, if not more important than the actual work performed (Pauletto, 1986; Pincivero et al., 1997b). Recovery is defined as the replenishment process of the energy stores specific to the energy-system(s) being used (Foss & Keteyian, 1998).

Based on the inconsistency in the literature, many rest periods appear to have been arbitrarily set based on anecdotal test experience or personal observation in isokinetic strength-testing (see Table 1). With some studies implementing rest periods of 30-s or less for maximal strength-tests (see Table 1), it is difficult to understand why these researchers have not referred to the human PCr substrate recovery paradigm established by many investigators, which is based on maximal strength production and strength recovery (Harris et al., 1976; Hultman et al., 1967; McCann et al., 1995; Takahashi et al., 1995). The importance of this PCr substrate recovery paradigm is monumental, considering this is the specific energy substrate used in any properly administered isokinetic strength test (Pincivero et al., 1998). Thus, with the luxury of data on PCr substrate recovery as accomplished through basic research, a more precise and logical approach is available in the prescription of rest periods (Harris et al., 1976; Hultman et al., 1967).

The half-life of PCr replenishment has been estimated to be approximately 20-30-s and as long as 36-48-s (Fleck & Kraemer, 2004; Harris et al., 1976; Kraemer, 1983). Fleck & Kraemer (2004) reported that “Within 20 to 48-s 50% of the ATP and PCr are replenished; in 40 to 96-s 75% is replenished; and in 60 to 144-s 87 % is replenished. Thus, the majority of the depleted ATP and PCr intramuscular stores are replenished within 3-4 minutes” (pg. 79). In agreement, Hultman et al. (1967) found that 70% of the ATP-PC stores were replenished in 30-s while most of the ATP-PC stores were replenished in 3-5 minutes. In congruence, Foss & Keteyian (1998) have recommended that the general rest period for ATP-PC recovery be 2-5 minutes.

Similarly, PCr recovery was graphically illustrated to occur approximately 4-minutes after cessation of exercise by McCann et al. (1995). However, it was indicated that 100% PCr recovery did not occur until 15-minutes after exercise (McCann et al., 1995). Harris et al. (1976) found that in dynamic exercise, 2-4 minutes of recovery led to an 84 and 89% restoration of PCr stores, respectively. By 8-minutes, 97% of the PCr stores were replenished (Harris et al., 1976). While the process of exercise recovery can be separated into two preliminary phases, the fast component (alactacid) and the slow component (lactacid) (Kraemer, 1983), Harris et al. (1976) demonstrated that there is a fast component and slow component for PCr recovery too. It was found that the fast component of PCr recovery had a half-life of 21-23 seconds and a slower component with a half-life of greater than 3-minutes (Harris et al., 1976).

In many of these studies and reports, complete recovery was presumed to mean an 87% or slightly greater concentration of PCr. This level of PCr was suggested to be the highest attainable level that can occur in the midst of exercise (Landwer, J., personal communication, April 1, 2004). The basis for this presumption of permitting an 87% or slightly greater PCr concentration during strength testing appears to be related to the weighing of time versus the significance of an added ≥ 13% of PCr recovery. The situation presents itself as follows: If PCr concentration is depleted, the estimated time to 87% has been found to range from 60-s to 4-minutes (Harris et al., 1976; Hultman et al., 1967; McCann et al., 1995), while the estimated time to 97 and 100% has been found to be 8-minutes (Harris et al., 1976) and 15-minutes (McCann et al., 1995), respectively. This difference is explained by the rate of PCr recovery exhibiting a fast component as suggested by Harris et al. (1976) with a slower component of PCr recovery following. Thus, the significance of waiting 4-14 additional minutes for a 13% repletion of PCr is irrational and unrealistic in a testing environment.

Not surprisingly, these 3-5 minute scientific findings of PCr recovery have coincided with the 3-5 minute general recommendations for strength and power recovery made by several lead investigators (Baechle, Earle & Wathen, 2000; Clark, 2001; Fleck & Kraemer, 1988; Fleck

& Kraemer, 2004; Kraemer, 2003; Kraemer & Fry, 1995; Pincivero, 2001; Weiss, 1991; Zatsiorsky, 1995). Even though these recovery rates have been established, the findings of PCr recovery were based on recovery from exhausting and extremely fatiguing exercise whereby PCr levels were severely depleted. Thus, one must consider the intensity and duration of the exercise bout prior to simply applying this 3-5 minute generalized recommendation (Brooks et al., 1996; McCann et al., 1995). To illustrate this, Hitchcock (1989) found that the intensity of prior cycle ergometer exercise altered the pattern in recovery of maximal short-term power output (STPO) in isokinetic knee extensions at 60 deg/s. Immediately after exercise, STPO fell to 85, 75, 55, and 47% of preexercise values for prior exercise equivalent to 60, 80, 100, and 120% of maximal O2 uptake, respectively (Hitchcock, 1989). STPO had fully recovered by 1 minute of postexercise after submaximal work rates (60 and 80%) whereas recovery was delayed until after 4 minutes of postexercise after maximal exercise (100%) (Hitchcock, 1989). Therefore, in order to truly understand the importance of strength recovery and how to administer rest periods, the preceding intensity and duration of the exercise bout need to be better determined and understood.

Proposed Method of Identifying Strength Recovery

Upon review of the literature, the prominent method of allotting and identifying rest periods appears to have been accomplished by utilizing already established rest periods from previous studies or by arbitrarily assigning rest periods based on empirical observation in isokinetic strength-testing (see Table 1). While these methods of identifying optimal rest periods are prominent in the literature, they are not preferable in terms of validity, reliability, and time efficiency (Pincivero et al., 1997a; Pincivero et al., 1998). Consequently, there have been conflicting findings regarding the optimal rest period in isokinetic strength testing. The ideal approach would be to use methods that control for most confounding and extraneous variables in subjects, and as a result, provide a greater consistency in research findings. If exercise science aims at truth, then it must aim at consistency (Lakatos, 1970). Such an approach of promoting consistency has been available through the methods of interval training (Fleck, 1983). While different from resistance training, the same basic principles used in interval training may be viable alternatives in standardizing rest periods in isokinetic strength testing (Pincivero, 2001). In interval training, the work:rest ratio method has been a prominent mode of identifying the optimal rest interval. This proposed method is based on the positive relationship that standardization of testing has on reliability of test results (Sale, 1991).

Work:Rest ratio method.

A common method of identifying optimal recovery is the work:rest ratio, which is based on the relationship between the work interval and the rest interval (Fleck, 1983; Foss & Keteyian, 1998). For example, a 1:3 work:rest ratio means that if the work bout is 10-s, the rest interval would be 30-s. Despite the work:rest ratio being an established method in interval training, there have been conflicting findings in regard to recommendations of work:rest ratios (Conley, 2000; Fleck, 1983; Fox & Matthews, 1974; Karp, 2000; Lamb, 1978; McArdle et al., 2001). Most research has shown a 1:3 ratio to be ideal for high-intensity exercise (Fleck, 1983; Foss & Keteyian, 1998; Fox & Matthews, 1974; McArdle et al., 2001). Conversely, Karp (2000) recommended a work:rest ratio of 1:3-1:6 for a 10-s bout of exercise. Similarly, Clark (2001) recommended a work:rest ratio of 1:5-1:12 when training for strength/power, which is characterized as 85-100% intensity (1-5 repetitions). In isokinetic performance research, only a few investigators have used the work:rest ratio as an indicator of muscle recovery (Pincivero & Campy, 2004; Pincivero et al., 1999; Pincivero et al., 1997b; Pincivero et al., 1998; Touey et al., 1994). Touey et al. (1994) found that 120-s optimized a work:rest ratio of 1:4 at 60 deg/s and a 1:12 work:rest ratio at 180 deg/s, although performance was maximized at 240-s. Pincivero et al. (1999, 1997b, 1998) have typically found a 1:8 work:rest ratio to be sufficient in allowing maintenance of strength performance. In a commentary that may elucidate some of the discordance, Pincivero (2001) indicated that, "Studies have shown work:rest ratios of 1:1, 1:3, 1:5, and sometimes even 1:8 were not enough to allow full muscle recovery " (pg. 1). Pincivero (2001) later suggested that using the work:rest ratio alone was not enough to dictate muscle recovery. Thus, it was recommended that an absolute minimum rest interval length of 3-5 minutes be employed when performing multiple bouts of resistance exercise (Pincivero, 2001). However, these comments by Pincivero (2001) regarding work:rest ratios were targeted towards resistance exercise of multiple bouts, which would imply longer durations that would emphasize the glycolytic energy system to a greater extent than in standard strength testing. In light of this distinction, Conley (2000) proposed that work:rest ratios of 1:12-1:20 be applied when performing high-intensity exercise lasting 5-10 seconds. In support, Bompa (1999a) has suggested a work:rest ratio of 1:4 to as high as 1:25 for high-intensity exercise lasting 4-15 seconds. The basis for the application of the 1:12-1:20 work:rest intervals was founded on the maximum attainable power for the ATP-PC system (15-s) and its corresponding substrate recovery times (3-5 minutes) (Conley, 2000).

Before implementing work:rest ratios into isokinetic strength testing, there are several factors that need to be addressed. The basis for the work:rest ratio in interval training was originally founded on relative strength rather than maximal strength. For example, in sprint interval training, the large leg muscles provide the forces necessary to maintain a level of strength relative to the individual's body weight. On the contrary, a heavy resistance training exercise (> 90% 1-RM) like the squat involves the same large leg muscles, however, these same muscles must provide maximal forces to sustain the level of strength required to perform the heavy squat movement. The difference is that the intensity of contraction is greater during a high intensity resistance exercise (> 90% 1-RM) such as the squat, because of the recruitment of a greater number of motor units and muscle fibers. This increase in muscle fiber recruitment is based on the size principle, which describes an orderly recruitment of muscle fibers from type I-to-type II fibers as determined by increasing intensity (Palmieri, 1983). With different metabolic costs such as these, the rest interval would need to be adjusted in order to accommodate these inherent differences in metabolic cost. In fact, this accommodation appears to have been apparent in the proposed work:rest ratios of Conley (2000). The basis for having higher work:rest ratios in resistance training is founded on the established differences in excess post-exercise oxygen consumption (EPOC) between resistance training (e.g isokinetic strength testing) and aerobic training (e.g. sprint interval training) (Burleson, O'Bryant, Stone, Collins, & Triplett-McBride, 1998). In a comparison between resistance training and aerobic training matched for VO2 rate and exercise duration, it was found that EPOC 30-minutes after exercise was significantly greater ($p < 0.05$) in resistance exercise (19.0 L) compared to aerobic exercise (12.7 L). Thus, this finding justifies the rationale of heavy resistance exercise having a higher metabolic cost due to the greater intensity of contraction, despite having identical contraction times. Except, with such a large variance in the ratio for high intensity exercise (1:3-1:25), to apply the work:rest ratio method would be no different than arbitrarily allotting rest periods. However, the standardization, consistency, and advantages of this method must be acknowledged before arriving to early conclusions. Although the application of this method seems to be no different than arbitrarily assigning rest intervals, the usage of this method warrants further study due to the fact that it presents unique traits that restrictive arbitrary rest intervals do not offer.

In the protocol used by Parcell et al. (2002), it was estimated that the contraction time and work for each test set lasted 2-6-s. The approximation of this contraction time was derived from taking the distance the working limb traveled (90 degrees) and dividing it by the test velocity, then multiplying this value by the total number of repetitions {[(ROM traveled/test velocity) x 1 for discrete single contraction OR x 2 for reciprocal contraction] x reps}. However, upon review, the actual estimation of contraction time per set was 1 ½-6-s. An important aspect of this calculation is that the 300 deg/s set was excluded, because after the 300 deg/s set, no subsequent sets commenced. In applying the 60-s rest interval found to be adequate in their protocol (Parcell et al., 2002), a work:rest ratio was devised for each test velocity based on this 60-s rest interval. It was found that the work:rest ratios were 1:10, 1:20, 1:30, and 1:40 for test velocities of 60, 120, 180, and 240 deg/s, respectively. This ratio would appear to be reversed, considering as test velocity increases, total contraction time along with peak torque production decrease. To support this rationale, Parcell et al. (2002) found a significant decrease in peak torque at 120 deg/s for the 15-s rest period but not the180- and 300- s rest periods. A possible reason for this difference is based on the level of PCr decline that likely followed the 60 deg/s slow-velocity set. A rest period of 15-s was just not enough to allow adequate strength recovery. However, the fulfillment of adequate strength recovery in the 60-s rest period may have been masked by the decreasing intensity of later sets, which may have allowed PCr repletion to catch up to depletion levels and subsequently allow satisfactory strength performance. If this presumption is true, then the 60-s of rest was less than needed for a 60 deg/s set and more than needed for the 180 and 240 deg/s sets, which would indicate ineffective test time management. Instead of this restrictive rest period allotment, the work:rest ratio accommodates for the workload by adjusting rest periods specific to the intensity of the set, which is founded on contraction time (see Table 2). However, since the intensity of contraction is such an elusive factor to measure or control for, higher work:rest ratios as proposed by Conley (2000) would need to be implemented to conform to this elusive factor that does influence PCr depletion rate.

Table 2

Accommodating Rest Periods

Proposed Work:Rest Ratios and Corresponding Rest Periods for Parcell et al. (2002) Strength-Testing Protocol			
Test Velocity	**1:3**	**1:8**	**1:12**
60 deg/s	18-s	48-s	72-s
120 deg/s	9-s	24-s	36-s
180 deg/s	6-s	16-s	24-s
240 deg/s	4.5-s	12-s	18-s

Note. Theoretically, the ideal work:rest ratio for the protocol by Parcell et al. (2002) would be a 1:12 ratio, although a 1:8 ratio may be prove to be adequate as well. Work:rest ratios were derived from usage of the following formula {[(*ROM traveled/test velocity) x 1 for discrete single contraction OR x 2 for reciprocal contraction] x reps}.

* ROM traveled is presumed to be 90 degrees in this protocol.

With the implementation of an optimal work:rest ratio, several benefits can be reaped. 1) They will accommodate to large testing groups and universally apply to most clinicians and researchers utilizing an isokinetic knee strength testing protocol. 2) It will eliminate the arbitrary assigning of rest intervals and provide a sound method that will apply to patients and athletes. 3) This method can also apply to strength testing protocols utilizing only one velocity (e.g. 60 deg/s or 180 deg/s). However, since most strength test protocols are of ascending order, this method may provide highly practical applications that will maximize test time effectively while ensuring optimal recovery, specific to each workload per set. For example, in a protocol with test velocities of 60, 120, 180, 240, & 300 deg/s, a 3-minute rest interval would make this strength test quite long. Moreover, it would seem logical to presume 3-minutes to be excessive after a test set of 240 deg/s that consisted of only 4 repetitions at a standard ROM of 90 degrees for the knee. Total contraction time in this set would be ~1.5-s at 4 reps in discrete single contractions, but still only 3-s at 4 repetitions in reciprocal contractions. For a 3-minute rest period, this workload would equate to a work:rest ratio of 1:60 and 1:120 for a discrete and reciprocal contraction mode, respectively. Instead, let's presume having a standard work:rest ratio of 1:20. Now, the rest interval for 240 deg/s would be ~ 30-s for a discrete test mode and 60-s for a reciprocal test mode. Although these rest periods are short, research has shown these rest intervals to be sufficient at this particular test velocity (240 deg/s) and other fast velocities (Parcell et al., 2002;

Perrin, 1993; Wrigley & Strauss, 2000). The idea of this example is, with the work:rest ratio, there is more clarity and standardization in testing. 4) Lastly, even if the work:rest ratio approach failed to clarify the research issue of interset rest periods, one could resort to the well established and generally recommended 3-5 minute rest interval as a safe-haven (Baechle et al., 2000; Clark, 2001; Fleck & Kraemer, 1988; Fleck & Kraemer, 2004; Kraemer, 2003; Kraemer & Fry, 1995; Pincivero, 2001; Weiss, 1991; Zatsiorsky, 1995). Thus, the work:rest ratio is a very promising method in searching for the optimal interset rest period and improving test time management in isokinetic strength testing.

When analyzing the data, the total test time in the isokinetic strength testing protocol of Parcell et al. (2002) was 252.5-s when taking into account the 60-s rest period for every test velocity set. However, with the implementation of a 1:8 and 1:12 work:rest ratio, the total test time was found to be shorter at 112.5-s and 162.5-s, respectively (see Table 3). While Parcell et al. (2002) found a 60-s rest period to be adequate, their protocol consisted of discrete single concentric knee extensions with a passive knee flexion against virtually no resistance. Thus, their finding is applicable in reference to discrete single concentric knee extension protocols, however, their finding may not be applicable to the prevalent and more common reciprocal concentric knee extension and flexion protocol used by most clinicians and researchers (Wrigley & Strauss, 2000). Therefore, it was the purpose of this investigation to use a common isokinetic testing protocol (Dvir, 2004) with a common methodological design such that the findings of this study can have practical application to current and future clinicians and researchers in the administration of isokinetic knee strength-testing and assessment.

Table 3

Restrictive Rest Period Vs. Accommodating Rest Periods

A Comparison of Total Test Time Between the Assigned 60-s Rest Period from the Parcell et al. (2002) Strength-Testing Protocol and a 1:8 and 1:12 Work:Rest Ratio			
Strength Recovery Method	**Total Contraction Time**	**Total Rest Time**	**Total Test Time**
60-s rest period	12.5-s	240-s	252.5-s
1:8 work:rest ratio	12.5-s	*100-s	112.5-s
1:12 work:rest ratio	12.5-s	*150-s	162.5-s

Note. * Total rest time was summated from the rest intervals per test velocity as tabulated from Table 2.

Summary

Whether testing isokinetic muscular strength in research, athletic, or rehabilitative settings, it is important to standardize the interset rest periods. When the objective is to ensure reliable results that can be attributed mainly to the effects of the training intervention's success, as opposed to other confounding factors such as fatigue or inconsistent rest periods, proper implementation of optimal rest periods becomes essential. In an attempt to aid in the standardization of an optimal rest period, the work:rest ratio method was suggested as being a viable strategy in the establishment of optimal muscle recovery. The application of the work:rest ratio is very promising in that it provides a scientific approach that will allow standardization among various patients and strength testing protocols. With the work:rest ratio method providing an applicable predication formula for researchers and clinicians {[(ROM traveled/test velocity) x 1 for discrete single contraction OR x 2 for reciprocal contraction] x reps},the implementation of this method is heavily warranted. However, since there has been little research on the impact of rest intervals on strength recovery, many researchers have defaulted to arbitrarily assigning rest intervals as opposed to having the type of standardized rest period allotment that can be offered by the work:rest ratio method.

It is important to recognize that while recommendations for short restrictive rest periods (60-s or less) may apply to some populations, it is critically important that a larger window of variability be permitted to accommodate for a wider variety of populations, training status, and workload changes in ascending order velocity spectrum testing. It has been shown that short rest periods induce physical (Pincivero et al., 1999) and mental fatigue (Tharion et al., 1991). Thus, it is important to eliminate physical and mental fatigue as a potential confounding variable by providing an optimal amount of rest between sets. Conceivably, the main purpose of searching for the minimal rest period in isokinetic testing is to manage time more effectively. Although this may be important for mass testing, this approach is not advised when measurement precision is an included objective. Therefore, an optimal work:rest ratio with resultant optimal rest periods (see Table 4) should be implemented to promote effective test time management (see Table 3) and to provide subjects with the best opportunity to attain optimal strength performance, which will lead to effective exercise program design, assuring improvements are induced only by the success of the program.

Table 4

Work:Rest Ratios for Current Strength-Testing Protocol

Proposed Work:Rest Ratios and Corresponding Rest Periods for Current Strength-Testing Protocol				
Test Velocity	**Contraction Time**	**1:3**	**1:8**	**1:12**
60 deg/s	15-s	45-s	120-s	180-s
180 deg/s	5-s	15-s	40-s	60-s

Note. Work:rest ratios were derived from usage of the following formula {[(*ROM traveled/test velocity) x 1 for discrete single contraction OR x 2 for reciprocal contraction] x reps}.

* ROM traveled is standardized at 90 degrees in this protocol.

Chapter 3

Methodology

Study Design

This study was a 3 x 3 repeated measures ANOVA design with the factors of velocity and work:rest ratio as the independent variables. The dependent variable was peak torque. The requirements for participation involved meeting for a total of 5 sessions (2 familiarization & 3 experimental), in which each session was separated by at least 48 hours. Each session lasted approximately 10-30 minutes in duration. The reason for this time fluctuation was because in the first two sessions, extra time was needed to complete the required preliminary paperwork (preparticipation forms) and for the participants to become accustomed to isokinetic resistance. Participants performed 3 sets of 5 repetitions of maximal isokinetic knee extensions and flexions. The progression of resistance followed an ascending order in which the resistance decreased while speed concurrently increased (60, 180, & 300 deg/s). The reason for usage of only three speeds was based on the intent of retaining the power of statistical significance. Additionally, this testing protocol has been used often and by many researchers (Adams, 2002; Bardis et al., 2004; Stumbo, Merriam, Nies, Smith, Spurgeon, & Weir, 2001; Weir, Evans, & Housh, 1996). More importantly, these three speeds are optimal intermediates across the velocity-spectrum (Kovaleski & Heitman, 2000). These three speeds encompass strength and power just as effectively as other intermediates (90, 120, 240 deg/s) (Kovaleski & Heitman, 2000). A different work:rest ratio was used in each experimental test session. Peak torque was used to quantify strength performance and recovery throughout testing.

Participants

Twenty-seven healthy college-aged (18-35 years) male students (age 23 ± 3.7 years, and body weight 175 ± 24.4 lb.) from the University of New Orleans (UNO) were selected for voluntary participation. This was a sample of college-aged male students who were not sedentary and met the minimal requirements of physical activity of 30-minutes per day, 3 days per week (Franklin, Whaley, & Howley, 2000). Recruitment was accomplished in the following ways: 1) Mass population email; 2) Flyers posted on-campus (see Appendix E); and 3) Referral from participants who completed testing. Incentives for participation included a free exercise program. The setting for familiarization and experimental test sessions was initially held in the UNO biomechanics laboratory (5 males), but then relocated to the Metairie Orthopedic and Sport Therapy Clinic (22 males) due to the UNO Cybex NORM becoming permanently damaged from power outages caused by the after effects of Hurricane Katrina. Subjects were excluded under the following conditions: Current orthopaedic knee-related pathologies, past history of knee injury/surgery or previous problems with knee extensions and flexions, cardiovascular or neurological disorders, and ergogenic dietary supplementation intake. In addition, subjects were pre-screened with a physical activity readiness questionnaire (PAR-Q) (see Appendix A) (Dwyer & Davis, 2005), health history questionnaire (see Appendix B) (Dwyer & Davis, 2005), and an informed consent (see Appendix C) prior to voluntary participation. Subjects were provided with pre-test guidelines (see Appendix D) (Dwyer & Davis, 2005), that included encouraging them to abstain from smoking, exercise, and alcohol consumption 24-hours prior to testing. Subjects were also required to wear exercise-conducive clothing that would allow freedom of movement in the legs and adequate thermoregulation. Approval for human subject testing was obtained from the University Institutional Review Board and ethics committee (see appendix F).

Instrument

The Cybex NORM (Cybex International, Inc. Ronkonoma, NY) was used to measure the muscles involved in concentric knee extension and flexion. Prior to any testing, the Cybex NORM was calibrated once per month according to the manufacturer's recommendations (Cybex NORM testing and rehabilitation user's guide, 1996). Gravity correction was used in all testing sessions. Intraclass reliability has been reported to be high in the usage of the Cybex NORM in various test protocols and populations (Cotte & Ferret, 2003; Karatas, Gogus, Meray, 2002; Kellis, Kellis, Gerodimos, & Manou 1999; Kellis, Kellis, Manou, & Gerodimos, 1998). Kellis et al. (1998) reported reliability to be 0.89-0.98 for concentric knee extension and 0.89-0.90 for concentric knee flexion. Kellis et al. (1999) later reported reliability to be 0.92-0.99

in isokinetic knee extension and flexion. In this study, 2 subjects were pilot tested on three occasions (one familiarization session and two pilot test sessions) at each testing site to assess instrument reliability prior to the start of this investigation. Reliability of the Cybex NORM in the UNO biomechanics laboratory was 0.990 (P = 0.001) for concentric knee extension and 0.975 (P = 0.001) for concentric flexion, while reliability of the Cybex NORM in the Metairie Orthopedic and Sport Therapy Clinic was 0.997 (P = 0.001) for concentric knee extension and 0.966 (P = 0.002) for concentric knee flexion.

Procedures

The subject's weight was measured at the first session. Limb dominance was determined by asking the subject which leg he preferred to use to kick a ball (Keating & Matyas, 1996). Subjects met a maximum of five times, starting with two familiarization sessions followed by three experimental testing sessions. Since the Metairie Orthopedic and Sport Therapy Clinic only permitted usage of the isokinetic apparatus during lunch break, the arrangement of a similar testing time for each participant (e.g. 11 a.m. - 1 p.m.) was incorporated.

Subjects were fitted into the Cybex NORM with the lateral femoral condyle of the dominant knee (axis of rotation) aligned with the axis of rotation of the dynamometer by first locating three anatomical landmarks, then using a visual assessment and subjective feedback from the participant thereby ensuring no slippage occurring, which is an indirect indicator of axis misalignment. Since the lateral femoral condyle is best palpated when the knee is flexed (Brunnstrom, 1966), identification of the axis of rotation was accomplished while the subject was seated in the dynamometer chair. The prominent fibular head was palpated first, followed by the epicondyle of the femur, and then the protuberance of the lateral tibial condyle was palpated with all three fingers forming an equilateral triangle (Brunnstrom, 1966). Axis of rotation alignment was then verified by checking for slippage in the complete ROM while the knee flexed and extended (Cybex NORM system testing and rehabilitation user's guide, 1996; Keating & Matayas, 1996). Extensive standardization of the knee axis of rotation is warranted due to the significant increase in measurement error that occurs if the two axes are incongruent (Rothstein et al., 1987).

Lever arm length was standardized as being the most distal usable leg length (Keating & Matyas, 1996). This position corresponded to the dorsal surface of the ankle just above the medial malleolus, whereby the subject was still able to dorsiflex the ankle without any significant restriction. For proper body positioning and alignment, various dimensions of body positioning included the following: seat height, seat inclination angle, dynamometer height, dynamometer lever arm length, and seat back rest. Subjects were then stabilized with seatbelt-type straps used to secure the waist and trunk, while Velcro straps served to secure the lower leg to the dynamometer and the thigh of the leg being tested to the seat to prevent any extraneous body movements that may have affected measurement (Weir et al., 1996). In addition, a contralateral leg pad was used to secure the contralateral leg to the dynamometer seat to prevent any extraneous movement as well. To maintain proper pelvic position, subjects were required to stabilize their body into the seat by grasping the seat handles. The recordings of body position were saved into the Cybex NORM computer software program for standardization for each subject. Any modifications of body position and stabilization were reconciled within the familiarization sessions.

Once body positioning and stabilization were established, subject set-up commenced. Height and body weight were entered into the subject profile on the Cybex NORM computer software program. Then, the position of anatomical zero was identified as 0-degrees at full knee extension. Thereafter, ROM was standardized at 90-degrees with software and mechanical stops set in place for every subject to ensure approximately the same contraction time. ROM was standardized at 90 degrees because this controlled for workload in addition to this ROM being commonly implemented by other researchers (Bilcheck et al., 1993; Pincivero et al., 1997; Pincivero et al., 1998; Pincivero et al., 1999; Pincivero & Campy, 2004). Next, gravity correction took place with the subject extending the leg to 45-degrees, whereby the weight of the limb at this position was used to estimate the effects of gravity throughout the entire ROM. Subjects were instructed to remain relaxed and not to move during this procedure. The importance of subject compliance was very important, as Kellis (2002) illustrated in his findings that excessive movements during gravity correction on the Cybex NORM can have a significant effect on test reliability. Lastly, the rest periods were entered into the Cybex NORM computer software program by creating three protocols labeled, 1:3, 1:8 and 1:12. The respective rest periods were entered for each work:rest ratio, while a seconds clock was visually seen on the computer screen between sets showing the length of the rest period.

Warm-up protocol.

Two familiarization sessions were conducted in an effort to minimize the test learning effect among inexperienced subjects thereby enhancing reliability of measurement. Research has shown that 1 day of familiarization is sufficient (Johnson & Siegal, 1978), but 2 days of familiarization were found to enhance reliability of isokinetic measurement more effectively than 1 day (Kues et al., 1992).

In this investigation, subjects underwent two familiarization sessions prior to any experimental testing. In each familiarization session, subjects were initially oriented to a general warm-up on a Monark 818E model cycle ergometer (Monark exercise AB, Varberg, Sweden) at the UNO biomechanics laboratory, but later, were oriented to a warm-up on a Cybex Metabolic 100 cycle (CYBEX, A Division of Lumex, Inc. Ronkonkoma, New York) at the Metairie Orthopedic and Sport Therapy Clinic in which they pedaled at a comfortable pace at a sufficient wattage (60-100 watts) for 5-minutes. A comfortable pace was used because research has shown a pedal rate slightly higher than most economical (50-60 RPM) to be preferred irrespective of cycling experience (Foss & Hallen, 2004; Marsh & Martin, 1993; Marsh & Martin, 1997). Seat height was adjusted for each subject in order to have a 5-degree knee bend during pedaling (Franklin et al., 2000). Once a comfortable seat height was determined, it was recorded. Subjects were instructed to abstain from stretching prior to any exercise. Although stretching has been a common pretest practice, many studies have indicated that stretching may be detrimental to strength and power performance (Kokkonen, & Nelson, 1996; Nelson, Guillory, Cornwell, & Kokkonen, 2001; Schilling & Stone, 2000; Young & Behm, 2002). However, stretching of the quadriceps and hamstrings was encouraged and recommended after every testing session to ensure safety, proper post-exercise recovery, and maintenance of flexibility.

Immediately following the general warm-up on the cycle ergometer, a specific warm-up followed, in which subjects performed 1 set of 3 (2 submaximal & 1 maximal) concentric reciprocal knee extension/flexion repetitions at each velocity of 60, 180, and 300 deg/s in ascending order. However, more repetitions were permitted only during the warm-up repetitions in the familiarization sessions to help subjects completely understand the required execution of maximal efforts during testing (Brown & Weir, 2001). During the warm-up repetitions, the level of subjective effort was progressed from 50% (half-effort) during the first repetition to 75%

(three-quarter effort) during the second and finishing at 100% (maximal effort) for the third and final repetition. Subjects were also provided with visual feedback to facilitate a better understanding of isokinetic resistance (Perrin, 1993). To ensure a staircase order of submaximal repetitions (50-100% subjective effort), subjects were given instantaneous visual feedback from the overlap tracing on the computer screen of the 3 warm-up repetitions. Additionally, subjects were instructed to establish a comfortable breathing pattern for safety precautions in avoiding the performing of a valsalva maneuver (Fleck & Kraemer, 2004).

Each test velocity was separated by a work:rest ratio of 1:3. Although this 1:3 work:rest ratio allocation is likely to prevent full muscle PCr recovery in some subjects, it was not the intent of a warm-up to maximally emphasize strength, but instead, to promote adequate blood flow to the knee musculature reducing the possibility of muscle strain and to effectively prepare the working muscles for optimal test performance (Osternig, 1986). Furthermore, since the first 2 repetitions are submaximal, this work:rest ratio was ideal.

With respect to the number of repetitions and intensity progression from submaximal to maximal, this warm-up sequence has been found to be adequate in producing stability of measurement (Mawdsley & Knapik, 1982; Osternig, 1986). An ascending order and a concentric reciprocal knee extension and flexion test protocol was used to accurately reflect the prevalent methodologies in the literature and to enhance external validity, whereby the results can be of greater benefit to practicing clinicians (see Table 1). In addition, reliability has been shown to be higher when following this order from slower-to-faster velocities (Wilhite, Cohen, & Wilhite, 1992).

Familiarization protocol.

After warm-up procedures, subjects rested 3-minutes before performing 1 set of 5 repetitions at each of the velocities of 60, 180, and 300 deg/s in ascending order at maximal effort. This 3-minute rest period used after the warm-up and before experimental testing has been found to be adequate in the complete replenishment of PCr stores and resultant strength (Foss & Keteyian, 1998) and very time effective in the confines of a busy physical therapy clinic. The rationale to performing 5 repetitions is based on the observation that it takes more repetitions to attain peak torque at faster velocities (Baltzopoulos & Brodie, 1989). Thus, 5 repetitions would be ideal across the velocity-spectrum because it encompasses an adequate number of repetitions for peak torque to be attained at slow velocities, while providing an acceptable number of repetitions for peak torque to be reached at fast velocities (Sale, 1991). Visual and verbal feedback were provided to subjects to promote maximum performance during testing (Campenella, Mattacola, & Kimura, 2000; Hald & Bottjen, 1987; Perrin, 1993). Additionally, each test velocity was separated by a 1:12 work:rest ratio. This work:rest ratio was selected for its effective management of test time, but more importantly, it was founded on the substrate recovery times of PCr and ATP as dictated by the intensity of the exercise bout (Bompa, 1999b; Conley, 2000; Harris et al., 1976; Hultman et al., 1967).

Experimental protocol.

The pre-test warm-up procedures were the same as during the familiarization sessions. The experimental test protocol included 1 set of 5 repetitions at 60, 180, and 300 deg/s. The work:rest ratios administered were 1:3, 1:8, and 1:12 in a counterbalanced fashion, with a different work:rest ratio being assigned for each of the three test sessions. In order to prevent ambiguity between treatment effects of the work:rest ratios and test learning effects related to peak torque variance, work:rest ratios were randomly assigned to each subject. This randomization of the work:rest ratio tested per session eliminated the confounding variable of test order effects that may have masked a treatment effect of the rest periods within the work:rest ratios. These work:rest ratios were selected based on their prevalence in the literature (Bompa, 1999b; Clark, 2001; Conley, 2000; Fox & Matthews, 1974; Pincivero et al., 1999) as well as their capability in managing test time efficiently, but also for their capacity to permit optimal strength recovery specific to each subsequent workload.

Statistical Analysis

This study was a 3 x 3 repeated measures ANOVA design with the factors of velocity and work:rest ratio as the independent variables. The dependent variable was peak torque and all tests used a significance level of $p \leq 0.05$.

Chapter 4

Results

The peak torque of all subjects was tested at velocities in the order of 60, 180 and 300 deg/sec. Rest periods within each work:rest ratio (See Table 4) were randomized for each subject.

To test the research hypothesis a repeated measures ANOVA ($p < 0.05$) was computed. Analysis of the data revealed a significant difference in knee extensor peak torque between velocities ($F = 498.239$, $P < 0.001$) (See Figure 1). Secondly, there was no significant interaction between rest and velocity ($F = 0.896$, $P = 0.468$) and there were no significant differences in knee extensor peak torque between each work:rest ratio ($F = 0.031$, $P = 0.969$) (See Table 5 & Figure 2). Therefore, the research hypothesis that there would be a difference in knee extension peak torque between work:rest ratios is rejected.

Analysis of the data also revealed a significant difference in knee flexor peak torque between velocities ($F = 1049.166$, $P < 0.001$) (See Figure 1). However, there was no significant interaction between velocity and rest ($F = 1.867$, $P = 0.119$) and there were no significant differences in knee flexor peak torque between each work:rest ratio ($F = 0.041$, $P = 0.960$) (See Table 6 & Figure 3). Therefore, the research hypothesis that there would be a difference in knee flexion peak torque between work:rest ratios is rejected.

In summary, rest periods did not have a significant effect on strength output. However, there was a trend of lower mean knee extensor and flexor peak torques for the 1:3, 1:8 and 1:12 work:rest ratios at 300 deg/s, respectively (See Table 7). This trend was more noticeable graphically in knee extensor peak torque (See Figure 2).

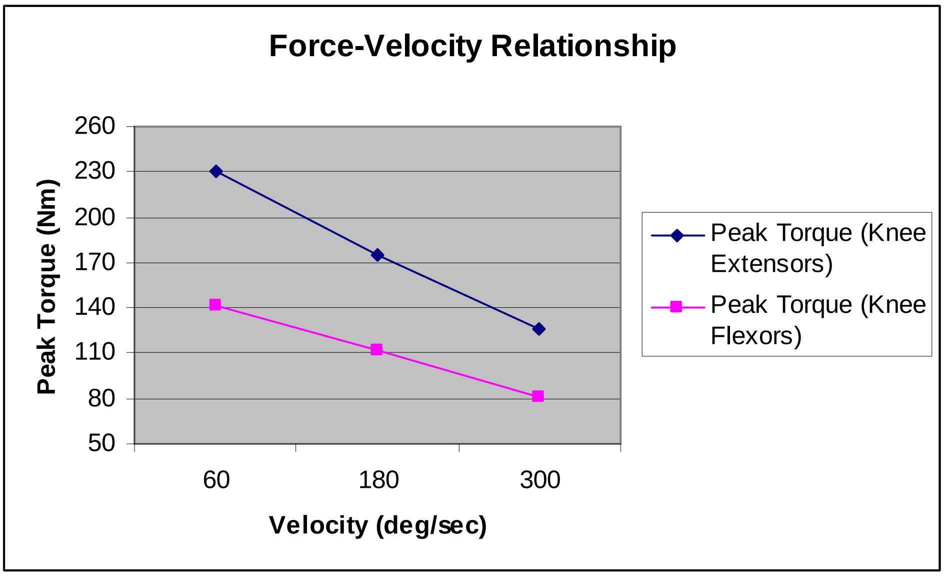

Figure 1. Torque-velocity curves from mean peak torque isokinetic knee extension and flexion contractions ($P < 0.001$).

Table 5

Means for Knee Extensor Peak Torque

Knee Extensor Peak Torque (Nm)			
Work:Rest Ratio	60 deg/sec	180 deg/sec	300 deg/sec
1:12	228.1 ± 39.3	174.9 ± 28.9	129.9 ± 23.1
1:8	229.2 ± 37.8	176.8 ± 30.1	127.3 ± 19.5
1:3	233.5 ± 41.6	172.2 ± 25.3	121.1 ± 21.0

Note. Data values are reported as means with standard deviations.

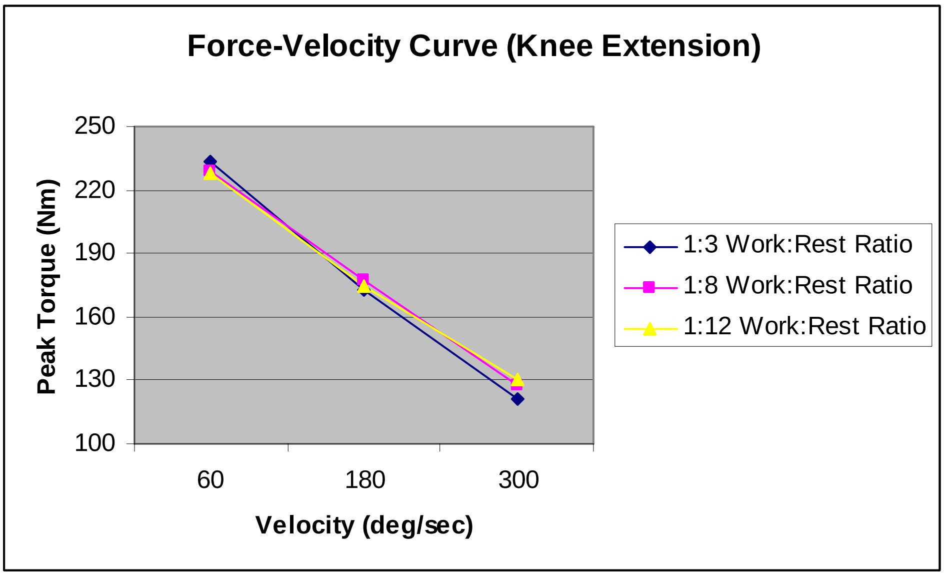

Figure 2. Torque-velocity curves from mean peak torque isokinetic knee extension contractions with three different work:rest ratios.

Table 6

Means for Knee Flexor Peak Torque

Knee Flexor Peak Torque (Nm)			
Work:Rest Ratio	60 deg/sec	180 deg/sec	300 deg/sec
1:12	139.8 ± 30.2	111.7 ± 24.3	82.9 ± 20.7
1:8	140.0 ± 30.2	111.1 ± 21.7	80.7 ± 19.2
1:3	144.9 ± 29.1	111.9 ± 22.0	79.5 ± 21.9

Note. Data values are reported as means with standard deviations

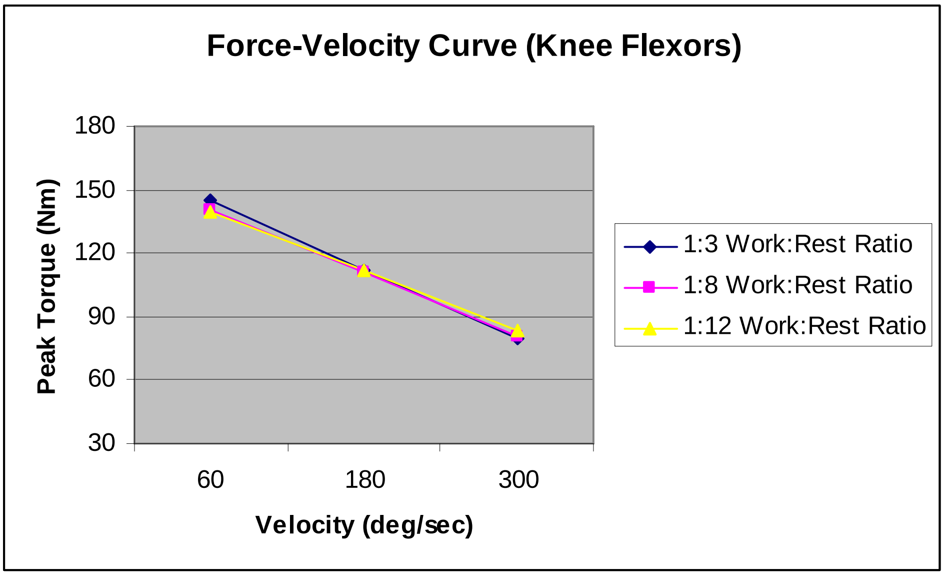

Figure 3. Torque-velocity curves from mean peak torque isokinetic knee flexion contractions with three different work:rest ratios.

Table 7

Descending Order Trend of Lower Mean Knee Extensor and Flexor Peak Torques at 300 deg/sec

300 deg/sec	**Knee Flexion Peak Torque (Nm)**	**Knee Extension Peak Torque (Nm)**
1:12	82.9 ± 20.7	129.9 ± 23.1
1:8	80.7 ± 19.2	127.3 ± 19.5
1:3	79.5 ± 21.9	121.1 ± 21.0

Note. Notice the nonsignificant trend of peak torque declining the shorter the rest period. Data values are reported as means with standard deviations.

Chapter 5

Discussion

The purpose of this study was to establish an optimal rest period that would allow consistent reproducibility of strength during a common isokinetic strength-testing protocol. With the software stops in place and the mechanical stops as a back-up in usage of the Cybex NORM, peak torque manifestation was optimal in achieving valid and reliable data [UNO biomechanics laboratory - 0.990 (P = 0.001) for concentric knee extension and 0.975 (P = 0.001) for concentric flexion; Metairie Orthopedic and Sport Therapy Clinic - 0.997 (P = 0.001) for concentric knee extension and 0.966 (P = 0.002) for concentric knee flexion]. In further support of reliability of the data, the peak torque values of the male population in this study were in close agreement with the peak torque values of the male population in the Parcell et al. (2002) study. Hence, the well-known force-velocity relationship was also observed in the present study (Foss & Keteyian, 1998; Hill, 1938) (See Figure 1). With no significant differences occurring among work:rest ratios and constituent rest periods (See Figures 2 & 3), it may appear that the findings are counterintuitive to the expected hypothesis of shorter rest periods leading to premature fatigue and subsequent differences in peak torque. However, upon further investigation, the findings are quite revealing.

Energy-System Specificity

Recall that the main energy system being utilized during strength testing is the ATP-PC system. Accordingly, with the appropriate energy system being identified, the correspondent energy system recovery time can be practically applied. This was indeed the case in the present study. Research has shown that the replenishment of the ATP-PC system is very rapid with 50-87% being restored in approximately 20-60-s (Fleck & Kraemer, 2004; Harris et al., 1976; Hultman et al., 1967; Kraemer, 1983). Foss & Keteyian (1998) suggested that 70% of the energy stores in the ATP-PC system can occur in as little as 30-s. The reason this physiological scenario is intriguing concerning the current findings, is that a likely explanation for fatigue not being a confounding factor can be found in the incredible resiliency of the human energy systems working cohesively. For example, it is well understood that energy system utilization works collaboratively rather than exclusively (Serresse et al., 1988). Thus, a specific energy system is emphasized while others contribute slightly or are trivial in contribution (Serresse et al., 1988). In the present study, it is plausible that although PCr stores may have been reduced, they were not depleted. Secondly, it has been shown that in spite of PCr depletion, ATP concentration does not decline below 60% of initial value (Conley, 2000). Hence, the incredible resiliency of the ATP-PC system to replenish energy stores in a very short period of time.

In Balsom et al's study (1992), overground sprinting was the test mode, however, the same physiological energy system was targeted. Their study design consisted of 15 x 40 m sprints on an indoor track with randomized rest periods of 30, 60 and 120-s. With the exception of overground sprinting being more metabolically costly than a single-leg isokinetic strength test (Fleck & Kraemer, 2004)**,** an important fatigue pattern was found in their study (Balsom et al., 1992). There were four relevant components that were reported in their results (Balsom et al., 1992). Out of 15 total sprints, acceleration times were significantly different after the 7th sprint in the 30-s group only, total 40 m times were significantly different after only the 5th sprint in the 30-s group, while total 40 m times were significantly different after the 11th sprint in the 60-s, whereas in the 120-s group, there were no significant differences throughout the entire 15 sprints (Balsom et al., 1992). Furthermore, in the mean running speed from 30-40 m, fatigue commenced in the 3rd sprint in the 30-s group, the 7th sprint in the 60-s group and in the 11th sprint in the 120-s group. Additionally, post-exercise lactate concentration in the 30-s group was significantly higher than the 120-s group, but there were no significant differences between the 120-s and 60-s groups (Balsom et al., 1992). The logical deduction drawn from these findings is in accordance with the present study rationale of PCr levels plummeting to suboptimal levels thereby encouraging earlier signs of fatigue in subsequent test sets (Dawson et al., 1997). This rationale is based on the concept of PCr gradually declining to a lower starting level after each set, whereby the duration of power output will only be dictated by the PCr levels. This rationale was impressively seen in the findings of Balsom et al. (1992). Again, workload was certainly a factor, and when workload is demanding enough to elicit fatigue, rest periods become of greater importance. Recall that it is only when inadequate recovery occurs that lactic acid begins to accumulate due to the inadequate replenishment of PCr stores, thus the natural transition from the ATP-PC energy system to the glycolytic energy system and ultimately a concomitant drop in peak torque due to a declined rate of energy expenditure and power output.

In many of Pincivero et al's (1997b, 1998, 1999, 2004) protocols, repetitions were on the higher end of the repetition continuum (10-20 reps). Hence, it could be logically presumed that perhaps longer rest periods would be required to preserve test reliability or maximal strength for these higher metabolically challenging protocols. This was the benefit of this study using three different work:rest ratios (1:3, 1:8, 1:12). Furthermore, no other study has used a work:rest ratio as high as 1:12, which was actually eluded to in Pincivero's (2001) editorial implicating that a 1:8 work:rest ratio may not have been adequate in optimizing strength recovery in strength tests.

In a further study, Spendiff et al. (2002) detected greater reductions in peak and mean torque in all test velocities (30, 60, 120, & 180 deg/s) following fatiguing exercise at low test velocities (30 & 60 deg/s). However, it should be disclosed that the isokinetic strength test was preceded by a fatigue task consisting of a range of reps from 15-26 (Spendiff et al., 2002). This lends support to the suggestion of workload being a primary determinant of fatigue. Additionally, it is ultimately when fatigue becomes more apparent that rest period duration will become more applicable for investigation and elucidation. Conversely, the goal of this study was to compare strength recovery responses spanning over three different work:rest ratios and ideally find an optimal work:rest ratio. Although there were no significant differences among work:rest ratios, there was a trend of lower mean knee extensor and flexor peak torques for the 1:3, 1:8 and 1:12 work:rest ratios at 300 deg/s, respectively (See Table 7). The implication is that although the values were not significantly different, fatigue was just beginning to commence at this point.

In fact, research has shown that after only 24-s of maximal exercise, fatigue begins to commence (Gaitanos et al., 1993). In their study, participants performed ten 6-s maximal cycle sprints of which each was separated by a 30-s rest period (Gaitanos et al., 1993). Mean power output was significantly lower than the peak value after the 4th cycle sprint. However, in the present study, the total time of maximal exercise was 23-s, and at that point, there was a nonsignificant decline in peak torque that arose in the last set (See Table 7). A study by Barnes (1981) investigated the specific effects of isokinetic resistance on fatigue. The protocol consisted of performing 10 reps at one velocity (60, 120, 150 or 300 deg/s) on different occasions (Barnes, 1981). It was found that after 5 reps, at least ~86% of peak value was still sustained, but only ~71% of peak value was sustained after 10 reps at each velocity (Barnes, 1981). In fact, Dvir

(2003) suggested that no real difference occurs unless there is a 20% difference in strength values. Based on this suggestion, only after 8-10 reps does fatigue appear to have a negative impact on peak torque (Barnes, 1981). Furthermore, their study mathematically described the isokinetic fatigue curve as producing a linear decline in peak torque (Barnes, 1981).
More importantly, this 86% peak torque value after only 5-reps also coincides with the 87% level of PCr stores commonly suggested as being optimal in strength restoration (Harris et al., 1976; Hultman et al., 1967; McCann et al., 1995). Thus, it is understandable that no significant difference in peak torque would occur in this study after only 5-reps since the level of PCr stores would still be adequate to produce maximal strength (Barnes, 1981). However, when a multitude of sets (60, 120, 180, 240 & 300 deg/s) are performed, such as in most isokinetic knee strength test protocols (Parcell et al., 2002; See Table 1), the interset rest periods will ultimately have an influence on PCr restoration and ultimately, peak torque.

The implications from the data suggest that fatigue is dependent not only on time-course of exercise (Barnes, 1981), but also whether the exercise is a multi- or single-joint movement (Fleck & Kraemer, 2004; Gaitanos et al., 1993). In essence, the two key variables that will ultimately determine fatigue and subsequent recovery duration are time-course of exercise and rate of energy expenditure. It is clear that multi-joint movements with correspondingly more active muscle groups being worked are more metabolically demanding than single-joint exercises (Fleck & Kraemer, 2004; Kraemer, W.J., Adams, K., Cafarelli, E., Dudley, G.A., Dooly, C., Feigenbaum, M.S., et al., 2002). Thus, for protocols with multi-joint protocols, sets and/or reps, significant differences may become more apparent. However, the purpose of this study was to use a protocol that eliminated fatigue as a variable to preserve test reliability in a common isokinetic strength test. Therefore, a 1:3 work:rest ratio is optimal in preserving test reliablility for a commonly used knee-strength testing protocol and very time efficient for a busy clinical setting, while the 1:8 and 1:12 work:rest ratios are available for higher workload protocols. More research needs to be conducted utilizing the following suggestive study designs:

1) Higher repetition and/or set protocols.
2) Different exercise modalities (multi- and/or single joint).
3) The same (1:3, 1:8, 1:12) or shorter work:rest ratios (1:1, 1:2).

The results of these suggestions would confirm or refute the present study findings and further elucidate the complexity of the human physiological system from an energy depletion and repletion standpoint.

Practical Applications

As suggested by Ariki et al. (1985), isokinetic testing with long rest periods lacks ecological validity since it would take up too much time in a busy clinical setting. In further support, it was apparent that the goal in the Parcell et al. (2002) study was to establish a minimum rest period that would permit reliable data in isokinetic strength testing. They were able to establish this rest period to be 60-s. However, as indicated earlier in this study, this restrictive rest period does not accomodate to the metabolic effect for each different workload for each set (Palmieri, 1983). Furthermore, this rest period actually had a longer total testing time when compared to the rest periods within the proposed work:rest ratios (See Table 3). Recall that in this study, the test protocol utilized was essentially the status quo not only in the predominant literature (Parcell et al., 2002), but also among practicing clinicians (Brown & Weir, 2001; Dvir 2004). Thus, the results of this study have the potential for significant bearing and impact on current testing practices.

The findings of this study are enlightening in that they have reached the goal of being practically applicable, time-efficient and reliable. They are practically applicable since a work:rest ratio of 1:3 can be used in a busy clinical setting with the confidence among clinicians that they will be accruing reliable data (See Figures 2 & 3). The impact of this reliable data on exercise program design and reliable reassessment, which tracks true and unbiased change in strength, is very encouraging. Furthermore, it should be noted that all work:rest ratios permitted reliable strength data (See Figures 2 & 3). Therefore, in consideration of differing test protocols and until more research in this area is conducted, a higher work:rest ratio can be implemented with the discretion of each practicing clinician, physical therapist and/or researcher. Additionally, the reliability of data would not be compromised since in the current study, all work:rest ratios were optimal in allowing adequate strength performance.

A New Approach to Standardizing Rest Periods

The work:rest ratio would be a great way to begin standardizing rest periods for isokinetic strength test protocols. Recall that with this method, there is a clear and established relationship between the workload and rest interval, which has not been the case up to this point in rest period establishment among many strength test protocols (Parcell et al., 2002). Although it was argued in this study that longer rest periods (1:12-1:20) would be needed due to the elusive nature of intensity of contraction, which would largely be influenced by participant motivation, the current findings strongly suggest a need to re-evaluate this position. On the contrary, shorter rest periods would be adequate in sustaining strength during a common isokinetic strength test (Parcell et al., 2002). Although the leg muscles in the current strength test protocol are being maximally loaded throughout the entire range of motion at a high intensity, the metabolic demands are not as high when considering this is a single-joint exercise with only two muscle groups being exercised (Fleck & Kraemer, 2004; Kraemer et al., 2002) and there is truly only one heavy set (60 deg/s) in this common isokinetic strength testing protocol (Brown & Weir, 2001; Parcell et al., 2002). Furthermore, when testing for strength, there is no need to retest repetitively. This is the difference between training and testing. When testing, the objective is to obtain a peak value and to obtain this value consistently in the early stages of rehabilitation or training progession. Thereafter, when a reassessment commences, a true change can be detected as a result of strength improvement and functional progression occurring from an exercise training intervention. Thus, when the objective is to ensure test reliability, the rest period can be minimal to not only promote adequate recovery, but also to maximize test time in a busy clinical setting. Only when the objective is to ensure maximal strength production (exercise training) for every repetition of each set does the rest period need to become more than minimal and perhaps optimized to specify a direct training effect on improving strength. With strength being such an ambiguous entity (Weiss, 1991), rest periods can be manipulated in a multitude of ways. For example, by shortening the rest periods, this would create a training stimulus by overloading the recovery systems thereby promoting improved recovery efficiency (Rooney, Herbert & Balnave, 1994). Another method would be to keep rest periods optimal to focus on quality of strength training, whereby different training adaptations would take place. However, with the goal of standardizing rest periods to ensure test reliability, these other effects of rest periods are irrelevant to the purpose of this study.

The goal of the Parcell et al. (2002) study was to eliminate the arbitrary nature of rest period allotment in isokinetic strength testing and to hopefully promote standardization in this important, yet overlooked aspect in strength testing. Their study sparked an interest for our research to replicate their protocol and purpose. Although we had two abstracts published on female participants (Warren & Blazquez 2004; Warren & Blazquez, 2005), the data was unreliable due to overshoot resulting from the software stops not being enabled. Recent data from Warren (2007) including the present findings offer further insight into the effects of rest period manipulation during a common isokinetic knee strength test protocol. The findings of Warren (2007) were based on an athletic female population and it was shown that the rest periods had no effect on torque reproduction. These results further support the present study findings of commonly used and physiologically-based rest periods not having an impact on torque reproduction. However, this should not support the continual arbitrary nature of assigning rest periods between sets in isokinetic testing. Being that most of the data entry on isokinetic machines is standardized (i.e. range of motion, repetition range, speeds, body alignment settings), rest periods deserve the same level of standardization procedures. This is the reason the work:rest ratio method should be considered a viable method in rest period standardization. The work:rest ratio is a relationship that will remain consistent, which is what defines standardization in the first place. With many different variables such as speed, range of motion, contraction mode (e.g. discrete or reciprocal) that change protocols, the work:rest ratio accommodates all these changes by providing a basis for sound judgment. The logic is founded on the idea that with the work bout being available to calculate (See Table 4), the corresponding rest period can then be calculated as well due to the coherent relationship within the work:rest ratio (Conley, 2000). Furthermore, this coherent relationship within the work:rest ratio is based on the physiological behavior of the ATP-PC system, which is the exact energy system of which maximum strength and power are produced (Conley, 2000). Therefore, the work:rest ratio should be implemented as the method of standardization of rest periods in isokinetic strength test protocols.

Recent research has shown that shorter rest periods (30-s and 60-s) and their corresponding work:rest ratios of 1:1 (30-s rest period) and 1:2 (60-s rest period) were sufficient enough in preserving reliablity in peak torque in older and younger women (Theou, Jones, Brown & Vandervoort, 2007). Although their protocol was different, it was actually more metabolically demanding than the present protocol since it consisted of 3 sets of 8 repetitions at 60 deg/s. In addition, they found that mean torque reproducibility was preserved with the 1:2 work:rest ratio and not the 1:1/2 or 1:1, while peak torque was preserved with the 1:1 and 1:2 work:rest ratio, but not a 1:1/2 work:rest ratio (Theou et al., 2007). The 15-s rest period (1:1/2 work:rest ratio) had a negative influence on mean and peak torque (Theou et al., 2007). The interesting implication from these findings is that peak torque may not require much rest between sets to remain preserved in isokinetic strength testing since peak torque is essentially one repetition out of the total number used (i.e. 3-6 reps). Thus, perhaps shorter work:rest ratios such as 1:1 and/or 1:2 may have sustained peak torque reliability in the present study.

In summary, the results of the present study indicate that a work:rest ratio as short as 1:3 ensures test reliability for a universal isokinetic knee-strength testing protocol among a college-aged male population. The basis for such ambiguity among the literature (Parcell et al., 2002) on rest periods can be explained by the principle of specificity (Fleck & Kraemer, 2004). With so many different factors involved (i.e. gender, population diversity, contraction mode, rep range, etc.) strength recovery becomes a very elusive entity that can be influenced by many of these factors. In fact, the influence of population diversity was similarly supported by Keating and Matyas (1996) who stated that muscle-fiber composition has an influence on fatigue and recovery patterns. Essentially, individuals with a higher proportion of fast-twitch muscle fibers tend to fatigue faster and recover slower than individuals with a higher proportion of slow-twitch muscle fibers (Colliander, Dudley & Tesch, 1988). In further support, Patton, Hinson, Arnold & Lessard (1978) found that males with high strength fatigued faster than females with low strength. It was rightfully concluded that the rest period between sets in isokinetic testing may vary in individual subjects (Keating & Matyas, 1996). Therefore, future research might include a greater number of participants, shorter work:rest ratios, different populations, gender comparison, different contraction modes, different muscle groups and more repetitions and/or sets.

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Appendices

Appendix A

PAR-Q Form

Name: ______________________________

Date: ______________________________

Many health benefits are associated with regular exercise, and the completion of PAR-Q is a sensible first step to take if you are planning to increase the amount of physical activity in your life.

For most people physical activity should not pose any problem or hazard. PAR-Q has been designed to identify the small number of adults for whom physical activity might be inappropriate or those who should have medical advice concerning the type of activity most suitable for them.

Common sense is your best guide in answering these few questions. Please read them carefully and check YES or NO opposite the question if it applies to you.

YES	**NO**		
□	□	1.	Has your doctor ever said you have a heart condition <u>and</u> that you should only do physical activity recommended by a doctor?
□	□	2.	Do you feel pain in your chest when you do physical activity?
□	□	3.	In the past month, have you had chest pain when you were not doing physical activity?
□	□	4.	Do you lose balance because of dizziness or do you ever lose consciousness?
□	□	5.	Do you have a bone or joint problem that could be made worse by a change in your activity?
□	□	6.	Is your doctor currently prescribing drugs (for example, water pills) for your blood pressure or heart condition?
□	□	7.	Do you know of <u>any other reason</u> why you should not do physical activity?

If you answered **NO** honestly to <u>all</u> PAR-Q questions, you can be reasonably sure that you can:

1. Start a graduated exercise program
2. Take part in a fitness appraisal

However, if you have a minor illness (e.g., cold) you should postpone activity.

If you answered **YES** to one or more PAR-Q questions, you should consult your physician if you have not done so recently before starting an exercise program and/or having a fitness appraisal.

Physical Activity Readiness Questionnaire ***Note.*** From *ACSM's health-related physical fitness assessment manual* (p. 162), by G.B. Dwyer & S.E. Davis, 2005, Baltimore: Lipponcott Williams & Wilkins. Copyright 2005 by ACSM. Reprinted with permission.

Appendix B

Health History Questionnaire

NAME____ AGE _____ DATE _______

First M.I. Last day/month/yr

DATE OF BIRTH ____

day/month/yr

ADDRESS-____

____

Street City State Zip

TELEPHONE (home) ________________________________ (Business)

____

OCCUPATION ___________________________ PLACE OF EMPLOYMENT

____

MARITAL STATUS: (circle one) SINGLE MARRIED DIVORCED
WIDOWED SPOUSE: ____

EDUCATION: (check highest level) ELEMENTARY _____ HIGH SCHOOL _____
COLLEGE _____ GRADUATE _____

PERSONAL PHYSICIAN ______________________________________ LOCATION

____

Reason for last doctor visit? ______________________________________ Date of last physical exam ____

Have you previously been tested for an exercise Program? YES _____ NO _____
YEAR (s) ____

LOCATION OF TEST ____

Person to contact in case of an emergency ________________________ Phone #
____________________ (relationship) ____

PAST HISTORY (Have you ever had?) YES NO	FAMILY HISTORY (Have any immediate family or grandparents had?) YES NO	PRESENT SYMPTOMS (Have you recently had?) YES NO
High blood pressure………. □ □	Heart attacks………………… □ □	Chest pain/discomfort…. □ □
Any heart trouble………… □ □	High blood pressure………… □ □	Shortness of breath……… □ □
Disease of the arteries…….. □ □	High cholesterol……………. □ □	Heart palpitations………… □ □
Varicose veins……………. □ □	Stroke……………………… □ □	Skipped heart beats……… □ □
Lung disease……………… □ □	Diabetes…………………… □ □	Cough on exertion……….. □ □
Asthma…………………… □ □	Congenital heart defect……. □ □	Coughing of blood……… □ □
Kidney disease…………… □ □	Heart operations……………. □ □	Dizzy spells……………… □ □
Hepatitis…………………. □ □	Early death……………….. □ □	Frequent headaches……… □ □
Diabetes………………….. □ □	Other family illness ____________________ ______________________________	Frequent colds………….. □ □

Heart murmur…………….. □ □	____________________	Back pain…………….. □ □
Arthritis…………………. □ □		Orthopedic problems…. □ □

(FOR STAFF)

____

____

____

____

HOSPITALIZATIONS: Please list recent hospitalizations (Women: do not list normal pregnancies)

Year Location Reason

____

____

____

____

____

____

Any other medical problems/concerns not already identified? Yes ___ No ___ (Please list below)

____

____

____

____

Have you ever had your cholesterol measured? Yes ___ No ___; IF yes, (value) _____ (Date) _____ Where?

____

____

Are you taking any Prescription or Non-Prescription medications? Yes ___ No ___
(include birth control pills)

Medication Reason for Taking For How Long?

____

____

____

____

____

Do you currently smoke? Yes ___ No ___ If so, what? Cigarettes ___ Cigars ___ Pipe ___

How much per day: <.5 pack ___ 0.5 to 1 pack ___ 1.5 to 2 packs ___ > 2 packs ___

Have you ever quit smoking? Yes ___ No ___ When? _______ How many years and how much did you smoke?

____

____

Do you drink any alcoholic beverages? Yes ___ No ___ If Yes, how much in 1 week?

Beer _______ (cans) Wine _______ (glasses) Hard liquor _______ (drinks)

____

____

Do you drink any caffeinated beverages? Yes ___ No ___ If Yes, how much in 1 week?

Coffee _______ (cups) Tea _______ (glasses) Soft drinks _______ (cans)

____

____

ACTIVITY LEVEL EVALUATION

What is your occupational activity level? sedentary ___; light ___; moderate ___; Heavy ___

Do you currently engage in vigorous physical activity on a regular basis? Yes ___ No ___

If so, what type? ____

How many days per week? ____

How much time per day? (check one) < 15min ___ 15-30 min ___ 30-45 min ___ > 60 min ___

Do you ever have chest discomfort during exercise? Yes ___ No ___ If so, does it go away with rest? ___

Do you engage in any recreational or leisure-time physical activities on a regular basis? Yes ___ No ___

If so, what activities?

____

____

On average: How often? ________________ times/week; For how long? ________________ time/session

FOR STAFF USE:

____

____

____

____

Note. Modified from *ACSM's health-related physical fitness assessment manual* (p. 163-164), by G.B. Dwyer & S.E. Davis, 2005, Baltimore: Lipponcott Williams & Wilkins.

Appendix C

Informed Consent

1. Title of Research Study

AN OPTIMAL INTERSET REST PERIOD FOR STRENGTH RECOVERY DURING A COMMON ISOKINETIC TEST

2. Project Director

Barbara L. Warren (253) 879-3710 blwarren@ups.edu
Professor and Chair
University of Puget Sound

3. Purpose of the Research

The purpose of this study is to determine the optimal rest period between sets in muscle strength testing. In previous research, the rest period times between sets have not been consistent. With rest periods having an affect on one's muscle strength performance, it is important that rest periods be long enough to allow one to perform to optimally in every given set.

4. Procedures for this Research

Each subject will be asked to come to the Metairie Orthopedic Sports Therapy Clinic a total of 5 times. Each test session will be separated by at least 48 hours. At the beginning of all sessions, the participants will warm up for 5 minutes on a stationary bicycle. The first two sessions will involve the participant performing some maximal effort leg extensions and curls at different resistances on the CYBEX isokinetic machine. These first two sessions are to allow the participant to practice and understand how to use the CYBEX when performing the leg exercises. The four subsequent experimental testing sessions will be used to collect data when the participant is tested. On each of the four experimental test sessions, participants will perform 3 sets of 5 maximal-effort repetitions of knee extensions and curls. Each set will follow a heavy-to-light progression in resistance. Rest periods will be counterbalanced across subjects. Each testing session should require approximately 10-30 minutes of the subject's time.

5. Potential Risks of Discomforts

Risks to the participant include possible knee muscle strain or possible discomfort from soreness, which might occur. However, the warm up before testing should reduce the possibility of a muscle strain or soreness. In the event that the subject experiences extreme discomfort or would like to discuss their discomfort after testing, please contact Dr. Barbara Warren at (253) 879-3710 or blwarren@ups.edu

6. Potential Benefits to You or Others

The benefit to the participant is that they will have an evaluation of strength of their thigh muscles. Participants will also receive a free exercise program and nutritional consultation. To the greater good will be the ability of the investigator to establish a consistent rest period for strength evaluation when using a CYBEX for strength testing. As a result, rest periods for further investigations using a CYBEX can be standardized.

7. Alternative Procedures

"Your participation is entirely voluntary and you may withdraw consent and terminate participation at any time without consequence." "Your decision to withdraw will not affect your grades or status at this university."

8. Protection of Confidentiality

All subjects will be assigned a number and the data will be organized according to the subject number to preserve the anonymity of the subjects. The investigator will be the only person evaluating the information collected. The confidentiality of the data files will be protected by being housed in the principal investigator's office and after the study the subjects' data will be removed from the computer files. No names and only group information will appear on any publication or presentation which might take place at the completion of the study.

9. Who to Contact with Questions

If you have any questions about your rights as a subject/participant in this research, or if you feel you have been placed at risk, you can contact Dr. Richard Speaker at the University of New Orleans at (504) 280-6534.

10. Signatures

I have been fully informed of the above-described procedure with its possible benefits and risks and I have given permission of participation in this study.

______________________	______________________	__________
Signature of Subject	**Name of Subject (Print)**	**Date**

______________________	**Ivan Blazquez**	__________
Signature of Co-investigator	**Name of Person Obtaining**	**Date**
Ivan Blazquez	**Consent (Print)**	

Appendix D

Pre-Participation Checklist

- Avoid strenuous physical activity 24-hours prior to testing.

- Testing & retesting have to be separated by a 48-hour period. i.e. (Monday-Wednesday).

- Do not eat a large meal before participating. i.e. (> 2 hours before testing).

- Testing dates need to be scheduled at roughly the same time of day (Afternoons or Evenings only). i.e. (Monday @ 3 p.m. and Thursdays @ 4 p.m.).

- Avoid smoking 12-24 hours prior to testing.

- Abstain from caffeine and nicotine products before testing (12-24 hours).

- Jeans are not allowed. Wear comfortable exercise-conducive clothing. i.e. (clothes that allow cooling).

- Abstain from alcohol before testing(> 24 hours)

- Properly hydrate by consuming an adequate amount of water.

Following these pre-participation guidelines will not only ensure your safety, but they will also ensure improved test results. If you should have any questions in regard to these guidelines set forth as such, please feel free to ask.

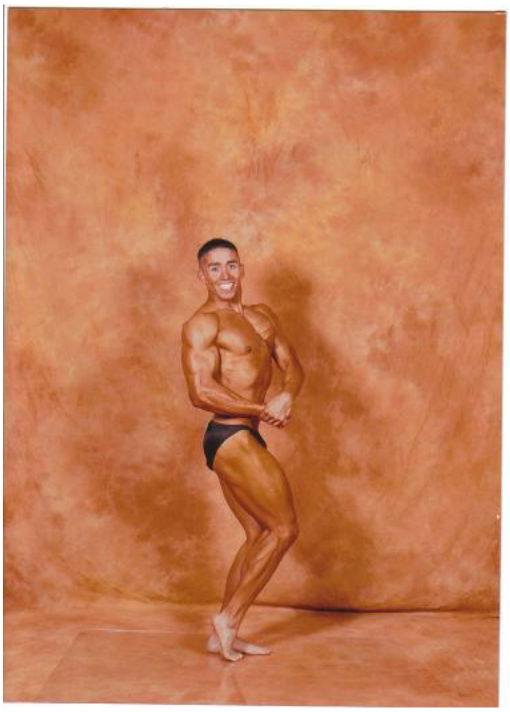
Note. Modified from *ACSM's health-related physical fitness assessment manual* (p. 89), by G.B. Dwyer & S.E. Davis, 2005, Baltimore: Lipponcott Williams & Wilkins. Copyright 2005 by ACSM. Reprinted with permission.

Appendix E

UNO STUDENTS…

WANT TO LOOK LIKE THIS?

HERE IS YOUR CHANCE.



The Department of Health Promotion and Human Performance is conducting a fitness research study. The purpose of this study is to look at the influence of rest periods between sets in resistance training. Ivan Blazquez is a graduate student who specializes in Exercise Physiology in the Department of Health Promotion and Human Performance. Blazquez is a certified personal fitness trainer at local health clubs and has been a competitive bodybuilder for 1-year.

QUALIFICATIONS:
Male students between the ages of 18-35
WHAT: Participants will be required to meet a total of five times. Each session will last approximately 10-15 minutes.

WHERE: Training and testing sessions scheduled at Metairie Orthopedic and Sport Therapy clinic
WHEN: Between 10:30 a.m. – 1:00 p.m.

Each participant will receive a personalized exercise program upon completion of the study. Participants will also have an opportunity to win a free therapeutic massage. So what are you waiting for? Get that sultry look you've desired. The right time is right now to look your utmost best.

Contact Information:

Ivan Blazquez

Cell 338-0749

clinicaltrainer@hotmail.com

Appendix F

University Committee for the Protection of Human Subjects in Research University of New Orleans

Campus Correspondence

Barbara Warren, PI
Ivan Blazquez

4/17/2008

RE: The influence of gender on an optimal interset rest period for strength recovery during a common isokinetic test

IRB#: 09apr05

The IRB has deemed that the proposed research project is now in compliance with current University of New Orleans and Federal regulations.

Be advised that approval is only valid for one year from the approval date. Any changes to the procedures or protocols must be reviewed and approved by the IRB prior to implementation. Use the IRB# listed on the first page of this letter in all future correspondence regarding this proposal.

If an adverse, unforeseen event occurs (e.g., physical, social, or emotional harm), you are required to inform the IRB as soon as possible after the event.

Best of luck with your project!
Sincerely,

Laura Scaramella, Ph.D.
Chair, University Committee for the Protection of Human Subjects in Research

University Committee for the Protection of Human Subjects in Research University of New Orleans

Campus Correspondence

Barbara Warren, PI
Ivan Blazquez

4/4/06

RE: The influence of gender on an optimal interset rest period for strength recovery during a common isokinetic test

Your request for a one year extension has been approved.

Please remember that approval is only valid for one year from the approval date. Any changes to the procedures or protocols must be reviewed and approved by the IRB prior to implementation.

If an adverse, unforeseen event occurs (e.g., physical, social, or emotional harm), you are required to inform the IRB as soon as possible after the event.

Best of luck with your project!
Sincerely,

Laura Scaramella, Ph.D.
Chair, University Committee for the Protection of Human Subjects in Research

Appendix G

Wolters Kluwer
Health

Lippincott Williams & Wilkins
530 Walnut Street
Philadelphia, PA 19106

215 521 8458 tel
www.LWW.com

04/01/08

IVAN BLAZQUEZ
5208 VINELAND ST
METAIRIE, LA 70001-1030

Invoice # P52209943 Customer # 000112784929 FEE: 0.00
Re: ACSM, ACSM HLTH REL PHYS FIT ASSESS
Spec Mat: Thesis only, pg. 162-164, health hist ques & pg. 69, pre-parti guide
-lines (matl must be orig to bk)

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8) Payment can be made via credit card (Amex, VISA, Discover and MC) or by check.

Card # ______________________ Exp Date: __________

Requestor accepts: Ivan Blazquez Date: 4-7-08

Vita

Ivan Blazquez was born on August 15, 1979 in Metairie, Louisiana. He is a graduate of Crescent City Baptist High School of Metairie. He graduated from the University of New Orleans in May 2003, with a Bachelor of Science degree in Human Performance and Health Promotion. He will graduate from the University of New Orleans with a Master of Arts in Human Performance and Health Promotion on May 17, 2008.