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The Acute Effect of Fatigue on Planned Agility Performance

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THE EFFECT OF ACUTE FATIGUE ON PLANNED AGILITY PERFORMANCE

BY

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To the Dean of the School of Human Performance and Leisure Science:

I am submitting here with the thesis written by Sofia Jakobsson entitled “The acute effect of fatigue on planned agility performance”. I have examined the final copy of this thesis for form and content and recommend that it be accepted in partial fulfillment of the requirements for the degree of Master of Science with a major in Movement Science with a specialization in Exercise Physiology.

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Constance Mier, Thesis Committee Chair

We, members of the thesis committee, have examined this thesis and recommend its acceptance.

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Accepted:

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Chair of Department of Sport and Exercise Sciences

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Dean of School of Human Performance and Leisure Sciences

ABSTRACT

We investigate the acute fatiguing effects of high intensity interval exercise (HIIE) on planned agility performance in 19 male (n = 9) and female (n =10) soccer players. An agility T-test was performed before (PRE), and twice following (POST 1 and POST 2) completion of four 4-sec cycle ergometer sprints. The sprint intervals were separated by 25-sec active recovery. POST 1 was performed approximately 25 sec following the final cycle sprint and POST 2 began two minutes after completing POST 1. Repeated measures ANOVA and Bonferroni post hoc tests were used to determine significant differences in the time (sec) to complete the T tests. During HIIE, the power drop measured as the difference between highest and lowest average power output achieved was 30.7 ± 9%. Time to complete the agility T-test significantly differed among the three tests (PRE: 10.46 ± .17 sec; POST 1: 11.67 ± .33 sec; POST 2: 10.96 ± .19 sec; $F(2, 54) = 6.174$, $p = .003$). Post hoc test revealed an increase in time from PRE to POST 1 ($p = .002$), but no difference between PRE and POST 2 (P =. 473). Nine participants (48%) were unable to complete POST 1 without errors; however, ten (52%) participants recovered well enough to perform POST 2 without error. These results show that acute fatigue from HIIE impairs planned agility, but performance can be recovered within a few minutes. Coaches can safely combine fatigue-inducing drills and planned agility training into a single session.

Keywords: High intensity intervals, Performance, Cycle sprints, Soccer, agility T-test

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CHAPTER 1

Introduction

Agility requires an explosive, total body movement with the ability to react, change speed and direction rapidly [58 52 116]. Agility performance relies on several neuromuscular components, including muscle strength, speed and balance [52] making the nature of agility performance demanding and complex which is the reason for why it is commonly viewed as a way to classify athleticism in sports requiring agility [115]. Agility can be further divided into planned and unplanned agility. Unplanned agility is also called reactive agility, and is the non-determined movement required throughout a game where the athlete must change direction quickly in reaction to a ball or opponent. In contrast, planned agility contains running and changing direction in predetermined patterns. The ability to master unplanned actions is what can separate amateur athletes from professional athletes, where the professional players are able to adapt better to the unplanned movements of his or her sport [52 59 66].

It is important to understand planned and unplanned agility needs to be trained in different manners [99]. While planned agility may show improvement from developing the neuromuscular components associated with agility, unplanned agility needs to incorporate perceptual and decision-making elements. Regardless of planned or unplanned, the training session has to be adapted and progressed based on the ability of the athlete [52]. The athlete should begin by training movement in different directions separately in a planned environment to refine the movements and attain a high level of technical proficiency before moving on and implementing stimulus for unplanned agility performance. Fatigue induced training can be a desired tool used depending on the goal of the agility training session. If technical proficiency is the goal, the athlete should perform the training in a non-fatigued state [52]. Serpell et al. [98] addresses the importance of explicit and implicit learning for superior agility performance in sports when athletes are under both psychological and physiological stress. Meaning that learner should both be guided through instruction as well as challenged to make own decisions depending on instructions given.

Because of its' explosive neuromuscular demand [41], both planned and unplanned agility increases the likelihood of injuries during practice and competition [58], especially when the athlete is fatigued since fatigue will alter neuromuscular components [41 111 112 53]. To minimize injury risks during fatigue, development of the muscular components (strength, power, balance and speed) associated with agility performance is important [58 41]. Agility during field sports, such as soccer, is performed in a repeated manner which increases the metabolic and muscular demands in order to withstand fatigue and maintain performance. Optimization of both metabolic capacity and neuromuscular function for agility performance can be challenging since it requires a lot of time. It is especially challenging for the student-athlete who has a limited amount of practice hours [15].

Performing two-a-day routines is a time efficient way to improve different components of performance, however the ability to combine training focuses, such as working on both endurance and skill-related components in one session without compromising one or the other would be time saving and beneficial. The predominant methodical approach for periodization focuses on training improving multiple physical abilities at once [56]. While this mixed-method is attractive and entertaining for the athlete, it might not optimize progression within each physical component due to factors associated with recovery, mental concentration, and further improvements within each training focus [56]. Therefore, the demand on the coaching staff to create effective training methods and proper periodization is high [29].

High intensity interval exercise (HIIE) is a strength and conditioning training method that can assist when training time is limited. HIIE relates to both endurance and resistance training and is performed in an interval like manner. The duration for intervals in endurance-based activity HIIE ranges between 1 to 8 minutes. The recovery between intervals will depend on the intensity and duration, and intervals lasting 3 to 4 minutes are commonly performed with a work to rest ratio of 1:1 or 2:1. Using rest periods will allows the athlete to perform intervals at higher intensity, usually above 90% of maximal oxygen uptake (VO_2max) [33]. Intensity has not been as well defined for HIIE relating to resistance training. Rather, some research suggests that the personal feeling of effort is more important than the numbers of repetitions and weights used [48].

HIIE has gained recognition over the past years because of the significant training adaptations that comes with the low training volume and short duration [100 90 33]. Endurance improvements from HIIE has been shown to be similar to its counterpart moderate intensity continuous exercise even though the total training duration for HIIE is significantly less [90]. For example, ventilatory threshold and peak power output [63], increased VO_2peak [108], time to exhaustion [33], lactate threshold and self-selected pace [57] are a performance improvements that have been observed from sessions lasting 15-18 minute performed over two weeks of training.

Greater agility performance improvements have been seen from training performed at higher intensity [13]. Since HIIE is very similar to the repeated agility performance that occurs in field sport competitions such as soccer, its' higher muscular demand will improve both cardiovascular components [83] and strength [103] making HIIE beneficial to prepare athletes for repeated agility that occurs during competition.. Eight weeks of HIIE resulted in 20% increase of distance covered, doubled the amount of sprints made, raised the running intensity with 25% and increased ball engagement with 23% [46]. These are all important components to optimize soccer performance [110].

Fatigue during HIIE and repeated agility is caused by reductions in the energy providing substrate phosphocreatine (PCr). Decrease in PCr levels causes a reduction in power output [106] since HIIE will have to shift towards utilization of muscle glycogen stores, glycolysis, which provides energy at a slower rate compared to PCr. Increased utilization of glycogen will increase the rate of byproduct accumulation which increases the acidity levels in the muscle. This will negatively affect the contractility of the muscles [40] [54] and reduce the motor unit recruitment ability of the CNS [72]. Shorter HIIE can also cause significant decrease in PCr and power levels. Ten 6-sec max effort bike sprints, separated by 30-sec, resulted in a total power drop of 27% with corresponding decline of anaerobic ATP utilization of 64% [30]. PCr concentration was decreased by 57% already after the first bout indicating a great decrease already after the first sprint. Fatigue might hinder performance acutely through reductions in balance [112], muscular function [86] [41] which essentially will increase ground contact time and slow down performance [115]. Studies have shown that following one 30-second maximal bike sprint PCr decreased to 17% and took 13 minutes to fully resynthesize [10]. Relating to soccer, Zemkova et al. [119] found that dynamic balance and ground contact time was degraded when measured 15 minutes after completion of the first half (45 minutes). In order to ensure that agility exercises are performed with the technique and at the intensity required for improvement, the recovery time following HIIE must be long enough for the athlete to recoup his or her power output [56 29 10 44].

HIIE has also shown to be able to negatively affect skill-performance [67 107]. Athletes that perform HIIE immediately prior to skill training were compared to those that perform skill training in a non-fatigued state, and demonstrated lower improvements in skill-related performance such as agility [58], landing mechanics [17], basketball shooting [20] and kicking velocity [25 60]. HIIE training should therefore be carefully implemented for optimal performance, especially during the competitive season when athletes already are experiencing a high training load and performance requirements are high [28].

There are various methods of applying HIIE into training routines. The work: rest duration and corresponding intensity will depend on the overall desired outcome of the training. Longer duration requires lower intensity intervals which correspond to a higher volume of training and aerobic adaptations such as increased VO_2max [108]. Additional factors affecting recovery needed are training-mode, where bike protocols tends to induce greater fatigue compared to treadmill [7], and the level of the athlete where advanced and power athletes are likely to need longer rest time post HIIE to recover due to their greater ability to deplete PCr stores and utilize glycogen for energy production which will result in a greater accumulation of byproducts [31 85 92]. During repeated linear sprints lasting less than ten seconds a work to rest ratio of 1:5 is recommended to fatigue the athlete while still maintaining speed, while a 1:3 work: rest ratio is suggested for shuttle sprints lasting ~18sec, and 1:2 for movements with multiple changes of direction performed ~12 sec [92].

In addition to varying the work:rest ratio, the type of recovery between intervals, active or passive is also considered. Active recovery is movement based recovery such as jogging or walking while passive recovery is achieved without movement. Active recovery relates better to sports performance [104] and the beneficial effects are possibly mediated by an increased blood flow to the previous exercised muscles which will accelerate byproduct removal and nutrient and oxygen provision. For sprint work durations of 2-4 seconds, active rest ranging from 21 to 90 seconds is said to be average among field sports [110] [104]. During longer intervals performed for four minutes at highest possible speed, no difference in performance was seen when using a variety of active rest duration, ranging from one to four minutes [96]. Researchers therefore believe that two minutes of active recovery would be sufficient following four minute intervals. Passive recovery have been suggested as superior for activities lasting less than 10 seconds since additional movement will prevent PCr restoration [104].

Stimulating hormonal response (growth hormone and testosterone) is important for muscle growth and is commonly seen with resistance training and endurance training HIIE [61]. Inducing fatiguing factors like these prior to agility training through HIIE has shown to yield greater improvements compared to agility training alone [117] [116]. The idea is to simulate game situations by increasing hormonal levels and stress the ATP-PCr system in the muscles prior to additional training [115] [117]. However, too high levels of fatigue can impair performance and through decreased ability to implement proper technique and lead to injuries [52] [111] [112] [53].

It has been suggested that in order to maintain performance and safely benefit from a skill-related practice session that follows an HIIE session, fatigue should be reduced only to certain point [58] [116] [17]. The ability to maintain optimal speed and technique throughout the movement is critical for development of motor abilities [52]. Indeed, research has shown that skills-related performance can be maintained if fatigue does not exceed 10% of maximal power output [86]. Ruscello et al. [92] suggests that training for agility performance without inducing sufficient fatigue level will not stimulate the energy systems involved in sport specific agility performance. However, when there is greater fatigue (> 10%) a decline in mechanical performance has been seen [7]. It is therefor recommended that fatigue stays within the range of 7-10% [92] for the athlete to achieve optimal agility improvements during training.

Significance

Because HIIE is low volume in nature, it would be beneficial to implement HIIE into conditioning routines for team sports. Coaches would not have to sacrifice a full practice to have enough time for strength and conditioning training. The ability to combine HIIE, skill and agility training in the same session without compromising one another or the remaining practice would be advantageous. However, there is little research on how to successfully combine HIIE training with agility training without compromising agility adaptations or performance during the remainder of practice. Therefore the purpose of this study is to investigate if the fatiguing effects of HIIE will acutely reduce planned agility performance and if planned agility performance can be fully recovered following a short rest period.

Limitations

1. Participants in this study were not randomly selected, rather recruited mainly from the male and female soccer team at Barry University as well as contacted through connections.
2. Participants were inexperienced with performing sprints on the bicycle ergometer
3. Participants were not screened based on performance and competition level.

Delimitations

1. All measurements were performed by the same investigator
2. All participants were given the same instructions both before and during the test
3. No verbal encouragement was given throughout the tests.
4. Participants underwent familiarization procedures for all parts of the testing protocol.

Assumptions

1. The T-test is valid and reliable.
2. Participants gave their maximal effort at every component of the testing procedure.
3. Participants followed pre-testing instructions.

Hypotheses

Hypothesis 1: The time to complete the planned agility T-test immediately following HIIE will be significantly greater than the pre-HIIE time.

Rationale: Rest periods of less than 30 seconds following repeated bike sprints has previously shown to affect sprinting performance negatively through decreased power output [72]. PCr has been seen to decrease with as much as 60% after just one repetition of six seconds [30] and recovery of PCr levels requires more than 13 minutes to fully recover following 30-sec maximal bike sprints [10]. Alteration in neuromuscular recruitment will result in decreased power output which will alter agility performance since maximal sprint exercise demands high levels of neural drive [89]. The failure of the neuromuscular system to fully activate the required musculature to contract should decrease force production and reduce agility performance [7].

Hypothesis 2: Planned agility performed 2.5 minutes following HIIE will not be significantly different from non-fatigued planned agility performance prior to HIIE

Rationale: A work to rest ratio of 1:5 is suggested to be enough to recover following sprinting. It is suggested that agility performance require less recovery than linear sprinting since fatigue following repeated agility sprints does not follow the same pattern as fatigue from repeated linear sprinting [92]. Additionally, recovery from sprint performance is said to be achieved when rest period exceeds 1 minute [72].

Definition of terms

Agility performance: an explosive, total body movement with the ability to react, change speed and direction rapidly. Can be divided into planned and unplanned (reactive) agility.

Athlete burnout: a psychophysiological syndrome and a dysfunctional condition characterized by emotional and physical exhaustion as well as a reduced sense of accomplishment, accompanied by distress and sport devaluation [42].

Fatigue: Decline in the ability to produce power relative to peak value

High intensity interval exercise (HIIE): Training method performed in repeated bouts ranging between 1-8 minutes at intensity above 90% of VO_2max. The intensity, duration and recovery in between bouts will depend on the desired outcome of training program.

Maximal Oxygen Uptake (VO_2max); maximum rate of oxygen utilization of the muscles during aerobic exercise.

Periodization: guideline to coaches and athletes that summarizes and organizes the techniques, focus, order and progression that establish the background for training.

Reactive agility: the ability to change direction in reaction to another object (i.e., ball opponent).

Recovery period: Set amount of time following high intensity interval exercise that provide partial or full recovery of power output.

Skill-related practice: Training involving sport specific components or technique drills.

Wingate Test: a test used to assess anaerobic power, consisting of one 30-s “all-out” sprint performed on a cycle ergometer against a resistance equivalent to 0.075 kg/kg body mass.

CHAPTER 2

Agility Performance

Agility is commonly defined as a high speed, explosive, total body movement involving the ability to react and adapt, change speed and direction rapidly [52] [58] [116]. Depending on the degree of the elements that influence the agility performance, it can be further referred to as planned or reactive agility where planned agility occurs in a pre-determined pattern while reactive agility consists of both physical and cognitive components forcing the practitioner to adapt the movement to a cue such as a ball or opponent while moving. Reactive agility is sometimes referred to as open skill agility, while the predetermined running course such as running around the bases in softball and baseball is referred to as closed skill agility [52]. Due to the different factors affecting agility performance, there is not one single agreement on the exact definition [98]. Rather, various definitions are used and some simply define agility as quickness or rapid change of direction. Regardless of the varying definitions, there is mutual understanding that improvements in agility performance are associated with the enhancement of athletic performance [116] particularly in sports such as soccer and basketball [18] that repeatedly requires change of direction.

Studies has shown that the level of agility performance distinguishes higher level-athletes from lower-level athletes. Sprint speed, planned and reactive agility were measured and compared in semi-professional and amateur male basketball players [66]. Acceleration and sprint speed were measured using a 10-meter sprint test, while planned and reactive agility were measured using the Y-shaped agility test. The Y-shaped test is a reliable measure of planned ($R^2 = 0.93$) and reactive ($R^2 = 0.83$) [79] agility performance that consists of 45º cutting in either a predetermined or reactive manner. Results showed that semi-professional athletes are significantly faster in reactive agility. The professional athletes were significantly faster (P = 0.5) compared to their amateur counter parts and completed the reactive test 6% faster in both left direction (2.519 ± 0.167 vs 2.672 ± 0.132sec), and right direction (2.528 ± 0.191 vs 2.696 ± 0.118sec). There was no significant difference between groups in the 10-meter sprint test and the planned agility test. This study indicates that planned and reactive speed and agility requires separate physical qualities, and that perceptual and decision making components play an important role to distinguish between athletic levels [66].

Additionally, Kaplan et al. [59] examined the relationship between athletic level and running speed and planned agility performance in soccer. Both professional and amateur male soccer players were used in this study, and assessed through a 10 x 5m shuttle sprint test. The professional athletes were faster than their amateur counterpart at each position, with mean time of 170.75 ± 7.17sec for completion of 10 x 5m shuttle sprints compared to amateurs averaging 185.05 ± 10.16sec for completion of the same test [59].

In relation to the difference seen between athletic levels, some research suggests that the best way to learn technique for agility performance is to study and attempt to mimic successful athletes as well as practice agility under competition constraints or fatigue-induced training, which will force the athlete to adapt to fatiguing and pressured situation [116]. Improving and understanding the technical aspect of agility will assist with acceleration, deceleration and stability [99]. Just like linear sprinting can be trained and improved, one can practice change of direction in a progressive manner [52].

Energy systems for agility performance

The primary energy systems used during physical activity depend on the intensity and duration of the activity. During short bouts of high intensity exercise such as agility performed through a T-test, lasting about 8-10 seconds in male athletes [1 62], the intramuscular high-energy phosphates in the form of phosphocreatine (PCr) and adenosine triphosphate (ATP) will be the primary substrates utilized for muscle contractions [88]. The muscle can store more PCr than ATP. The muscle storage capacity is about 25 mmol of ATP/kg dry mass, and 70-80 mmol of PCr/kg dry mass [106]. PCr can be broken down at a rate of about 9 mmol/kg second [7], making the expected total decline in PCr stores during the initial 10-sec is 75-85%, with the greatest degradation occurring in the first 1-2 seconds of maximal effort [31]. This corresponds well to earlier studies with sprinters that have shown a decrease in PCr stores with 60% during a 60-m sprint, lasting less than 10sec [50]. From the onset of high intensity exercise and as the PCr-ATP storage declines, energy contribution will shift toward anaerobic glycolysis. The relative contribution from glycolysis is expected to increase from 40 to 90% within the first 10 seconds as PCr levels decreases [106].

While the energy contribution of the anaerobic systems during high intensity short sprints is dominant, 13% of the energy comes from aerobic metabolism [89]. The contribution of aerobic metabolism to sprinting activity will increase with duration reaching 27% after 20 seconds. During 30 seconds of maximal exertion, 20-30% of ATP will be provided through aerobic metabolism, 46-53% through anaerobic glycolysis and 24-27% through PCr system [9 106]. The farther away the energy provided gets from the PCr system, the greater the decrease in power output is expected to be [89].

Neuromuscular factors and Agility Performance

Continuous short sprints, such as the Wingate cycle test, lasting up to 30 seconds rely primarily on once ability to produce anaerobic power. The peak power assessed during the first seconds rely more specifically on the PCr-ATP energy system and will decline as energy shifts towards reliance on anaerobic and aerobic energy system. Even though peak power during agility sprints such as the T-test also relies on the PCr-ATP energy system [62], agility performance does not correlate well to peak power measured through the Wingate test in soccer [62] and basketball players [1]. Kutlu et al. [62] wanted to assess the correlation between the T-test, peak and average power measured through the Wingate test in amateur and professional soccer players. Results showed no significant relationship between the T-test and peak power (p>0.071) nor average power (p>.019). This indicates that anaerobic capacity is not the only physical ability that affects agility performance; rather there may be other neuromuscular factors contributing to agility performance.

Components affecting change of speed are related to physical components and biomechanical factors such as maximal straight sprint speed, skeletal muscle qualities and the individuals' technique [116]. Additionally, reactive agility performance relies highly on perceptual and decision making factors [116]. The perceptual and decision making factors are the ability to visually anticipate and react to movements and plays. These factors have shown to be superior among high-level athletes [66] together with muscular components such as muscular strength and power [4]. The skeletal muscle qualities suggested to be of importance for agility performance are strength, power and reactive strength, with reactive strength being a specific form of muscular power commonly referred to as stretch shortening cycle (SSC) [37 99 116], which is the muscles ability to produce a stronger concentric contraction following an eccentric contraction.

The ability to generate force throughout eccentric and concentric contractions, or the ability to coordinate muscle fiber recruitment are all factors that influence performance. The difference in the athletes' ability to produce these different types of contractions could be one of the factors that results in performance differentiation in various types of sprints. Little et al. [65] used a 10-m sprint test, a zigzag test with three changes of direction and a flying 20-m test to find the correlation between acceleration, planned agility and maximal linear sprint speed. Results showed that both linear sprint speed and planned agility (r = 0.458, p < 0.0005) and maximal and acceleration and planned agility (r = 0.346, p < 0.00005) in professional soccer players r shared physiological and biomechanical determinants, however coefficient of determination indicated that even if they are significantly correlated, they are independent in nature (r^2 = 0.388 and r^2 = 0.209 respectively). On the same topic, Young et al. [114] compared the effect of straight sprint training on planned agility performance with five changes of direction in male athletes. They found that while straight sprint performance improved by 3%, no improvement was seen in the planned agility.

Compared to the tests used to assess agility performance in the other studies, Sahin et al. [94] used the T-test. The T-test is one of the most commonly used assessments for agility. The T-test as described by Pauole et al. 84 requires the subject to run forward, backwards and shuffle both right and left and change direction four times at maximal speed. Agility performance and acceleration speed (through a 10-m sprint) were assessed and compared to the vertical jump test in female volleyball players. Both the agility performance (0.78) and the acceleration speed (0.80) showed a significant relationship (p=0.05) with the vertical jump test.

Since muscular strength relates to muscular power [37] it should be a significant contributor to agility performance. However, an inconsistent relationship between muscle strength and agility performance has been shown, where some studies show no significant relationship between muscular strength and agility performance [18 69]. Marcovic et al. [69] looked at the relationship between leg concentric and eccentric strength, leg power and planned agility performance in active males. Leg concentric strength was assessed through isometric contraction, 1RM back squat and a weighted jump squat. Leg eccentric strength was assessed through vertical jump, maximal hopping place, and drop jump. Leg power was assessed through vertical jump test and horizontal jump test. Agility performance was assessed through three different agility tests; lateral stepping, 20-yard shuttle run and a slalom run. Results showed that the strength and power tests performed only explained 20% to 35% of the agility performance. This suggests that multi-joint strength and power measures are weak predictors for planned agility performance. Dowson et al. [21] suggests that one of the reasons for this inconsistency lies in the method of the research performed where joint angle, type of contraction and overall investigation of the relationship might vary between studies.

Since the training surface can affect the amount or type of muscular development, Gortsila et al. [37] wanted to see how training surfaces would affect agility performance and passing skills in young female volleyball players by comparing a 10 week training protocol performed either on hard court or in the sand. The training program was the same for both groups and consisted of countermovement jumps (CMJ), sprint training and technical drills. The group training on sand showed a greater increase in agility performance performed on hard court (pre-training 3.45±0.0 post training 2.98±0.06sec) and agility performance in the sand (pre-training 3.55±0.09 post-training 3.32±0.10sec) compared to the group training on hard court (hard court agility pre-training 3.34±0.15 post-training 3.18±0.14sec, sand agility pre-training 3.50±0.11 post-training 3.35±0.11sec) who did not improve their agility performance to the same extent. Authors believes that the differences in improvements between groups have to do with higher relative intensity of the training for the athletes training in the sand. Walking on the sand compared to a hard surface requires 1.6-2.5 more mechanical work, and running requires 1.15 more mechanical work [64]. Higher training loads will result in greater muscular adaptations[49], both as it relates to balance, which previously has shown to contribute to agility performance [97] [37], and strength.

Cronin et al. [18] measured speed and acceleration over five, ten and fifteen meters as well as 3RM maximal squat strength, drop jump, jump squat and isokinetic strength in professional male rugby league players. Since SSC is an important component of all of these factors [115], a relationship was expected. Indeed, significant relationships between linear acceleration and power measured from the drop jump test were observed, without a relationship with strength measures. This suggests that shorter agility distances, requiring more frequent bouts of acceleration, have a greater relationship with strength and power [115] [99] [119]. The power muscle action required to increase acceleration speed relies on proper utilization of the SSC. Greater utilization of the SSC through eccentric loading will occur over shorter agility distances due to multiple changes of direction and speed [94] [114].

Further, Young et al. [115] compared the relationship between 8-meter straight sprints as well as seven agility protocols with muscle concentric power output in recreationally active male athletes. Sprint performances was measured over 8-m, ranging from being performed in a complete straight manner to change of direction ranging from 20-60º. Muscular concentric power output was measured through an isokinetic squat, and reactive strength through a drop jump. Results showed that there was significant relationship between reactive strength and straight sprinting speed ($r = 0.55$, $p < 0.05$). Change of direction sprinting performance showed greater correlation with reactive strength compared to concentric power, with four changes of 60º having among the highest correlations ($r = 0.54$ left foot and $r = 0.59$ right foot, $p = 0.05$). Additionally, results showed that participants turned faster when able to push of with their strength dominant leg.

Test for Agility Performance

Different tests has been used to measure planned agility. Sporis et al. [105] measured the reliability and validity of the T-test, sprint with backward and forward running (SBF) and sprint with 180º turns (S180) test for measurement of agility performance in soccer players. Participants ran each test three times and the results showed the T-test was highly reliable (ICC 0.93) and valid ($r = 0.79$). Pauole et al. [84] measured reliability and validity of the T-test as a measurement of leg speed, leg power and agility by comparing it to the 40-yard dash for leg speed, the hexagon test for agility, and the vertical jump test for leg power. Result showed highest correlation between the T-test and the 40 dash with a correlation of 0.55 and 0.73 for men and women respectively ($p <0.05$). Further, the T-test had a correlation of 0.55 and 0.40 with the vertical jump, and a 0.48 and 0.42 with the hexagon test. Therefore, the authors suggest that the T-test can be used as a highly valid test to assess various muscular components and athletic abilities including leg power, leg speed and agility.

High Intensity Interval Exercise (HIIE)

High intensity interval exercise (HIIE) is a training method related to both resistance and endurance exercise. The main goal of HIIE is to keep the intensity as high as possible while maintaining proper form [48]. Endurance HIIE such as biking and running consist of intervals typically lasting from 1 to 8 minutes [33]. The duration will depend on the intensity which typically is greater than 90% of maximal oxygen uptake (VO_2max). Together the intensity and duration dictates the rest time. Duration for interval training designed to develop aerobic endurance typically consists of intervals lasting 3 to 4 minutes with a work to rest ratio of 1:1 or 2:1. Seiler et al. [96] saw a small increase in running velocity during 4 minutes intervals when increasing the rest period from 1min to 2min, but no further increase in speed when increasing recovery from 2min to 4min in well trained runners, indicating that 2 minutes was sufficient. The guidelines for resistance style HIIE does not seem to have been quantified. Rather, Herodek et al. [48] suggested that the individual feeling of perceived exertion is more important than the number of repetitions and weight used.

Through HIIE, subjects are likely to overcome a performance plateau as sometimes seen in traditional training if progressive overload is not applied [100]. This is because, compared to traditional continuous endurance training, HIIE allows one to work at, or near maximal capacity for longer period when appropriate rest periods are applied between each sprint [48 75 100]. Working closer to one’s maximal capacity has shown to yield superior adaptations compared to working at a lower intensity [22]. Paoli et al. [81] compared the effect of three different 12-week training protocols in healthy elderly population, aged 50-65yr. The programs were continuous endurance exercise performed at 65% of estimated maximal HR, low-intensity circuit training where subjects alternated between endurance work on the treadmill and resistance training, and high-intensity circuit training consisting a mixture of resistance and endurance training but performed at a higher intensity compared to the other groups. The high-intensity group showed greater reductions in body weight and body fat, improvements in lactate threshold, upper body and increases in lower body strength when compared to both of the other groups.

Further related to resistance training, Berger et al. [6] compared bench press strength increase in non-active male college students after eight weeks, following either a three session per week strength training program consisting of ten 1RM or a program consisting of one set at 10RM. Results showed a 60% greater increase in strength among the individuals performing ten 1 RM even though the total amount of work performed in the 10RM group was higher.

Spriet et al. [107] has shown that working closer to or at maximal capacity requires more energy. Their study compared continuous contractions in the form of 16 electrically induced contractions lasting 1.6sec each with intermittent contractions with an initial equal force production. The results showed that the contractions separated by rest time required 20% more energy. Edge et al. [22] also compared programs designed with different intensities but matched for total work. Two 5-week training protocols were used, ne protocol consisting of six sets 10x2min cycle intervals, performed at 120-140% of lactate threshold. The other program was a continuous cycle protocol performed at about 80-

90% of lactate threshold. Each program was performed three times per week and total duration and work was matched. Both groups showed an increase in VO_2peak (12-14%, $p < 0.05$) and lactate threshold (7-10%, $p < 0.05$), while HIIE showed greater improvement in hydrogen ion buffering capacity. Additionally, the metabolic rate following HIIE has shown to stay elevated for 48 hours following HIIE while it will only last as long as the session when performed in a steady state [48]. This makes HIIE advantageous for weight loss.

The significant improvements in relation to the short duration might be the most important benefit of HIIE [34 90 100]. Improvements from HIIE has shown to be similar to its counterpart continuous exercise when matched for total workload, even though the total training duration for HIIE is significantly less. Rowan et al. [90] compared the effect of HIIE and traditional endurance training performed twice weekly for five weeks in female division III soccer players. HIIE consisted of five 30-sec maximal sprints, separated by 3.5-4.5 minutes of active recovery; total duration was 25 minutes. The endurance training group performed a 40 minute steady state run at 80% of VO_2max. Results showed a mean increase in VO_2max by 2.36 $ml.kg^{-1}.min^{-1}$ (4.73%) for the sprint group, and 1.66 $ml.kg^{-1}.min^{-1}$ (3.42%) for the endurance group. The intervention also resulted in increased distance covered during repeated sprint performance in both groups, improving from 1857±423m to 2131±436m in the sprint group and from 1473±494m to 1613±510m in the endurance group. These improvements occurred even though total duration was significantly less for HIIE. On a side note, the HIIE group expressed greater satisfaction with their training program witch potentially could have beneficial motivational factors.

Burgomaster et al. [12] also focused on difference in duration or total work load in relation to improvements following HIIE. They used two groups of active but unfit males and females that performed either HIIE or continuous endurance training for six weeks, three days a week. The HIIE consisted of 4-6 30-sec bike sprints separated by 4.5 minutes, and the continuous endurance training program consisted of 40-60 minutes of steady state cycling at 65% of VO_2peak. Despite the fact that the total work volume were significantly difference where HIIE group performed work equal to 225kJ/week and the steady state cycling group performed work equal to 2250 kJ/week, the two groups showed the same improvements in mitochondrial enzymes as well as decreased glycogen usage and increased lipid oxidation during training.

Gibala et al. [34] conducted a similar protocol, comparing steady state training with HIIE in active males. The protocol was performed over two weeks in six sessions consisting of either 4-6 six seconds sprints separated by 4 minutes, or 90-120 minutes continuous cycling at 65% of VO_2peak. The total work duration in the HIIE was 2.5 hours versus 10.5 hours in the continuous exercise group. There was no significant difference in the HIIE group and continuous endurance groups' improvements in muscular skeletal muscle oxidative capacity, buffering capacity (7.6 and 4.2%), glycogen content (28% and 17%), and exercise performance (4.1% and 3.5%).

Additional adaptations from HIIE are improved running economy through greater energy supplied through fat oxidation [108], elevated lactate and ventilatory threshold. [63] Talanian et al. [108] measured ventilatory threshold, VO_2max and metabolic, hormonal and cardiovascular responses to exercise following seven HIIE sessions consisting of 10x4min bouts. The training resulted in a 13% increase in VO_2peak and a 36% increase in whole body fat oxidation which had a sparing effect on muscle glycogen. Laursen et al. [63] used a program of shorter duration and saw an increase in ventilatory threshold and power output after as little as four HIIE sessions of 20x60sec in highly trained cyclists. They also measured VO_2peak but did not see a significant difference, suggesting that the total volume for improvements in VO_2max needs to be greater [108].

Related to soccer performance in male elite junior athletes, Helgerud et al. [46] investigated in the effects of HIIE on distance covered, amounts of sprints, intensity and ball engagement during a soccer match. The athletes performed eight weeks of 4x4-min intervals at 90-95% of maximal heart rate, separated by a 3 min jog. The conditioning program increased distance covered by 20%, doubled the amount of sprints made, raised the running intensity with 25% and increased ball engagement with 23% during a soccer match among junior male athletes. These are all important performance indicators since greater total intensity and distance covered is associated with superior soccer performance [86].

Energy Systems for HIIE

HIIE challenges all three energy systems. However, similar to agility performance, the primary energy system utilized during HIIE will depend on the intensity, duration and number of repetitions. Higher intensities will have a greater contribution of anaerobically produced energy. Energy contribution from aerobic metabolism increases with the duration and numbers of repetitions of the intervals. It is suggested that the aerobic system contributes with 20-30% of the energy during intervals of 2-3 minutes while equal contribution between the systems will occur closer to intervals lasting 4 minutes [3]. Research has shown that aerobic energy contribution increases with each interval [9]. Just between two bouts of 30-sec maximal bike sprints, separated by 3.8 minute rest, the aerobic energy contribution, reflected through an 18% increase in VO_2, was calculated to have increased from 34±2% during sprint one to 49±2% during sprint two. This forced action of aerobic metabolism contribution during HIIE increases the aerobic capacity of muscles to oxidize fat [108], this is an important adaptation since it will spare glycogen stores [34], and is a factor that explains the improvements in aerobic performance seen following HIIE.

A decrease in power output or total work during the HIIE is associated with decreased PCr and glycogen stores and therefore the shift towards aerobic metabolism that produces energy at a slower rate [44 47]. During maximal exercise, PCr and ATP, starts to degenerate after only 1.3 seconds [70]. Almost full depletion of PCr has shown to be possible in about 10-15 seconds, corresponding with the rapid decline in power output [9] when working at maximal intensity. Hultsman et al. [54] showed that PCr levels in the quadriceps femoris muscle were fully depleted after 50 seconds of electrical stimulation of 20 Hz which on average is equal to 70-75% of maximum tension. The duration to get close to PCr depletion was longer in studies by Spriet et al. [107]. PCr levels decreased by 80% following 16 maximal isokinetic contractions in healthy male subjects. Only an additional 13% decrease in PCr occurred after the 48th contraction, with and no further decrease shown before the final 64th contraction. The contractions were performed over 3 minutes and 20 seconds with a corresponding PCr reduction of 93%.

As a result of decreased ATP production through PCr system, the rate of glycolysis increases. ATP production through glycolysis peaks after five seconds of maximal exercise [70]. The average peak ratio of ATP synthesis from both PCr and glycolysis during high intensity exercise <10sec is 6-9 mmol ATP/kg/sec [106], with at greater contribution, 15 mmol ATP/kg/sec, during the initial six seconds [31]. Gaitanos et al. [30] used this time interval in their protocol consisting of ten 6-seconds sprints. This protocol resulted in a 27% power drop and corresponding 64% decrease in anaerobic ATP contribution.

Research by Bogdanis et al. [9] showed that as energy contribution of glycolysis decreases about 45% from the first to the second interval, in two repeated 30-sec maximal bike sprints, mean power output between sprints only decreased with 18%. This is attributed to the 78% PCr resynthesis during the four minute recovery period, and the greater rate of energy provided aerobically. The increase in aerobic metabolism during repeated sprint is supported by an increase in VO_2 [106]. Additionally, a lower pH value during sprint one compared to sprint two is another indicator of energy contribution being shifted from anaerobic to aerobic metabolism [54]. Gharbi et al. [32] assessed increase in blood lactate concentration during repeated sprint sessions in male team-sport players. The athletes performed 30m shuttle sprints with 30sec of rest in between. Blood lactate levels increased rapidly, but remained unchanged between sprint four and five.

Neuromuscular components of HIIE

Skeletal muscle are distinguished as type I and type II fibers, also called slow-twitch and fast-twitch. In untrained individuals, the metabolic enzyme content is about twice as high in type I fibers compared to type II fibers, making type I fibers more fatigue resistant. Even though fiber types cannot be converted, they can adapt to the counterparts characteristics. For example, type I fibers can improve their energy production at higher intensities which will spare glycogen stores [9 33 63], while type II can improve their aerobic capacity and the functions generally associated with type I fibers, such as fatigue resistance [51 89].

As the name fast-twitch indicates, type II muscle fibers have greater speed of contraction compared to type I fibers, and are therefore highly associated with HIIE. Mechanisms for the faster speed of contraction in type II muscle fibers are related to muscular properties and enhanced anaerobic capabilities such as glycolytic enzyme content, myosin heavy chain size, and calcium (Ca^{2+}) handling [2]. Mitochondrial adaptations are limited to the muscle fibers that are recruited for contraction, and glycolytic enzymes have shown little improvement following moderate intensity endurance training [51]. Therefore, HIIE is necessary to increase the mitochondrial content of type II muscles.

An important characteristic of type II muscle fibers explaining speed of contraction are the fast myosin heavy chain (MHC) isoform. The type of MHC isoform plays an important role in the speed of contraction through the rate of ATP consumption and cross-bridge cycling [2]. The ability to utilize the anaerobic system is not only related to the ability to produce ATP, but also the ability to break down and utilize the ATP as mechanical energy. Ortenblad et al. [80] found that five weeks of repeated 8-sec bike sprints increased the numbers of ryanodine receptors which are intracellular Ca^{2+} channels within the sarcoplasmic reticulum (SR), responsible for the release of Ca^{2+}. SR Ca^{2+} release is essential for cross-bridge cycling and faster Ca^{2+} pumps will allow the muscle to utilize ATP at a quicker rate [2 88].

Allan et al. [2] described HIIE's effect on type II fibers during acute exercise in three phases. The first phase consisted of an initial 10-20% decline in force generation followed by a rapid adaptation and increase of Ca^{2+} release. The second phase consist of a relatively constant rate of force production and the duration of this phase typically depends on the muscle cell's oxidative capacity. The last phase is recognized through a rapid decline in force and power output as the muscle is fatiguing.

Because of their structure and function, type II muscle fibers are more prone to get damaged and cause soreness [14]. The Z-lines, which are thinner in type II muscle fibers compared to type I fibers, are of greater risk to be damaged during type II fibers' forceful contractions following their immediate responds to intense exercise. Additionally, their low fatigue resistance and greater concentric and eccentric contractile ability will induced metabolite disturbances that together with muscle damage can impair energy synthesis resulting decline in the power-generating capacity of the recruited muscle fibers [30].

Sprint HIIE

Some literature have used the term sprint interval training (SIT) or repeated sprint training (RST) to describe short interval duration during HIIE. During SIT, the subject is working at maximal exertion for 6-30 seconds [13 76 102]. Even though highly anaerobic, HIIE has shown to improve aerobic performance in as little as 15-18 minutes per session [57]. Burgomaster et al. [11] used a protocol consisting of six sessions of 4-7 repetitions of 30-sec sprints, separated by 4 minutes of active recovery. Recreationally active males participated in this study that lasted for two weeks. Results showed 38% increase in the aerobic enzyme citrate synthase and 26% increase in resting glycogen storages. This reflected in both aerobic and anaerobic performance improvements. The subjects doubled their time to fatigue in cycling endurance capacity despite no increase in VO^2max.

Additionally, peak power output increased and also fatigue index, resulting in no difference in mean power output.

Jakeman et al. [57] decreased the HIIE interval duration to six seconds to investigate whether or not that was sufficient to improve aerobic performance in triathletes. Six sessions were performed over two weeks and consisted of ten 6-sec bike sprints. Improvements were assessed through a self-paced 10-km time trial and an incremental time to exhaustion test on a cycle ergometer where blood lactate analysis was performed. The initial work load was 60W, with a 30 W increase every fourth minute. Training resulted in a 10% decrease in the time to complete the self-paced 10-km time trial. Even though correlated, lactate threshold improved significantly while only a moderate increase was seen in time to exhaustion.

Besides improving endurance and time to exhaustion, short duration HIIE has shown to yield repeated agility improvements [13]. Both anaerobic and aerobic physiological variables were measured in male football players following seven weeks with two HIIE sessions per week consisting of either four minutes intervals at 90-95% of HR max, or repeated maximal shuttle sprints (SIT) consisting of 40 meters sprint with a change of direction every 10 or 20 meter. Both groups showed similar improvements in VO_2max, while the SIT group showed greater improvements in the Yo-Yo intermittent recovery test, which is a football specific agility endurance test recording the total distance covered. Authors believed that the superior repeated agility performance seen in the SIT group is related to their programs higher demand of muscular strength and power which they suggested to be important components for short distance sprinting.

Combining Resistance and Endurance based HIIE

Combining endurance and resistance training in HIIE is a common method to improve strength and cardiovascular endurance simultaneously while saving time [81 103]. Skidmore et al. [100] wanted to see if a combination of circuit weight training and interval bike sprints (CER) would induce greater acute physical responses in recreational women compared to endurance (EX) and resistance (RX) program separately. The training sessions were matched for time (40 min) and the combination of weight training and endurance training resulted in a significantly greater increase in blood lactate levels (EX 2.3mmol, RX 4.8 mmol, CER 6.7mmol) and heart rate (% of HR max, increased of 2.2 EX, 2.2 RX, and 2.6 CER, $p<0.001$). The interaction between ($p<0.001$). Monteiro et al. [75] used a mixture of recreationally active males and females to investigate the difference in physical responds performing 60sec intervals of resistance training compared to two 30sec intervals of resistance and endurance training. The intervention showed that combining weight and endurance HIIE results in higher relative and absolute VO_2 as well as energy expenditure values for both genders ($p<0.05$).

Paton et al. [83] investigated in the effects of combined methods HIIE on mean power, peak power, and lactate-threshold following 4-5 weeks of training during the noncompetitive phase of the season in competitive male cyclists. The sessions were performed 2-3 times per week and consisted of three sets of 20 explosive single-leg jumps alternated with three sets of five repetitions of 30-sec bike sprints performed at 60-70 rpm against the highest resistance possible. The program showed a significant improvements in both lactate threshold (3.9%) measured through two submaximal workloads, peak power output (3.4%) measured through an incremental bike test, and mean power output measured through a 1-and 4km time trial which increased 2.3% and 3.3% respectively.

Combining various training methods to simultaneously target metabolic and neuromuscular components of skill-based performance is often required for many sports. Gabbett et al. [29] used sub-elite rugby players to compare the difference in sport specific skill-related and neuromuscular improvement from traditional conditioning and skill-based conditioning. The sessions were performed twice per week for nine weeks during in-season training. Traditional conditioning session focused on speed, agility, endurance and muscular power separately while the sport specific skill-based program was designed to develop passing, catching, and ball-carrying technique, tackling technique, scrambling defense and support play, play-the-ball speed, defensive line speed and shape as well as ball control. VO_2max was estimated through a multi-stage fitness test. Agility was measured through the L-test and sprint speed measured over a 10, 20 and 40 meters. The groups has similar training loads, and showed similar improvements in VO_2max and 10 meter sprint speed. However, skill-related training group showed greater improvement in 20 meter (-3.2% vs 0.0%) and 40 meter (-3.0% vs -0.2%) sprint performance and significant improvement in vertical jump ($p < 0.05$). Authors suggested that the difference in outcome, despite similar volume of training, lies in the higher intensity derived from the competitive environment during skill-based conditioning training. However, the performance discrepancy did not showed any difference in terms of overall seasonal performance, but the skills related conditioning group showed a greater points differential by the end of the season.

Overtraining

An insufficient periodization by constantly overloading might reverse the training effects and negatively alter performance, a state known as overtraining [91]. Overtraining, or athletes' burn out increases the risk for suppressed immune function with concomitant increased levels of catabolic hormones [42]. There are different severity levels of overtraining that would alter the signs and symptoms. However, some possible symptoms are persistent feeling of being heavy, stiff, or sore, and lack in enjoyment from exercise routine [91]. Because of its intense nature, researchers has raised the red flag for potential overtraining effects of HIIE [95].

Gustafsson et al. [42] attributed the trend of increased cases of the athlete burnout symptoms to increased training loads, in particular since most sports are performed all year without a true off-season. The theory of deliberated practice states that regardless of total volume, it is the amount of training hours where the athletes are engaged and highly focused that counts and results in superior performance [24]. However, total training volume has increased over the years, with an increase from 924 hours/year in 1970 to 1200 hours year 1990 among rowers. Among rowers related to performance, the increased training volume did correlate with a 12% increase in VO_2max [26]. The total volume needs to be closely monitored, since there is a linear correlation between training hours performed and athletic burnout [38 78].

Recovery

The speed of acute recovery will depend largely on the individual's training status and number of sprints performed prior to the rest [31 85]. Pesta et al. [85] measured PCr levels to compared recovery rates in power and endurance athletes and non-athletes post knee extensions to exhaustion. The protocol consisted of continuous single-leg extensions starting with a resistance of 4.5W, increasing by 1.5W every 2 min until exhaustion. The aerobic athletes recovered the fastest (30 ± 4sec) followed by the untrained group (41 ± 9sec), while the power group took the longest time to recover (50 ± 17sec). Aerobically trained athletes recovered their PCr levels 40% faster compared to untrained and anaerobically trained athletes. The authors suggested this to be related to power athletes' ability to produce greater power and therefore have lower pH levels and greater PCr changes. Additionally, endurance athletes have superior mitochondrial function assisting in recovery.

Bogdanis et al. [10] measured recovery of power output and muscle metabolites in physically active males after two 30-sec cycle sprints. The passive recovery between repetitions were either 1.5, 3 or 6 minutes. By the end of the first 30 seconds sprint, PCr had decreased to 19.7 ± 1.2 % of resting value, and ATP had decreased to 70.5 ± 6.5% of resting value. The greatest increase in PCr resynthesize was seen during the first 1.5 minutes of recovery, increasing PCr levels to 65 ± 2.8%, while having 6 minutes of recovery only increased the PCr levels to 85.5% of pre exercise values. The 85.5% of PCr resynthesis following six minutes allowed the subjects to reach 90% of the mean power output achieved during sprint one. These data indicate that PCr stores could take up to 13.6 minutes to replenish. The ability to restore peak and mean power output might vary as a result of the amount of PCr and glycolysis contribution for energy supply in the first few seconds and over the entire 30 seconds of the sprint.

Agility performance may require less recovery compared to linear sprinting or higher load that induce the same fatigue [92]. In order to keep the fatigue within a certain range and maintain required speed, a work to rest ratio of 1:5 is commonly recommended for repeated sprinting ability when sprints last less than ten seconds. In their study, Ruscello et al. [92] tested trained male soccer players to determine if there were different trends in fatigue following three different modes of sprinting performance. Subjects sprinted a total of three sets of seven 30-m repetitions as either a straight sprint, shuttle sprint or sprint with change of direction. In this study, fatigue appears immediately in straight sprinting but not in agility performance, despite the same distance covered. This indicates that recovery time needs to be very specific to the activity performed to simulate adaptations. A 1:2 work rest ratio is suggested to be more appropriate for agility performance if aiming to induce fatigue similar to 6-7 repetitions of straight sprinting.

Active recovery is typically suggested to be superior to passive recovery, since passive recovery following HIIE has shown to delay lactate clearance rate [106]. However, research suggests that the preferred mode of recovery will depend on the duration and intensity of the activity performed. In female soccer, the average sprint duration is suggested to be 2-4 sec duration, repeated 39 times, separate by 90 sec active recovery [110]. Spencer et al. [104] compared active and passive recovery following a training protocol based on data from a field hockey competition. During the competition the average sprint duration was 2-3 seconds with as little as 21 seconds in between sprints during the most intense periods of the game. Therefore, six repetition of 4-sec sprints were performed by moderately trained males and separated by 25-sec of either moderate intensity recovery (35% of VO_2max), low intensity recovery (25% of VO_2max) or passive recovery. Researchers saw a significant reduction in peak power following both of the active recovery protocols in comparison to the passive recovery group. Greatest difference between passive and moderate intensity recovery was seen in the 3rd repetition, where peak power output was 6.0 ± 3.8% lower in moderate intensity active recovery. Greatest difference seen between passive and low intensity active recovery was seen in the 6th repetition, where peak power output was 3.70 ± 2.38% lower in low intensity active recovery. This data suggests that any intensity of active recovery after short duration sprints will inhibit PCr resynthesize, and therefore passive recovery is the preferred recovery method.

Even though contrary to previous studies, Castagna et al. [16] saw the same results when comparing the effect of passive and active recovery for repeated sprinting ability in highly competitive male athletes. A significantly greater fatigue was seen in the group performing active recovery following ten 30-m shuttle runs. Fatigue index during the repeated sprints was significantly greater in active compared to passive recovery group (5.05 ± 2.4sec vs 3.39 ± 2.3%, $p < 0.001$) as well as total sprint times (62.2 ± 3.0 vs 60.6 ± 1.6 sec, $p = 0.04$)

It is likely that recovery of both single-sprint performance and repeated sprinting ability requires different durations depending on mode. Mendez et al. [72] compared fatigability during two sets of six sec cycle sprints in young males. A total of 16 sprints were performed, with a 6 minute rest after the 10th repetition. There was no difference in total work performed between the fourth sprint in and 11th sprint, while the decrease in total work performed was significantly greater in the seconds set (20.3%) compared to sprint 4 to 10 (14.5%). This indicates that single-sprint performance was matched after 6 minutes of recovery between the sets, however 6 minutes rest was not enough to recover RSA between sets [72]. Yaggie et al. [112] found that a fatigue-induced increase in postural sway following two maximal 30 second Wingate tests was regained after 10 minutes of recovery, indicating that more than 6 min as used by Mendez et al. [72] might be required to recover after repeated sprints.

Fatigue

Fatigue is defined as a muscular decline in power output caused by repeated muscular contractions at or near maximal capacity [7 31 73]. Energy supply and depletion, muscle recruitment, biomechanical and psychological/motivational factors are all proposed models to explain fatigue [78]. The cause of fatigue will vary depending on the characteristics of the activity performed such as type of contractions, muscle groups involved and exercise duration and intensity. This is commonly called task dependency of muscular fatigue [73]. Additionally, the characteristics of the subject as well as the subjective view of the person studying the fatiguing factors play a role [7].

The two most common explanations of fatigue are grouped and defined by their location in relation to the neuromuscular junction (NMJ). Fatigue is either related to central fatigue, meaning contributing factors are proximally located of the NMJ, or peripheral fatigue meaning that the fatiguing factors are distally located of NMJ [31 73]. Central fatigue is related to the central nervous system's (CNS) ability to maintain adequate stimuli to working muscles. Any dysfunction related to the CNS's ability to signal muscular contraction will result in fatigue [19]. Peripheral fatigue is related to what occurs at the muscular level and affects the muscle's ability to produce and use ATP. Some of the peripheral factors studied are differences in blood lactate removal ability [109], H^+ accumulation [47], PCr degradation [35], or impairments of excitation–contraction coupling through altered levels of intracellular Ca^{2+} [80].

Even though it is likely that fatigue is multifactorial, such as decreased joint proprioception (peripheral fatigue) caused by a decline in muscular mechanoreceptor activation (central fatigue) [101], it has been suggested that lower levels of fatigue (<10% measured through MVC, decrease in EMG amplitude) are mainly peripheral in nature, whereas a greater level of fatigue (>10%) is from a combination of central and peripheral factors [7]. While the systems can affect each other interchangeably, Zemkova et al. [119] used male elite soccer players to demonstrate how fatigue compromises proprioceptive input. Balance was measured through changes in postural sway in both static and dynamic positions before competition, during half time and after competition. Postural sway was measured through approaching and kicking a soccer ball as fast as possible. Additionally, post competition fatigue resulted in increased static postural sway when subjects attempted to balance with their eyes closed. This indicates a decrease in the central nervous system's ability to accurately process neuromuscular signals provided by the proprioceptors in the muscles when fatiguing.

Relating back to contraction type, activity, intensity, duration and task specificity, supplying energy anaerobically will eventually cause fatigue since energy provided through glycolysis can lead to accumulation of blood ammonia, lactate hydrogen ions, inorganic phosphate ADP, AMP and IMP [36 40 106]. These byproducts are believed to disturb sodium/potassium pumps, Ca^{2+} cycling, cross-bridge cycling [40] and enzyme activity [55]. Mode of exercise has a big effect on the level of fatigue and there is a correlation between power output and muscle metabolites [30]. Highly trained anaerobic individuals are likely to experience higher levels of peripheral fatigue since they are able to achieve higher maximal power outputs. The ability to produce higher power outputs is associated with a fast rate of decline in PCr levels and earlier onset of glycolysis. As a result of higher power output, an anaerobic athlete will produce greater amount of muscle metabolites compared to an aerobically trained or untrained individual [7]. Additionally, resynthesis of PCr and recovery of power output have shown to be related to endurance capacity, where aerobically trained athletes have superior buffering capacity through greater mitochondrial density [10]. Relating to mode of exercise, strength loss can be between 20-35% after prolonged skiing or running [86] and cycling protocols tends to result in greater decrements scores compared to running protocols (cycling 10-25% vs running 5-15%) [27]. Relating to duration, central fatigue is associated with longer external suggested to be caused by spinal alterations and inhibition of type III and IV group afferents or disaffiliation from muscle spindles [73].

In comparison to causes of central fatigue, fatigue during shorter duration activity such as repeated sprinting, is believed to be caused mainly by peripheral factors [7]. ATP is constantly broken and must be re-generated during muscle contraction. Production of ATP through anaerobic glycolysis results in the accumulation of metabolic by-products associated with peripheral fatigue [7]. As PCr levels decline during maximal exercise, the rate of glycolysis increases. ATP production from glycogen results in production and eventual accumulation of hydrogen ions (H^+), and increased in muscular acidity. A low pH levels has shown to decreases glycolytic enzyme activity, which in turn result in a decline in ATP production [7 55 78]. Another byproduct of phosphorylation is inorganic phosphate (Pi). Increased amount of Pi will also decrease pH-levels and has been seen in combination with impaired muscular function [82].

The belief that peripheral factors are the main cause of fatigue during repeated sprints has been supported by research using surface electromyography (EMG) during 13 bike sprints. Hautier et al. [45] measured power, velocity and torque during 15 sprints of 5sec, separated by 25sec. Results showed that the mean EMG activity remained the same in most muscles but that there was a significant decline in power output from the first to the 13th sprint (957.1 ± 217.3W vs 849.3 ± 199.3W, $p<0.01$). The higher percentage maintained EMG signal indicates that the level of neural activation to the muscle was maintained, implying that the cause of fatigue was likely occurring at the muscular level [47 54].

However, other research supports the combination of fatigue models. Mendez et al. [72] compared muscular fatigability during two sets of 10 repeated 6-sec cycle sprints, and observed a decline in both performance and EMG activity from the first to seconds set. There was a greater decrease in peak power output (PPO) in first set compared to the seconds set (1st set 24.1 vs 2nd set 17%) and total work (TW) (1st set 27.2 vs 2nd set 20.3%). Additionally, EMG decreased in amplitude (14.3%) and frequency (10.6%) during the first 10 sprints. Following 6min of rest, EMG amplitude did not recover. However, EMG frequency did and increased (11.9%) from the last repetition of the first set performed before the recovery (10th sprint), to the first repetition in the second set (11th sprint) performed after six minutes of rest. The EMG frequency achieved in the 11th sprint was similar to the EMG frequency achieved in the first sprint in the first set without matching peak power output and TW. Rather, the 11th sprint matched the peak power output and TW of the fourth sprint in the first set.

Since it consists of repeated sprinting, soccer fatigue is suggested to be a mixture of central and peripheral fatigue. Rampinini et al. [86] attempted to define the time course and contribution of central versus peripheral fatigue in male professional soccer players. Contractile ability of the muscles was measured through EMG readings and peak torque through seated leg extension, soreness and sprinting ability before competition and 40 minutes, 24 hours and again 48 hours following competition. A reduction in EMG wave amplitudes were seen together with reduced quadriceps contractile properties assessed through knee extensor muscle voluntary contraction (MVC) and sprinting ability after the game. Soreness remained elevated for 24 hours following competition. Authors suggest this to confirm the combination of central fatigue, a reduction in EMG amplitude, MVC and sprinting ability, and also peripheral fatigue defined through increased soreness following competition. Further, Rampinini et al. [86] suggest higher level athletes recover faster after soccer-induced fatigue since they are better train to sustain the load. Early research by Ekblom et al. [23] suggested that the decrease in glycogen stores and the corresponding increase in blood lactate levels due to the sports intense nature impaired the neuromuscular performance required for skill-related soccer components. Some research state that lactate production is an important physiological function for activation the aerobic energy system, while others views it simply as a natural byproduct of glycolysis [106]. Byrne et al. [14] suggested that beside reduced EMG amplitude following exercise, decreased voluntary muscular contraction could be a result of muscular stiffness, swelling and acute soreness[14].

In addition, causes of central fatigue during sprinting may be explained through a psychological motivational model [78]. This is related to performance being sustained through conscious effort. Consciously maintaining maximal force output is challenging and even well trained, motivated individuals tend to decrease their psychological drive [78].

Fatigue and Agility Performance

Understanding the effects of fatigue on performance is important for the safety of the athlete, particularly during demanding workouts and in-season when performance requirements and the over-all volume of activity is high. As mentioned previously, repeated sprints are highly associated with peripheral fatigue which can result in stiffness, swelling and soreness in the muscle [14 86] through muscular micro tears and accumulation of metabolic by-products such as hydrogen ions, inorganic phosphate (Pi), AMP, ADP and IMP [40]. Pathare et al. [82] studied rehabilitation patients and saw a correlation between resting Pi levels and muscular contraction ability during rehabilitation following seven weeks of immobilization, where high Pi levels impaired muscular force production. Further, increased muscular stiffness has shown to decrease balance through decreased proprioceptive function [86]. Altered proprioceptive function which will result in decreased sensory feedback of the periphery system to the central nervous system resulting in impaired joint stability [41] which will change dynamic balance [119] and increase postural sway as a compensatory effect [112]. Lundin et al. [67] measured unilateral stability in male subjects before and after an isokinetic fatigue protocol and found a correlation between increase in postural sway and decrease in force and power output.

Overall, it appears that in order to effectively change direction, optimization reactive strength and SSC are of great importance. Zemkova et al. [119] found that ground contact time assessed through a drop jump increased (pre-soccer 0.270 ± .045ms vs post-soccer 291 ± .048ms, p <0.01) among male elite soccer players. Cortes et al. [17] measured landing mechanics following four rounds of fatigue-inducing reactive agility drills in division I female soccer players. Results showed that the fatigued athletes maintained a more erect posture during the landing phase which decreased their ability to absorb the jump. This indicates a decreased ability to utilize the SCC which will increase ground contact time and affect efficiency of change of direction [116]. Any fatigue-causing alterations in SSC function and decrease in power output will negatively affect agility performance.

Many studies have studied the onset of fatigue during long duration exercise. Fatigue-induced changes in biomechanics are commonly seen towards the end of competitive activities and will increase the risk of injuries in the lower extremities [53 111 112 118], especially in unplanned agility motions [52] where the total load on the knee being is greater [99]. Related to soccer, as much as 47% of match-play hamstring strains occurred in the last 15 minutes of each 45 minute half among professional soccer players [118]. This is highly related to the great variety of power movements such as cutting, kicking and jumping performed in soccer, all of which rely on lower body mechanics and have shown to be altered by fatigue. Greig et al. [41] investigated whether eccentric hamstring strength would decrease following an intermittent treadmill protocol designed to simulate a soccer game, covering a total distance of 9.72km. Eccentric hamstring strength measured through the Biodex showed that eccentric hamstring strength was reduced proportional to time in male professional soccer players. Since eccentric muscle actions are associated with deceleration actions from jumping and change of direction, the ability to utilize it properly is vital for agility performance [99]. Additionally, Greig et al. [41] found that the risk of injury is speed and direction dependent. Higher speeds are associated with higher risks of injury since change of direction performed at higher velocities require greater eccentric contraction and there is a linear relationship between eccentric hamstring strength and its ability to produce power [99].

The correlation between fatigue and kicking velocity has been measured in male amateur soccer players [25]. Fatigue was induced by a 90-sec continuous circuit consisting of explosive exercises such as jumping, sprinting and agility. After the 90 seconds, participants were instructed to kick the ball as far as they could three times before resting 90 seconds before the next circuit round. The procedure was repeated for a total of five rounds. The ball velocity in all rounds decreased compared to pre-circuit, showing that fatigue influences kicking velocity negatively. Ferraz et al. [25] believed that this to be related to approach speed, skill level and decreased strength in the muscles involved in kicking.

Additionally, as a result of fatigue, the total distance covered and volume of high intensity runs were lower in the second half of a soccer game among male athletes [86]. The investigators observed a 9-10% decrease in maximal muscular contraction, 2-3% decline sprinting ability, and increase in muscular soreness after a 90-minute soccer game in high-level professional soccer players. These data were supported by a significant decrease in average heart rate between first and seconds halves, indicating that intensity level dropped. Interestingly, this study did not show a significant decrease in skill-related performance measured through short-passing ability.

Sheppard et al. [99] suggested that the decrease in agility performance associated with a decline is muscular strength and power is significant over shorter distances. As previously discussed, different components of agility performance are sprint speed and muscular strength and power. Zemakova et al. [119] found that reactive agility time, measured through touching mats four positioned in the corners of a 80 cm wide square increase by the end of the game (90 minutes) without a corresponding increase in time for reactive performance over a longer distance (1.5 meter). Indicating that change of direction over shorter distance would rely on the muscular components to a greater extent than speed.

Besides changes in running technique through decreased knee flexion when hamstring strength is decreased, agility-specific fatigue is associated with altered hip position through increased internal rotation, decrease in step length and cadence [43]. During a five kilometer race, biomechanical changes in running mechanics were altered as early as 2400 meters in competitive runners [43]. The fatigue resulted in reduced gait length and cadence. Authors explained this partly through hamstring fatigue, resulting in decreased knee flexion which limits the swing phase of a stride. In particular during weight bearing exercise, a more elastic and efficient muscle will improve exercise performance since the movement will require less energy and therefore prevent the accumulation of metabolic byproducts and increase in body temperature [77].

Finally, it has been proposed that fatigue levels greater than 10% measured through EMG results in decreased muscle recruitment, fire rate or both and corresponds to the decline in mechanical performance [7]. This is why a general recommendation to strength and conditioning coaches is to keep fatigue between 7-10% when attempting to improve agility performance through fatigue-inducing training [92].

Fatigue-induced training

Forced correction of muscular strength imbalances and clearance of muscle metabolic byproducts produced during high intensity training can improve agility performance [115]. HIIE, with short rest intervals stressing the ATP-PCr system and large muscle masses prior too additional training will elevate the lactate levels and increase levels of hormones such as growth hormone [39 61 106]. Since greater circulation of hormonal levels in the blood increases the likelihood of hormonal interaction with receptor present either on the target tissue or cell membrane, the acute increase in growth hormones as seen with resistance exercise is critical for tissue growth and has also showed greater improvements in endurance, strength, speed and agility adaptations as oppose to training in a non-fatigued state [61 116 117].

If an adequate stimulus is presented, anabolic hormonal responses such as testosterone and growth hormone levels can remain elevated 15-30 minutes following exercise [61]. Research conducted on strength training showed superior improvements in upper body dynamic strength when fatigue was induced through continues repetitions, compared to sets where repetitions (contractions) were separated with 30-sec rest periods [87]. A study by McGawley [71] examined if there is an importance of the order of concurrent HIIE and strength training applied in the same session in semi- and professional soccer players. The sessions were conducted three times per week over five weeks. The protocol for HIIE was performed in different variations with and without ball while each strength training session was designed to cover both upper and lower body. Sessions were separated by five minutes and after the five weeks performance improvements were seen in both groups with no significant differenced suggesting that endurance HIIE and strength training can be equally fatiguing.

One benefit of fatigue-induced training such as HIIE is that it will force the aerobic system to contribute at higher intensities to assist in power output maintenance. Anaerobic power drop was measured in physically active males before and after an intervention consisting of seven repetitions of 30-sec bike sprints three times per week over seven weeks [68]. After the seven weeks of training, the power drop from the first interval to the fourth was ~15% compared to 25% pre-intervention meaning that the athletes were able to recover faster after the training protocol. Indeed, ability to recover between sprints and overall sprint performance is associated with aerobic endurance and improved aerobic metabolism [10].

Onset of fatigue will result in the reduction in mental concentration and skill-related performance [28 93]. Decreased function of neuromuscular peripheral function as seen during sports might increase the athlete's central motor drive in order to maintain performance [86]. Gortsila et al. [37] measured agility and skill-related components in young volleyball players who were divided into groups where one performed volleyball training and conditioning on hard court while the other trained on sand. Training consisting of counter movement jumping, squat jumps, sprinting exercise and technical and passing skills performed three times per week for ten weeks. Results showed that 10-weeks of training in the sand led to superior agility and skill-related performance (13.8 ± 0.7% vs 4.7 ± 0.7%) measured through the T-test. The sand training group also showed significantly greater improvements in overhead and forehand passing accuracy compared to the hard court training group (39.7 ± 7.5% vs 13.5 ± 3.7%). The authors believed that the superior improvements were due to the greater load associated with training in the sand. However, subjects in this study were beginners which also could affect the result.

Not all research has shown positive adaptations following fatigue-induced training. A soccer-specific fatigue-inducing agility drill was performed prior to assessing instep kicking mechanics in male amateur soccer players [60]. Lactate concentrations increased (1.44 ±0.49mmol/L vs 6.24 ±1.20mmol/L) and fatigue showed significant effect on angular velocity of the shank and angular positioning of the ankle decreasing the ball to foot speed ratio (1.40±-0.12sec vs 1.33±-0.18sec, $p<0.01$). Finally, velocity of the ball decreased from 24.69 m/s prior to the protocol to 21.78 m/s after the protocol ($p<0.01$) [60]. These results indicates that fatigue has a negative acute effect on skill-related performance.

Additional research has shown that fatigue-induced training can have negative effects on skill-related performance adaptations. Julien et al. [58] wanted to see how leg-strengthening exercise before speed training would affect running speed and agility performance in soccer players, measured through a 7.32m and 10m sprint test, shuttle runs and a sport specific timed circuit. Soccer players were divided into three training groups before performing a competitive agility circuit. The groups performed the training programs five times/week for a total duration of three weeks. The first group performed three sets of 3RM squats (90%) and a sprint. The second group performed a circuit designed to improve agility, balance and coordination, and the third group did not performed any additional training except the competitive agility drill that all groups performed. Interventions did not induce any significant sprinting speed improvements in any of the groups, but time improvements were seen across the board with the exception of shuttle sprint time that increased with 0.27sec in the squat group. The agility group showed greater time decrease in the agility circuit (-1.16sec), balance and coordination training compared to the group performing strengthening before agility testing (-0.53 sec), balance and coordination.

Delextrat et al. [20] wanted to compare the difference physical and technical performance in male junior basketball players following six weeks of conditioning in form of either small-sided basketball games (SSG) or traditional HIIE. HIIE consisted of 15 sprints performed at an intensity equal to 95% of highest completed stage during a VO_2max treadmill test. The intervals were separated by 15 seconds of active recovery. The protocol was performed in two bouts, each 8-9 minutes in duration. The SSG were performed on a smaller than normal basketball court (28 x 7.5 meters) for two bouts of two repetitions, 3-4 minutes. Results showed that the interventions lead to similar improvements in aerobic fitness, repeated sprinting ability and offensive agility. However, SSG resulted in greater defensive agility performance improvements measured through a T-test compared to HIIE who increased their time (-4.5% vs + 2.7 %). Additionally shooting skill accuracy (7.4% vs -2.4%) and upper body power (7.9% vs -2.0%) showed greater improvement in SSG compared to HIIE. Authors states that higher intensities (>90% HR_{max}) as seen in both the SSG and HIIE protocol is preferable to lower intensities to improve endurance capacity in junior athletes. Further, results from this study suggests that conditioning method should be varied according to seasonal focus.

The conflicting results seen among studies where some fatigue-induced exercise leads to superior improvement indicates that finding the right combination of training mode, load and rest prior to agility training or skills specific training for performance improvements is critical [20]. Some research indicates that pre-fatiguing muscles in order to improve agility does not outweigh the benefit of specificity [58]. Too much fatigue initiated early in the session could potentially decrease the athlete's ability to maintain performance and proper technique throughout the remainder of the session. Lack of technique could create bad habits and have a negative effect on the adaptations from agility and skills-related practice [52]. In addition, total seasonal load should be taken in consideration as a factor that can effect overall performance in addition to acutely induced fatigue [28].

Summary

This review has discussed agility performance, high intensity interval exercise (HIIE) and fatigue, and has attempted to create an understanding for their interaction. Similar to HIIE, agility performance in sports is performed in a repeated manner and the ability to maintain intensity is dependent on recovery of the anaerobic energy system, the ATP-PCr energy system or once ability to utilize the aerobic energy system at higher intensities. Fatigue during agility performance is believed to be a combination of central and peripheral factors impairing multiple components associated with planned and unplanned agility performance such as biomechanics, muscular strength, balance, ground contact time and perceptual factors such as reaction time.

Since research has shown a correlation between agility performance and athletic level, maintaining agility performance throughout competition is vital for successful performance. Implementing desired fatigue to stimulate a game-like environment in practice can assist in raising the level of threshold for fatigue-induced decrease in agility performance during competition. Determination of fatigue's acute effect on agility performance is an important step in learning how to combine HIIE with skill-related performance such as agility. This applies both to the ability to incorporate fatigue-induced training where performance can be maintained at desired level, and also the ability to ensure full recovery of the athlete when desired. Therefore the purpose of this study is to investigate if the fatiguing effects of HIIE will acutely reduce planned agility performance and if planned agility performance can be fully recovered following a short rest period.

Methods

The purpose of this study is to investigate if the fatiguing effects of HIIE will acutely reduce planned agility performance and if planned agility performance can be fully recovered following a short rest period.

Subjects

We aim to recruit a total of 40 soccer players. Participant will be from the men's and women's soccer team at Barry University in Miami Shores, Florida as well as currently recreationally active soccer players who have competed at collegiate level within the last ≤5 years. Athletes will be recruited within the Barry University Athletic Department and through email. Both males (n: 20) and females (n:20) will participate since muscular components affecting planned agility performance has shown to vary slightly with gender [97]. Criteria for inclusion in this study include ≥3 years of competitive soccer experience, and no injuries or illnesses that has kept the athlete from competition the last three months. Each of the participants will read and sign an informed consent, approved by the Barry University Institutional Review Board. Additionally, they are encouraged to ask questions related to their participation in the study before and during the test.

All test will be completed in the same order and by the same technician and technician assistant to ensure reliability. Prior to the test day, each athlete will participate in two training sessions to practice the agility test, the T-test, in order to avoid any time discrepancies due to test familiarization. The last training session will be completed within one week of the test. Participants will be asked to refrain from strenuous physical activity 24 hours prior to the test time, make sure they wear proper attire for the test out, that they stay hydrated and have a balanced meal 2-3 hours prior to the test.

Study Design

We seek to determine if HIIE performed on a cycle ergometer results in an immediate decline in planned agility performance and if two minutes provides enough time to fully recover planned agility performance measured by the time to complete the T-test.

Procedures

Warm-up

On the test day, the study investigator has to make sure that the participant is wearing the appropriate attire. Before performing any activity, the participant will be measured for height and weight to assist in completion of a demographic questionnaire before being connected to a heart rate monitor (Monark, Sweden). A standardized warm up on a Wingate cycle ergometer (Monark 874-E, Monark, Sweden) will be performed with the intention of preparing the major muscles associated with repeated bike sprint performance to avoid musculoskeletal injuries. The seat will be set to a height so that the knee is in a 25º flexion when the leg is in extended position. The bike warm up will consist of five minutes at 75 revolutions per minute (rpm) with a resistance of 0.5 kg. The last 15sec of the 2^{nd}, 3^{rd} and 4^{th} minute, the subject will perform a maximal bike sprint and return to 75rpm once maximal rpm has been reached. During this time, strong vocal encouragement will be given to push participant to achieve true max rpm. Following the cycle warm up, the participant will be taken through a sport specific dynamic warm up in the gymnasium lead by a certified strength and conditioning specialist with the intention of preparing the major muscles associated with agility performance to avoid musculoskeletal injuries.

Repeated Sprint Protocol

The sprint protocol will be performed on the same cycle ergometer as the warm up with a resistance corresponding to 7.5% of the subject's body weight. The subject will be instructed to accelerate to maximal rpm. Once study investigator sees a plateau in rpm similar to the number achieved during the warm-up, study investigator will release the weight onto the flywheel. Once the weight is applied against the flywheel, the time starts and each subject will perform four 4-sec sprints, remaining seated throughout the four second bouts while attempting to keep rpm as high as possible. When the four seconds are up, study investigator will release the weight from the flywheel and the 25 seconds active recovery at a self-selected pace with a 0.5kg load begins. At the end of the 25-sec recovery, the subject will begin to accelerate towards maximal rpm to begin the next sprint. Vocal encouragement will be given during each sprint to keep the rpm as high as possible. Fatigue during the sprint protocol will be determined through drop in average power, expressed as percentage. Once the final sprint is done, subject will have 25-sec to be escorted to the gymnasium to perform the first agility test post-fatigue.

The bike sprint protocol was designed based on the average duration seen among sports. The average sprint in soccer lasts for 2-4sec [110], additionally, Spencer et al. [105] have used similar protocols following analysis of field hockey, proposing that field hockey is a sport that contains movement similar to elite soccer. They suggested that a repeated sprint protocol involving six 4-s sprints with approximately 20 seconds of active recovery between sprints would be more sport specific and superior longer duration sprints with passive recovery to assess repeated sprint activity. Even though fatigue induced following long duration (19 min 30 sec) has shown to produce greater fatigue (12 vs 5.8%) compared to fatigue induced over short duration (4 min 17 sec), maximum voluntary contraction force has shown to be the same following 30 second of rest [5].

Short bike sprints are not a training modality that is familiar and currently used among soccer players due to its lack of sport specificity. Fatigue while cycling compared to running will differentiate in blood distribution due to the local activation of leg muscles when cycling. From research performed on triathletes, Millet et al. [74] concluded that the difference between weight bearing and non-weight bearing activity and differences in leg movement frequency when transitioning from biking to running can cause loss of coordination and effect knee angle and knee extension which in turn will effect running economy, stride length and trunk gradient. These biomechanical changes are associated with long-distance cycling, performed at lower intensity. Although not sport specific, biking compared to treadmill running does allow the athlete to perform at a voluntary maximum [71]. It will also control the level of fatigue which will enable study investigator to quantify power output, and fatigue as measured by a reduction in power output relative to initial power output. Additionally, the physiological benefits and performance improvements from short bike sprints are significant and well supported [33] [57]. Therefore a short bike sprint protocol can easily be incorporated and beneficial to soccer players as a strength and conditioning method while bringing a variety to training.

Agility Test

The T-test, has shown high reliability (0.89) in male soccer players [62]. For validity and reliability purposes, agility tests should be practiced with maximal effort prior to the actual test due to motor learning abilities [105]. This applies to athletes as well as non-athletes. In addition, the agility protocol should be sport specific [116]. Therefore, all athletes will be participating in two agility training sessions designed to prepare the athletes for the T-test by having each athlete perform the T-test at maximal speed three times each session following a dynamic warm-up lead by a certified strength and conditioning specialist, designed to prepare all the major muscle groups used during the T-test. The participants will be instructed in how to do the T-test and the performance errors that would cause termination of the test results.

For the data collection, the T-test will be performed on wooden floor in two rounds, twice prior to the repeated bike sprint protocol where the fastest time will be recorded, and twice following the sprint protocol where both times will be used. After the dynamic warm-up, the subject will perform two T-test at maximal speed, separated by three minutes to ensure accurate recovery [84]. The active recovery between agility bouts consists of walking, and the subject will be informed about the remaining rest time every 30 seconds.

The T-test is a multi-directional movement test including forward running, backwards pedaling and lateral sliding. Four cones, a foot high, will be used and positioned as a T. Participant will start with both feet aligned behind the baseline and begin the test when they feel ready. The test begins with a 10yard forward sprint, the participant will touch the cone at the 10yard mark with his right hand and change direction into a five yard lateral slide to their left, touch the cone end with their left hand before shuffling 10 yard to their right and touch the end cone with their right hand and finally shuffle five yards back to the left, touch the middle cone with the left hand before backpedaling 10 yards backward pass start position. If the participants performs the test wrong through crossing their feet, falling or failing to touch the cones with the right hand, the test will be terminated. No verbal communication or encouragement will be given during the T-tests.

Each T-test will be recorded with two video cameras, one will record the time by being positioned in line with the start, and the other one will be positioned to record the test from an anterior view. The videos will be downloaded onto a computer for subsequent analysis in Dartfish Prosuite software v4.0 (Dartfish, Atlanta, GA, USA). The video will be analyzed for time to completion to $1/100^{sec}$ starting the time by the last point of ground contact of the last foot, and ending when the first foot makes ground contact behind the starting line. Besides time, the video will be analyzed for changes in stride length and frequency, distance between hip and ground when changing direction as well as correct performance of the test without errors such as failure to touch the cones, falling or crossing the legs. Times from tests completed but performed with errors will not be used in data analysis. Heart rate will be recorded three times throughout the protocol, as the highest number immediately following bike sprint protocol and immediately before both of the post-fatigue T-tests.

Statistical Analyses

Data will be analyzed with PASW statistics v18.0 (SPSS Inc, Chicago, IL, USA). A one-way ANOVA repeated measures will be used to test for significant differences between agility tests. The sprint protocol is the independent variable while time to complete the T-test is the dependent variable and a Bonferonni *post hoc* test will be applied if a significant effect is observed. Data are expressed as mean ± standard deviation & significance set at $p \leq 0.05$.

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APPENDIX A. MANUSCRIPT

TITLE: The Acute Effect of Fatigue on Planned Agility Performance

RUNNING HEAD: Fatigue and agility performance

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TITLE: The Acute Effect of Fatigue on Planned Agility Performance

ABSTRACT

We investigate the acute fatiguing effects of high intensity interval exercise (HIIE) on planned agility performance in 19 male (n = 9) and female (n =10) soccer players. An agility T-test was performed before (PRE), and twice following (POST 1 and POST 2) completion of four 4-sec cycle ergometer sprints. The sprint intervals were separated by 25-sec active recovery. POST 1 was performed approximately 25 sec following the final cycle sprint and POST 2 began two minutes after completing POST 1. Repeated measures ANOVA and Bonferroni post hoc tests were used to determine significant differences in the time (sec) to complete the T tests. During HIIE, the power drop measured as the difference between highest and lowest average power output achieved was 30.7 ± 9%. Time to complete the agility T-test significantly differed among the three tests (PRE: 10.46 ± .17 sec; POST 1: 11.67 ± .33 sec; POST 2: 10.96 ± .19 sec; $F(2, 54) = 6.174$, $p = .003$). Post hoc test revealed an increase in time from PRE to POST 1 ($p = .002$), but no difference between PRE and POST 2 (P =. 473). Nine participants (48%) were unable to complete POST 1 without errors; however, ten (52%) participants recovered well enough to perform POST 2 without error. These results show that acute fatigue from HIIE impairs planned agility, but performance can be recovered within a few minutes. Coaches can safely combine fatigue-inducing drills and planned agility training into a single session.

Keywords: High intensity intervals, Performance, Cycle sprints, Soccer, agility T-test

INTRODUCTION

Agility requires an explosive total body movement with the ability to react, and change speed and direction rapidly (15, 19, 40). Because agility relies on several neuromuscular components, including muscle strength, speed and balance (15), agility performance is often viewed as a way to evaluate overall sport performance (40). Agility can be further divided into planned and unplanned agility where planned agility contains running and changing direction in predetermined patterns while unplanned agility contains a cognitive reactive component. It is important to understand that planned and unplanned agility need to be trained in different manners (37). Compared to unplanned agility that requires perceptual and decision-making elements, planned agility performance may show improvements from training programs that targets neuromuscular adaptations (15).

Agility movements during field sports such as soccer, occur repeatedly and the fatiguing effects that take place when the metabolic and neuromuscular demands are high can alter performance negatively. Optimization of both metabolic capacity and neuromuscular function for agility performance is challenging, especially for the student-athlete who has a limited amount of practice hours (5). Because of the repeated nature of high intensity interval exercise (HIIE), it is very similar to the repeated agility performance that occurs in field sport competitions such as soccer, it is a beneficial way to physically prepare athletes for competition while allowing time to focus on multiple components of performance in one session. HIIE has shown to improve agility performance (18). It has also shown to improve sports performance (14). Eight weeks of HIIE conducted among soccer players resulted in 20% increase in distance covered, doubled the amount of sprints made, raised the running intensity by 25% and increased ball engagement by 23%

during a soccer match. These are all important components to optimize soccer performance (36).

Fatigue during HIIE and repeated agility sprints is caused by reductions in the energy-providing substrate phosphocreatine (PCr) (3). A decrease in PCr levels results in a reduction in power output and greater utilization of glycogen which in turn cause byproduct accumulation and increased acidity levels in the muscle. This will negatively affect the contractility of the muscles (11, 17 and reduce the motor unit recruitment ability of the CNS (24) which in turn impairs muscular function (12, 30) including balance (37). Inducing fatigue prior to agility training through HIIE has shown to yield greater agility improvements compared to agility training alone (39, 40). In fact, it is suggests that training for agility performance without inducing sufficient fatigue level will not stimulate the energy systems involved in sport-specific agility performance (33). Likewise, Serpell et al. (32) addressed the importance of explicit and implicit learning for superior agility performance in sports when athletes are under both psychological and physiological stress. Training needs to consist of a mixture of guidance and self-made decisions, altering fatigued and non-fatigued state where the athlete sometimes work fatigued and non-fatigued condition in order to simulate game situations by increasing hormonal levels (38) and stress the ATP-PCr system in the muscles prior to additional training (36). Stimulating hormonal response and release (growth hormone and testosterone) is important for muscle growth and occurs during resistance training and endurance training HIIE (19).

Even though fatigue-induced training can be beneficial and time-efficient if implemented correctly, high levels of neuromuscular fatigue can impair the ability to implement proper technique and can therefore put the athlete at risk for injuries due to the explosive neuromuscular demand of agility performance (12, 16) both during practice and competition (6, 12, 15). Additionally, fatigue following HIIE has shown to negatively affect skill performance, including agility, landing mechanics, basketball shooting and kicking velocity (7, 29). HIIE training should therefore be carefully implemented for optimal performance where technical proficiency is the goal (15).

The ability to maintain optimal speed and technique throughout movement is critical for development of motor abilities in a safe manner (15). Therefore, it has been suggested that in order to maintain performance and safely benefit from a skill-related practice session that follows a HIIE session, fatigue should be imposed only to certain point (6, 18). Indeed, research has shown that skills-related performance can be maintained if fatigue does not exceed 10% of maximal power output (28). However, when there is greater fatigue (> 10%) a decline in mechanical performance has been observed (2). It is therefore recommended that fatigue should be equal to no more than 7-10% drop in performance (30) in order for athletes to achieve optimal agility improvements during training. However, controlling for power drop during conditioning sessions in field settings are problematic.

Since HIIE is a time efficient way to improve performance, team sports and coaches would benefit from utilizing it during in-season and off-season training, especially when time is limited and athletes are under high volume training. By improving our understanding of HIIE and recovery, HIIE could be combined with skill and agility training safe and effectively without compromising skill training or putting the athlete at risk for injuries. However, there is little research on how to successfully combine HIIE with agility training without compromising agility adaptations or performance during the remainder of practice. Therefore the purpose of this study is to investigate the fatiguing effects of HIIE on agility performance and if agility performance can be fully recovered following a short rest period. We hypothesized that HIIE will result in a decrease in agility performance, but agility performance will be recovered following a short rest period.

METHODS

Experimental Approach to the Problem

HIIE is known to cause fatigue which may negatively impact neuromuscular skills such as agility; yet it is an important component of a strength and conditioning program that places emphasis on agility training. We sought to investigate the effects of HIIE on agility measured by the time to complete the agility T-test and also to determine if performance can be recovered within a short period of time. College male and female soccer athletes performed the agility prior to HIIE and twice following the HIIE. HIIE was performed on a cycle ergometer and consisted of four sets of 4-sec sprints with 25-sec active recovery periods. The T test was performed immediately prior to HIIE (PRE), immediately following HIIE (POST 1) and two minutes after POST 1 (POST 2). Time to complete each T test was measured by one technician using video analyses. A repeated measures ANOVA and Bonferroni post hoc tests were used to determine differences between tests.

Subjects

Nine male soccer players (22 ± 2 yr, 80.0 ± 11.6 kg, 180.0 ± 7.8cm) and 10 female soccer players (20±2yr, 64.5 ± 4.6 kg, 166.0 ± 4.5cm) participated in the study. The majority (n = 16) were currently active in their post-season at the college level while the remaining previously had been competing at college level within the last five years. Criteria for inclusion included ≥3 years of competitive soccer experience, and no injuries or illnesses that had kept the athlete from competition the last three months. We asked that subjects refrain from exercise on the day of the tests and to avoid high intensity exercise within 24 hr prior to each test. Subjects were informed of the risks of the investigation prior to signing a consent form approved by the Barry University Institutional Review Board to participate in the study.

Procedures

The agility T-test, has shown high reliability (0.89) in male soccer players (20). For validity and reliability purposes, it is recommended that the agility test is practiced with maximal effort prior to test to avoid time improvements caused by taking the test multiple time (9). Thus, prior to the test day, each subject practiced the T-test in two separate training sessions in order to avoid any a learning effect during the study. On the day of the test, height and weight were measured. A standardized warm up on a Wingate cycle ergometer (Monark 874-E, Monark, Sweden) was performed for five minutes at 75 revolutions per minute (rpm) with a resistance of 0.5 kg. The seat was adjusted to a height so that the knee was in a 170 º extension in the down position. During the last 15sec of the 2nd, 3rd and 4th minute, the subject performed a maximal cycle sprint and returned to 75rpm once maximal rpm was reached. During this time, strong vocal encouragement was given to push the subject to achieve true max rpm. Following the cycle warm up, the subject performed a dynamic warm up in the gymnasium lead by a certified strength and conditioning specialist in order to prepare the major muscles associated with agility performance to avoid musculoskeletal injuries. Movement were performed both in a linear and lateral manner.

The T-test is a multi-directional movement test including forward and backwards running and lateral shuffling. Four 1-ft high cones was used and positioned as a T (Figure 1). The subject began with both feet behind the start line either in an athletic or staggered stance by point A and began the test volitionally by sprinting 10-yd forward to point B and touched the cone with the right hand. Subjects then shuffled to the left (5 yards) and touched cone C with left hand. Subject then shuffled to the right and (10 yards) touched cone D with left hand. Subject then ran backward, passing the finish. Performance error included crossing the feet, falling or failing to touch the cones, touch the cones with the right hand or failing to perform the test with correct rest time between. No verbal communication or encouragement was given during the T tests. All T tests were performed on a wooden floor. Prior to the cycle sprint protocol, each subject performed two T tests serving as the baseline (PRETEST 1 and PRETEST 2), separated by three minutes to ensure accurate recovery for reliability purposes. Each T test was recorded with a video camera. Each video was downloaded to a computer for subsequent analysis in Dartfish Prosuite software v4.0 (Dartfish, Atlanta, GA, USA). Frame-by-frame observation determined at what point the second foot lost contact with the ground behind the start line and at what point the first foot made contact with the ground on or over the finish line. The time between the two points was recorded as the time to complete the T test and was measured to 1/100th of a second, and analyzed by 1/30 frames. Additionally, each test was analyzed for errors (i.e., failing to touch a cone, crossing the feet). To further assess agility performance, we analyzed running variables during the T-test. The patterns and the times to perform that we looked at was right and left foot ground contact time (GC R and GC L), forward motion (LIN F), lateral motion (LAT) and backward motion (LIN B).

The sprint protocol was performed on the same cycle ergometer as the warm up with a resistance corresponding to 7.5% of the subject's body weight. The subject was instructed to accelerate to maximal rpm. Once a plateau in maximal rpm was observed, the weight was applied to the flywheel by the primary investigator. Each subject performed four 4-sec sprints, while seated throughout and attempting to keep rpm as high as possible. In between sprints, the subject actively recovered for 25 seconds at a self-selected pace with a 0.5kg load. At the end of the 25-sec recovery, the subject accelerated towards maximal rpm to begin the next sprint. Vocal encouragement was given during each sprint to keep the rpm as high as possible. Fatigue during the sprint protocol was determined through the difference between highest and lowest average power output achieved, expressed as a percentage. Once the final bike sprint was completed, subject was escorted to the gymnasium to perform the first agility test post-fatigue (POST 1) within 25 sec after the final sprint. After completion of POST 1, the subject was given two minutes of rest before performing the final test, POST 2.

Statistical Analyses

Data were analyzed with PASW statistics v21.0 (SPSS Inc, Chicago, IL, USA). A one-way ANOVA repeated measures was used to test for significant differences in the time to complete the T-tests, power drop and running variables. The Bonferonni post hoc test was applied when a significant difference was observed among the tests. The sprint protocol is the independent variable while time to complete the T-test (seconds) is the dependent variable for time. The sprint protocol is the independent variable while the time of the running variable assessed is the dependent variable. The cycle sprint number protocol is the independent variable while the power output (watts) is the dependent. To test the reliability of the T-test, mean differences in time to complete both PRE tests were tested using dependent student t-test and a Pearson Product Moment correlation coefficient was calculated. Data were expressed as mean ± standard deviation and significance was set at $p \leq 0.05$.

Results

The mean time for the two PRETESTS were 10.63 ± 73sec for PRETEST 1 and 10.4 ± .67sec for PRETEST 2. There was no significant difference between the means (p = 0.085). Since PRETEST 1 and 2 showed high correlation (n = 19, mean difference 0.18 ± .2 sec, r = .928). The test resulting in the best score (PRETEST) was used for analyses. In the cases where one test was performed incorrectly, the other test was used in the final analyses.

Average times during the T-test was 10.46 ± .74sec for PRETEST, 11,66 ± 1.47sec for POST 1 and 10.96 ± .81sec for POST 2. A significant difference in time to complete the agility T-test was found among the three tests (F (2, 54) 6.51, p = .003), see figure 2. Post hoc revealed that there was a significant difference between PRE and POST1 (p = .002), but no significant difference between PRE and POST2 (p = .473). The relative time difference between PRE and POST 1 (n = 19) was 11.7% and 4.8% between PRE and POST 2.

Out of the 19 subjects, only 10 (52%) completed all three tests without error. Out of the nine who had an error performing POST 1, one subject fell, two subjects stumbled, two didn't touch all cones, and two crossed their feet. Additional two subjects failed to complete the test at the right times. One due to technical difficulties with the cameras and the other one due to dizziness following the cycle protocol. Therefore, a separate analysis was performed included only those that did not commit an error. Mean time for the group (n = 10) was PRE 10.42 ±.75sec, POST 1 11.33 ±.89sec and POST 2 10.90 ±.70sec. A significant difference was seen (F (2, 27) = 3.369, p = .049) between tests. Post hoc showed that there was a significant difference between PRE and POST1 (p = .045), but not between PRE and POST 2 (p = .544). The 10 subjects performing POST 1 without any errors had a mean increase in time between the PRE and POST1 of 0.91sec ±.35 which is equal to an 8% increase in time. Meanwhile the remaining subjects (n = 9) who performed the test with error had a 15% increase in time from PRE to POST 1.

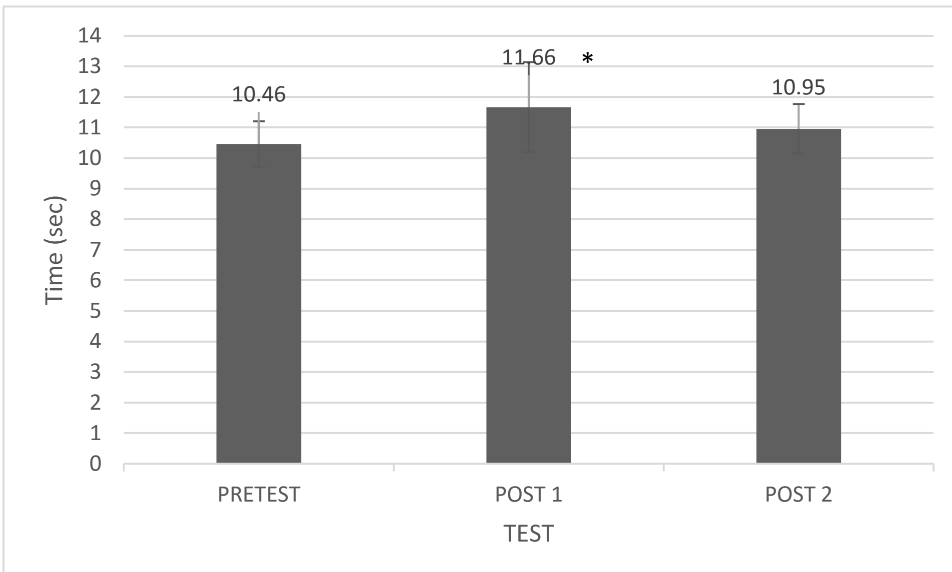

Figure 2. Significance * >.05 from PRE

The average power output was 624.61± 190.32 watts for sprint one, 531.03± 190.29 watts for sprint two, 470.71 ± 188.55 watts for sprint three, and 437.80 ± 154.08 watts for sprint four. The average power drop between sprint one and four was 30.20% with the greatest drop (16%) occurring between sprint one and two. There was a significant difference between tests, (F (3, 72) = 3.869, p = .013). Post hoc showed that there was a significant difference between sprint one and four (p = .013).

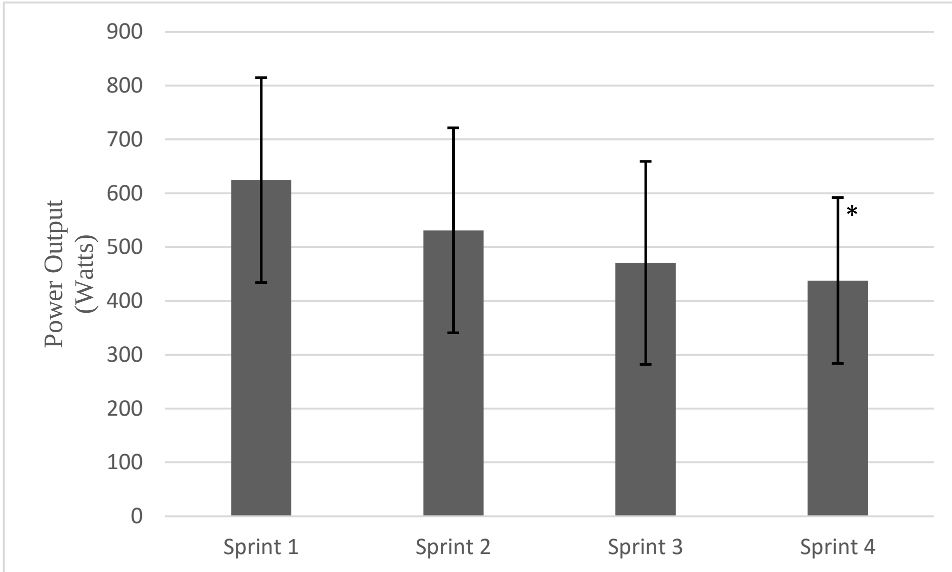

Figure 3. * Significance >.05 compared to Sprint 1

Analysis of running variables showed that there was no significant difference in GC L and GC R between the three tests. There was a significant difference between PRE and POST 1 in LIN F (F (2, 54) = 7, 275, *p* = .002), LAT (F (2, 54) 6.586, p = .003) and LIN B. (F (2, 54) = 6.008, p = 0.004), but no significant difference in any of the variables between PRE and POST 2 or POST 1 and POST 2.

DISCUSSION

The purpose of this study was to determine if a fatiguing bouts of HIIE cycling would affect planned agility performance, and if performance could be recovered following a short rest period. As we hypothesized, there was an acute decrease in agility performance following HIIE but performance was recovered within a few minutes.

How fatigue is defined can vary by the subjectivity of the investigator (2). Energy supply and depletion, muscle recruitment, biomechanical and psychological/motivational factors are all models used to explain fatigue (24).The main cause of fatigue depends on the activity performed (23). Variables to consider are intensity, duration, mode of activity, subjective characteristics, type of muscular contraction and muscle groups involved (26). These factors are commonly called task-dependency of muscular fatigue (23). These factors can lead to and be further classified as either central fatigue, meaning proximally located of the neuromuscular junction (NMJ), or peripheral fatigue meaning distally located to the NMJ (2). Fatigue during shorter duration activity such as repeated sprinting and the HIIE used in this study that rely heavily on ATP/PCr system for performance, and energy production is believed to be caused mainly by peripheral factors (2, 3). Peripheral fatigue is related to what occurs at the muscular level and will acutely affects the muscle's ability to produce and use ATP. Decrease in PCr and increase in hydrogen ions is believed to be the main contributor to fatigue during short duration HIIE (21). It has been suggested that lower levels of fatigue (<10% measured through decrease in EMG signals amplitude and power) mainly are caused by peripheral factors, whereas a greater level of fatigue (>10%) is a combination of central and peripheral fatigue variables.

The HIIE cycle sprint protocol used in this study was designed based on the average sprint duration (2-4sec) and repetitions (3-7) observed among field sports (34) and has previously been used for sport-specific purposes to simulate, assess and improve repeated sprint ability (9, 21, 34). This lead us to believe that 4 s sprints should be sufficient to cause local fatigue following cycle sprints, and influence agility performance. As bike sprints is not a modality commonly used as a conditioning method among field sports, it needs to be practiced for reliability purposes. McGawley et al. (21) examined the reliability of fatigue by having female athletes perform 5 x 6sec bike sprints on a wind-braked front access, cycle ergometer, separated by 24sec active recovery on five separate occasions. The highest power drop was 20% and investigators found that two familiarization sessions was sufficient for reliability purposes. Another study measured fatigue during ten 6-sec sprints on an air-braked cycle ergometer, separated by 30-sec passive recovery periods resulted in a 27.2% drop in total work among young males (22). This result was similar to the drop in average peak power output in our study of 30.7 ± 9%, with no difference between genders (males 29.71%, females 30.19%).

The acute effects of fatigue such as muscular stiffness, swelling (4, 29) accumulation of metabolic by-products such as hydrogen ions, inorganic phosphate (Pi), AMP, ADP and IMP (11) altered levels of intracellular $Ca2^{+}$ (25) are factors that impairs muscular force production. Bogdanis et al. (3) looked at alterations in PCr levels caused by cycle sprints. After 30sec PCr had decreased to 19.7 ± 1.2% of resting levels following. After 1.5 minutes of passive rest, PCr levels had recovered to 65.0 ± 2.8% and the subjects were able to achieve a power output equal to 80% of initial power output. That shows the importance of PCr availability to reproduce power output. Additionally, low pH levels caused by accumulation of byproducts have shown to decrease glycolytic enzyme activity, which in turn result in a decline in ATP production and impairs performance (2).

Performance can also be impaired as there is a connection between energy required and alteration in biomechanics. Less efficient movements will increase the energy cost of the activity. Research done on triathletes transitioning from cycling to running showed that the kinematic alterations such as increase in forward leaning posture increased the energy cost of running. This could further increase internal hip rotation which has shown to decrease in step length and cadence (13). The increase in energy cost when switching from biking to running among triathletes varies from 1.6% to 11.6% and the type of biking performed prior to transition plays a big role (23).

Biomechanical alterations among soccer players was seen as Cortes et al. (6) looked at alterations in reactive agility performing. They performed two trials, one with sufficient recovery between trials and one without rest between trials. They found that the athletes decreased their ability to utilize the stretch shortening cycle (SCC) and were forced to maintain a more erect posture when performing decelerating actions. Change of direction movements rely on the eccentric contraction of the hamstring, therefore decreased hamstring strength through fatiguing exercise is one of the main factors for reduced ability to utilize SSC (12, 37) and has an immediate impact on agility performance. Any fatigue-causing alterations in SSC function will decrease power output and negatively affect performance since maintaining power output is vital for agility performance (37). Therefor as a result of fatigue, our data showed that there was a significant increase in agility time between PRE and POST1.

Our data show a significant decline in agility performance immediately following HIIE. Additionally, almost half of the participants (48%) in this study were unable to perform the POST 1 agility test without any error following the cycle protocol. The types of errors such as failing to touch the cone, falling or stumbling or crossing the feet could be a result of decreased proprioceptive function and lack of motor control. Accumulation of by products in the muscle can decrease balance through decreased proprioceptive function (26, 36). Altered proprioceptive function will decreased sensory feedback from the proprioceptors of the peripheral system to the central nervous system. This means that it will be harder for CNS to accurately process and interpret these signals resulting in impaired joint stability (12) and reduced dynamic balance (40).

Turner et al. (35) states that the higher frequency of ACL and other knee related injuries among women is correlated to their reduced neuromuscular control compared to males'. In our study, the subject who fell or stumbled (n = 3) were women while the majority of the males performing errors either failed to touch the cones or cross their legs (n = 4). There was no difference in the average power drop among genders (males 29.71%, females 30.19%), however the subjects who performed POST 1 with error had a slightly higher power drop (33.26%) than average value, and so did the 3 females who fell or stumbled (34.04%). Since there is not a great difference between the percentage power drops, it is likely that something else can affect the results. Strength and power has shown to be better predictors for agility performance among women than men (32) while balance is said to be a predictor in trained adult males (31). It is possible that females therefor are relying more on strength for agility performance and will have to produce a higher relative contraction to maintain performance. This increases level of peripheral fatigue, muscular and joint stiffness and further explains the greater reduction in proprioceptive function.

Following 2 minutes of recovery it was evident that agility performance was recovered judging from lack of significant difference between PRE and POST 2. Thus, two minutes of recovery was sufficient to recover from the HIIE cycle sprint protocol used in this study. The speed of acute recovery will depend somewhat on the type of athlete measured. Aerobically-trained athletes recover PCr levels 40% faster than untrained or anaerobically trained athletes due to a greater amount of slow twitch fiber, greater mitochondrial density and superior buffering capacity (28). Due to the demands of a 90 minute game, soccer players are suggested to be aerobically developed as this will result in greater distance covered during games and superior performance (35). However, the characteristic of the soccer player will vary depending on position and style of play. It is therefore possible that this aspect can have affected our result as the majority of the participants in our study were midfielders (n = 8).

Studies investigating time to recover have used durations similar to our study. It has been shown that most of PCr restoration, which is vital for anaerobic performance, occurs in the first few minutes in untrained subjects (3). After passive rest following a 30-sec cycle sprint test, PCr levels reached 19.7 ± 1.2% of baseline value but initially increased rapidly to 65.0 ± 2.8% following 1.5min. After the initial increase, restoration of PCr slowed down only to reach 85.5±3.5% after 6 minutes. It takes more than 13 minutes to fully recover depleted PCr (3) it is not possible that the subject in our study were able to fully restore PCr. However, since the T-test is fairly short in duration, it is possible that there is a correlation between restoration required to maintain performance and duration following fatigue. Research by Behm et al. (1) has shown that maximal voluntary contraction can be reproduced in as little as 30 seconds after fatiguing exercise regardless of exercise duration. In their study, moderately active to active participants went through knee extension protocols to fatigue as either short (4min 17sec) or long duration (19min 30sec). Even though there was a greater initial decrease in muscle action potential and muscle voluntary contraction following long duration exercise, all subjects were able to reproduce MVC following 30-sec of rest. Additionally, the "flush model" has been explained as being an energy reservoir that serves as a constant security reserve for muscular recruitment at the highest level of peripheral fatigue (7). This security reserve can combined with increased motivational factors recover acute performance. Relating to sports performance Rampinini et al. (28) saw a decline in sprinting ability (30 and 40yd) by 3% after a soccer game among professional soccer players. They attributed the change in sprint time towards central fatigue judging by an 11% decrease in maximal voluntary contraction. However, they did not see a corresponding decrease in short-passing ability where performance does not rely on maximal continuous muscular contraction.

When looking at the different running variables, significant difference was seen in all variable between PRE and POST 1 besides ground contact time. Movement with multiple changes of direction such as LAT in this study, relies on multiple eccentric muscle actions which are greater at higher velocities and inhibited by fatigue. Since there is a linear relationship between eccentric hamstring strength and its ability to produce power, the speed of the movement during acceleration will be negatively affected (17). Additionally, placing ones feet laterally as a pivot point, stability will be disrupted as ankles and knees has limited lateral flexibility and ability to rotate which increases the demands of balance to compensate for lack of stability (31).

Greater power outputs are generally associated with the greatest power drop. Compared to shuffling and backpedaling, linear motion is a movement that all athletes are likely to be familiar with and therefor able to exert themselves to their max which produces a high power output which possibly is followed by a higher power drop. Additionally, Ferraz et al. (7) attributed change in kicking velocity following fatigue to change in linear approach speed.

Possible reasons for the acute difference in LIN B can be increased reliance on proprioceptive muscle qualities and balance when running backwards as one cannot see distance or terrain. The fact that it recovered within as short time could both have to do physiological recovery and increased motivation due to awareness of being close to finish (7).

Compared to the findings by Young et al. (37) the result in our study did not show an increase in ground contact time following fatigue. Increase in ground contact time is associated with impaired SSC. Byrne et al. (4) analyzed studies looking at vertical change of direction an stated that ground contact time increases due to decreased strength, reflex activity (CNS ability to process the proprioceptive information) and stiffness. This results in decrease efficiency in change of direction movements (37). Perhaps changes in ground contact time have a higher correlation with central fatigue and the body's ability to react to stimulus and therefore be evident if HIIE used was longer in duration or agility was reactive rather than planned.

As mentioned previously, a decrease in power output with less than 10 % in MVC EMG amplitude is considered mild fatigue where neural activation can be maintained while greater fatigue (>10%) would impair mechanical performance (2). Ruscello et al. (30) states that the target movement (T-test in our case) needs to be kept between 7-10% in order to maintain performance without mechanical alterations. Relating to our study, the nine subjects performing POST 1 tests with error had an increase in their agility time with 15% compared to the other group who increased their time with 8%. It could be claimed that the subjects who had a time difference of 15% (>7-10%) were to fatigued to get any benefits out of performing skill-related drills as their mechanical performance was impaired judging by performance error. When broken down by gender, the time increase was greater among females (16%) than among males (6.49%). The percentage time increase among women was less (8.83%) when only analyzing participants performing the test without errors.

Practical Application

We conclude that planned agility drills safely and beneficially can be performed within two minutes of fatigue-inducing HIIT cycle protocol. Suggested research on the topic is addressing potential differences between HIIT protocols and modalities and unplanned agility and skills.

Since research has shown a correlation between agility performance and athletic level, maintaining agility performance throughout competition is vital for successful performance. Implementing desired fatigue to stimulate a game-like environment in practice can assist in raising the threshold for fatigue and decrease in agility performance during competition. Determination of fatigue's acute effect on agility performance and how to recover from it is an important step in learning how to combine HIIT with skill-related performance. This will allow correct application of fatigue-induced training, further challenging the athlete without risk of injuries and creating bad habits by avoiding improper technique.

Enabling incorporation of a short cycle sprint protocol as a strength and conditioning method could be beneficial to soccer players even though it's not sport specific since the physiological benefits are well supported. Bike sprints would bring a variety to their training by putting a different muscular demand on the athletes. A variety of training is needed for producing well-rounded neuromuscular adaptations.

Finally, coaches should be encouraged to implement HIIT into their conditioning routines, especially during seasons when practice times are limited and athletes already experience high volume through training. There needs to be awareness that fatigue induced training requires sufficient recovery periods that will vary according to the demands of the agility drill as an open and competitive environment will require greater effort than closed environment.

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APPENDIX B. RESEARCH WITH HUMAN PARTICIPANTS PROTOCOL FORM

Barry University

Research with Human Participants Protocol Form

PROJECT INFORMATION

1. **The effect of fatigue on acute agility performance**

2. **Principal Investigator** (please type or print)

Student Number or Faculty Number:1849782
Name: Sofia Jakobsson
School – Department: Exercise Physiology, Human performance and leisure science
Mailing Address: Apt 412, 2200 Diana Drive, Hallandale Beach 33009 FL
Telephone Number: (786)-797-8984
E-Mail Address: sjakobsson@barry.edu

NOTE: You ***WILL NOT*** *receive any notification regarding the status of your proposal unless accurate and complete contact information is provided at the time the proposal is submitted.*

3. **Faculty Sponsor** (If Applicable)

Name: Dr Constance Mier
School – Department:
Mailing Address:
Telephone Number:
E-Mail Address:

Faculty Sponsor Signature:________________________________ Date: _____________

4. **Is an IRB Member on your Dissertation Committee? Yes _____ No: ________**

5. **Funding Agency or Research Sponsor**

6. **Proposed Project Dates**
Start: February 5th, 2016
End: February5th,2017

Note: It is appropriate to begin your research project (i.e., the data collection process) only *after* you have been granted approval by this board. Proposals that list starting dates occurring before the date of submission will be returned without review. Please allow time for approval when determining your start date. It is best if the end date you choose is one year after the start date.

Please Provide the Information Requested Below

A. Project activity STATUS is: (Check one of the following three as appropriate.)

___ **NEW PROJECT**
___ **PERIODIC REVIEW ON CONTINUING PROJECT**
___ **PROCEDURAL REVISION TO PREVIOUSLY APPROVED PROJECT**
(Please indicate in the **PROTOCOL** section the way in which the project has been revised.

B. This project involves the use of an **INVESTIGATIONAL NEW DRUG (IND) OR AN APPROVED DRUG FOR AN UNAPPROVED USE** in or on human participants.
___ YES ___ NO
Drug name, IND number and company:
____

C. This project involves the use of an **INVESTIGATIONAL MEDICAL DEVICE (IMD)** or an **APPROVED MEDICAL DEVICE FOR AN UNAPPROVED USE.**
___ YES ___ NO

D. This project involves the use of **RADIATION** or **RADIOISOTOPES** in or on human participants.
___ YES _X_ NO

E. This project involves the use of Barry University students as participants. (If any students are minors, please indicate this as well.)
X_YES Barry Students will be participants (Will minors be included? ___ YES X __NO)
___ NO Barry Students will participate

F. **HUMAN PARTICIPANTS** from the following population(s) would be involved in this study:

___ Minors (under age 18)
___ Abortuses
___ Prisoners
___ Mentally Disabled
___ Other institutionalized persons (specify)
___ Other (specify) Student Athletes
___ Fetuses
___ Pregnant Women
___ Mentally Retarded

G. Total Number of Participants to be Studied: 40

Description of Project

1. **Abstract** (200 words or less)

This study seeks to investigate in how fatigue effects agility performance, and if a decline in agility performance can be recovered through a short rest period. This study intends to recruit participants from the Barry University male and female soccer team. On the test day, before starting the exercise protocol, the participants will performed a timed T-Test to assess agility performance. The exercise protocol that followed consisted of four 4-sec maximal sprints with 25sec of recovery between each sprint on a cycle ergometer. After the fourth bike sprints, subjects completed three additional timed T-test. The first T-Test was performed 25-sec after the last bike sprint, and the second T-test was performed 2 minutes after the first T-Test, and the final T-test was performed 2 minutes after the seconds T-test.

2. Recruitment Procedures

Describe the selection of participants and methods of recruitment, including recruitment letter if applicable. (**NOTE**: If the investigator has access to participants by virtue of his or her position within the study setting, please provide a brief description of such access.)

Participants will be recruited from Barry University mens' and womens' soccer teams. Members of a sport team will be approached through the cooperation of the team coach. First, the coach will be asked if the study investigator can meet with the athletes briefly to present the study and ask for participants. This will be during one of the team's training sessions in the weight room where the team coach would not be present. Athletes that are interested in participating may provide their name and email address for contact.

Inclusion criteria

3. Methods

Describe procedures to which humans will be subjected. Include a description of deceptive techniques, if used, and debriefing procedures to be used on completion of the study. Use additional pages, if necessary.

For familiarity purpose participants will undergo two training sessions with the intention of practicing the agility test used prior to the test day. The T-Test is a multi-directional and multi-movement test commonly used to assess agility performance. It involves forward backward and sideways movements and takes around 10-sec to complete depending on the level of the participant. (APPENDIX of T-test)
On the test day, the participant will begin with a warm-up on a cycle ergometer with the intention of preparing the body through warming the muscles and avoid injury. The subject will be asked to perform three sprints during warm up bike protocol. Following the warm up, the participant will be given the chance to perform any additional warm-up if desired before performing two timed T-Test, separated by two minutes of active recovery. The best time will serve as the base line. Following completion of the T-test,

instructions will be given for the repeated bike sprint protocol. Participant will accelerate to maximal sprinting speed and manually add weight to the flywheel (7.5% of body weight) by pressing a button on the handlebar. Once the weight is released, the 6-sec time starts. Each subject will perform 4x6-sec sprints with 25-sec active rest in between sprints. Once the fourth sprint is completed, participant will have 25-sec to get to the gymnasium next door where a third timed T-Test will be performed. Following the second T-Test, participants will be given an additional two minute rest before performing the T-Test the fourth and final time.

4. **Alternative Procedures**

Describe alternatives available to participants. One alternative may be for the individual to withhold participation.

Participation will be strictly voluntary and subjects may decline to participate at any stage of the protocol. Participants are free to stop and/or withdraw from the testing at any time. Should they choose not to participate or withdraw completely from the study, there will be no adverse effects on them

Other than choosing to not participate, there are no alternative procedures.

5. **Benefits**

Describe benefits to the individual and/or society.

Participation in this study will have no direct benefits to the participant.

6. **Risks**

Describe risks to the participant and precautions that will be taken to minimize them. Include physical, psychological, and social risks.

The risks of involvement in this study are minimal, including only the moderate discomfort felt during high intensity intermittent exercise. All participants are athletes that experience this type of exercise on a regular basis and are at a relatively high level of fitness that allows quick recovery and avoidance of muscle soreness that can follow this type of exercise. We will ask participants to avoid participation if they have a musculoskeletal injury or another condition that will increase the risk of unusual pain and discomfort during the test.

The risks are minimized by a standardized bike warm up followed by a dynamic movement preparation lead by a certified strength and conditioning specialist.

7. **Anonymity/Confidentiality**

Describe methods to be used to ensure the confidentiality of data obtained.

At the end of the test, the camera video will be transferred from the camera to the lab computer and faculty supervisor’s office computer. The video will be erased from the camera once successful transfer to the computers has been made. From the computer, the time to complete the agility test will be determined using the Dartfish software program. Once the data are recorded, the video will be erased from both computers.

The information obtained during this experiment is confidential. Only the primary investigator and faculty supervisor will have access to the information. The signed consent form will be kept separate from the data in a locked cabinet in the faculty supervisor's office. Data sheets will be coded and will not contain participant's name or any other identifying characteristics, such as a phone number or email address. Data sheets will be scanned and kept electronically on the faculty supervisor's computer hard drive. Once scanned and transferred to the hard drive, all paper data will be destroyed. Paper data sheets will be kept in the PI's office during the study and destroyed at the end of the study. The information will not be released to any person not associated with the study. The data will be presented in research reports and presentations as group averages, without any other form of identity being disclosed. All data will be kept indefinitely after the completion of the study.

Password protected computer
Each participant will be assigned a number (e.g., participant #1) which corresponds to their consent form. Only the principle investigator will have access to the assigned numbers linking participants consent forms and their data.All data will be maintained for a minimum of five years after completion of study.
Hard copies will be typed up and then the hard copies will be destroyed.

8. **Consent**

Attach a copy of the consent form(s) to be signed by the participant and/or any statements to be read to the participant or informational letter to be directed to the participant. **(A copy of the consent form should be offered to each participant.)** If this is an anonymous study, attach a cover letter in place of a consent form.

9. Certification

I certify that the protocol and method of obtaining informed consent as approved by the Institutional Review Board (IRB) will be followed during the period covered by this research project. Any future changes will be submitted to IRB review and approval prior to implementation. I will prepare a summary of the project results annually, to include identification of adverse effects occurring to human participants in this study. I have consulted with faculty/administrators of any department or program which is to be the subject of research.

________________________________ ____________________

Principal Investigator *Date*

***Reminder*: Be sure to submit sixteen (16) individually collated and bound (i.e. stapled or paper clipped) copies of this form with your application.**

*NOTE: Your proposal **WILL NOT** be reviewed until the completed packet is received in its entirety.*

APPENDIX C. CONSENT FORM

Approved by Barry University IRB :

Date : 1/27/2014

Signature :

Barry University
Informed Consent Form

Your participation in a research project is requested. The title of the study is the effect of fatigue on agility performance. The research is being conducted by Sofia Jakobsson, a student in the human performance and leisure science department at Barry University, and is seeking information that will be useful in the field of exercise physiology and performance. The aims of the research are to see how agility performance is affected by fatigue and if it can be recovered following a short recovery. We anticipate the number of participants to be 40.

If you decide to participate in this research, you should be aware that there are no direct benefits to you for participating in this study, your performance will be recorded with a video camera and you will be asked to meet with the investigator on three separate occasions for a total time of 60 minutes, approximately 20 minutes for each meeting. The first two sessions will be to practice the agility test used in the study, and the third meeting is to perform the test which includes four agility tests (T-test) and one cycle sprint test. Following a warm-up, two T-tests are performed followed by a cycle sprint test (four 4-sec sprints with 25-sec recovery in between). Two additional T-tests are performed following the cycle sprint.

The agility T-test involves typical movements encountered during a soccer game (running forward, sideways, and backwards). The diagram below illustrates the layout of the test. You will be asked to perform the test as fast as possible.

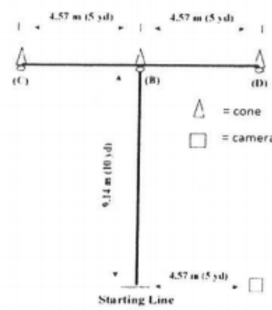


Figure 1. Layout of the T-test.

The cycle sprint test is performed with a weight that is approximately 7.5% of your body weight applied to the flywheel. You will be asked to pedal as fast as possible while the weight is applied to the wheel for 4 seconds. Following the 4 seconds, the weight is removed while you recover for 25 seconds. The sprint is repeated three times.

Your consent to be a research participant is strictly voluntary and should you decline to participate or should you choose to drop out at any time during the study, there will be no adverse effects on your athletic performance.

The risks of involvement in this study are minimal and include effects of fatigue during maximal intensity activity such as muscle soreness or weakness, dizziness, nausea and falling while running. The following procedures will be used to minimize these risks: standardized bike warm up, dynamic warm up lead by certified strength and conditioning professionals, and constant communication of feeling of fatigue.

As a research participant, the information obtained during this experiment is confidential. Only the primary investigator and faculty supervisor will have access to the information. The signed consent form will be kept separate from the data in a locked cabinet in the faculty supervisor's office. Data sheets will be coded and will not contain participant's name or any other identifying characteristics information you provide will be held in confidence to the extent permitted by law. Any published results of the research will refer to group averages only and no names will be used in the study. Data will be kept in a locked file in the researcher's office.

The agility test will be recorded with a camera. The video will be transferred from the camera to a password protected computer in the lab and faculty supervisor's office computer. The video will be erased from the camera once successful transfer to the computers has been made. Once data are analyzed, the videos will be deleted from the computers. All data will be retained indefinitely.

If you have any questions or concerns regarding the study or your participation in the study, you may contact me, Sofia Jakobsson sjakobsson@barry.edu at (786) 797-8984, my supervisor, Dr. Constance Mier cmier@barry.edu at (954) 899-3573, or the Institutional Review Board point of contact, Barbara Cook, bcook@barry.edu at (305) 899-3020. If you are satisfied with the information provided and are willing to participate in this research, please signify your consent by signing this consent form.

Voluntary Consent

I acknowledge that I have been informed of the nature and purposes of this experiment by Sofia Jakobsson and that I have read and understand the information presented above, and that I have received a copy of this form for my records. I give my voluntary consent to participate in this experiment.

____________________ __________

Signature of Participant *Date*

____________________ __________ ____________________

Researcher *Date* *Witness* *Date*

(Witness signature is required only if research involves pregnant women, children, other vulnerable populations, or if more than minimal risk is present.)

APPENDIX D. FIGURES

Figure 1. The Agility T-test

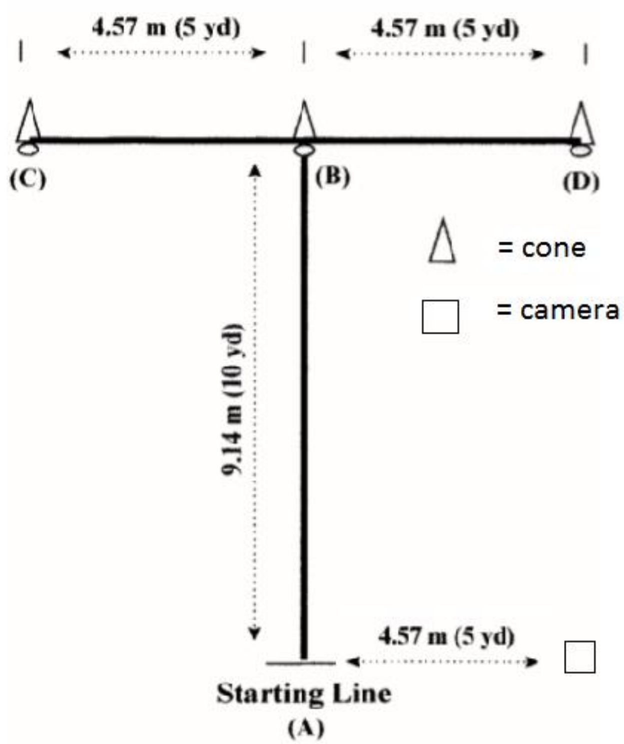


Figure 2. Time to complete the T-test before and after a fatiguing cycle sprint protocol.

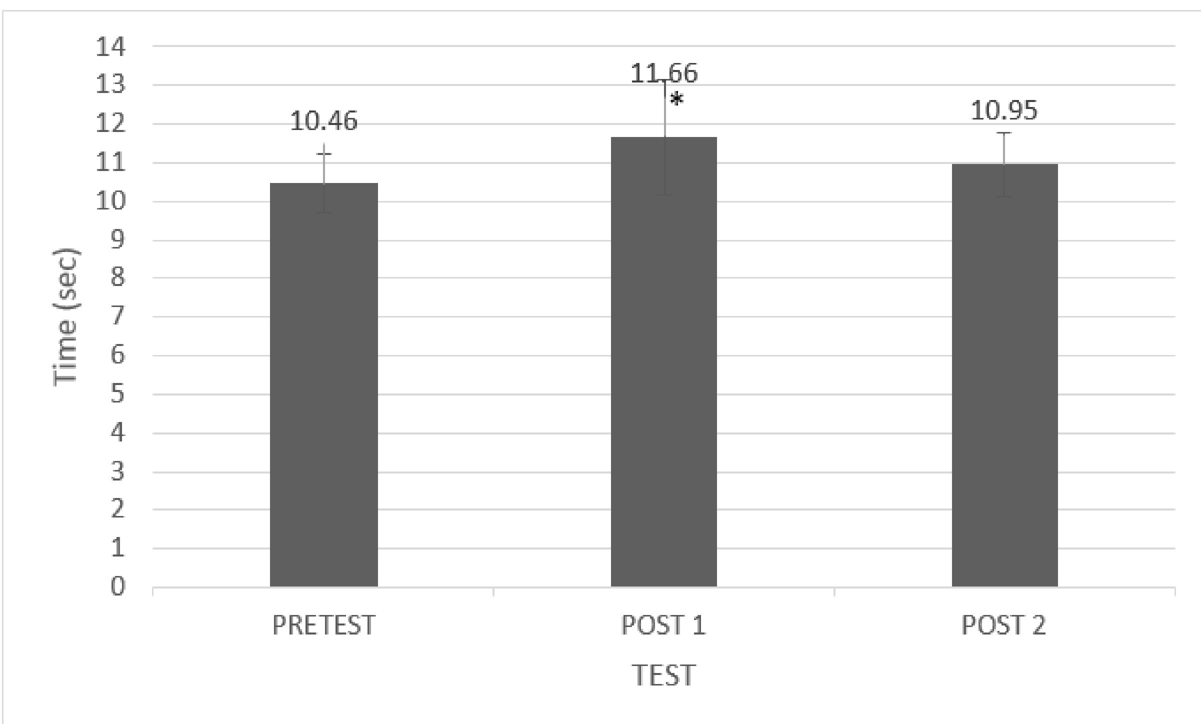
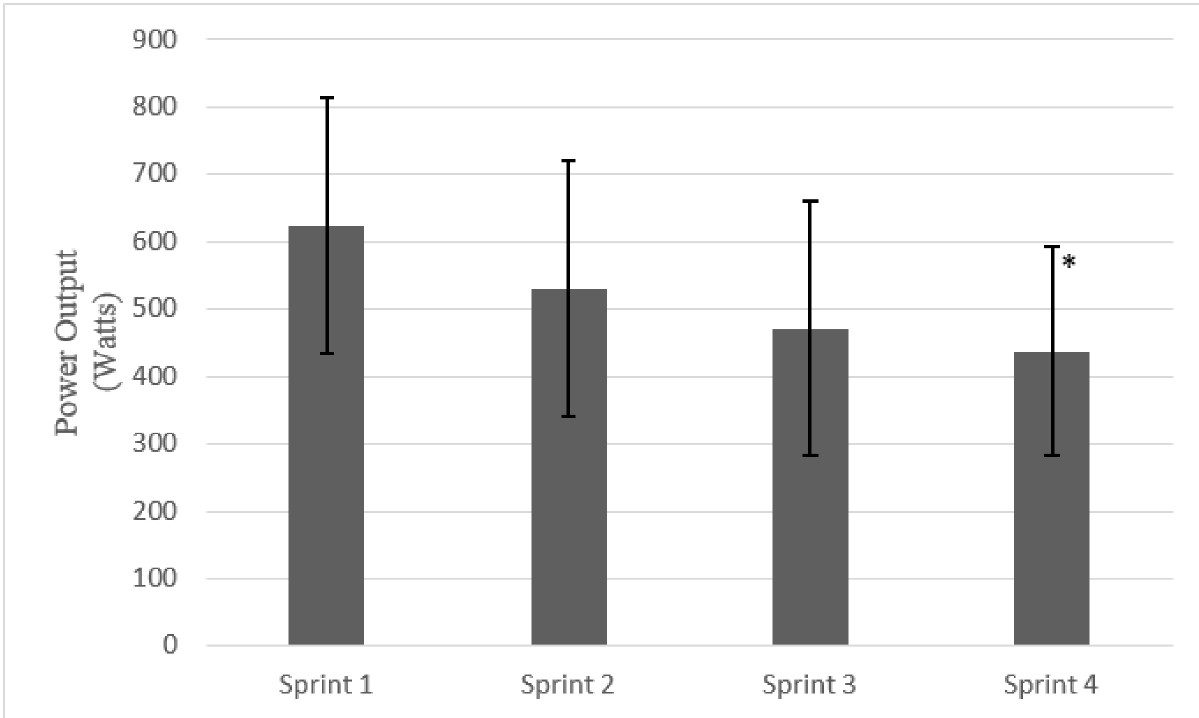


Figure 3. Power output achieved during a repeated cycle sprint protocol.



APPENDIX E. COLLECTED DATA

TIME TO COMPLETE THE T-TESTS

SUBJECT	PRETEST	POST1	POST 2
1	10.624	15.148	11.612
2	10.644	11.545	11.144
3	11.111	12.179	11.111
4	10.844	11.979	11.779
5	11.611	13.647	12.479
6	11.477	12.312	11.477
7	10.377	11.211	11.111
8	11.2	11.867	11.034
9	10.6	14.633	12
10	9.734	10.233	9.733
12	9.766	10.8	10
13	9.509	9.911	9.71
14	9.68	10.05	10.077
16	9.467	10.2	9.977
17	9.276	10.945	10.944
18	11.378	11.412	11.344
20	9.977	10.411	10.21
23	11.044	11.979	11.643
24	10.477	11.178	10.777

POWER-OUTPUT (WATTS) DURING FOUR 4-SEC CYCLE SPRINT PROTOCOL.

SUBJECT	Sprint 1	Sprint 2	Sprint 3	Sprint 4
1	484	350	265	286
2	458.73	348.78	316.91	274.72
3	485.08	440.99	373.11	385.95
4	538.13	433.17	396.91	384.11
5	418.14	317.7	260.27	345.43
6	416.96	438.79	397.28	388.01
7	524.99	416.97	345.43	361.51
8	496	422	358	318
9	349	252	200	196
10	629	566	475	392
12	838.28	651.97	654.81	560.37
13	682.42	559.09	556.66	489.18
14	682.97	556.67	453.42	379.34
16	1008.9	877.4	824.53	745.57
17	846.09	680.95	650	601.35
18	977	984.31	896.6	790.66
20	732.97	744.93	613.61	550.01
23	689.93	535.92	397	454.02
24	609	512	509	416

AVERAGE AND TOTAL POWER-DROP DURING A REPEATED SPRINT PROTCOL

PD 1 and 2	PD 2 and 3	PD 3 to 4	POWER drop %
28%	24%	-8%	40.91%
24%	9%	13%	40.11%
9%	15%	-3%	20.44%
20%	8%	3%	28.62%
24%	18%	-33%	17.39%
-5%	9%	2%	6.94%
21%	17%	-5%	31.14%
15%	15%	11%	35.89%
28%	21%	2%	43.84%
10%	16%	17%	37.68%
22%	0%	14%	33.15%
18%	0%	12%	28.32%
18%	19%	16%	44.46%
13%	6%	10%	26.10%
20%	5%	7%	28.93%
-1%	9%	12%	19.07%
-2%	18%	10%	24.96%
22%	26%	-14%	34.19%
16%	1%	18%	31.69%

RUNNING VARIABLES MEASURED DURING THE T-TEST

LEFT AND RIGHT GROUND CONTACT TIME

GC L PRE	GC L POST1	GC L POST 2	GC R PRE	GC R POST1	GC R POST2
0.6	0.633	0.667	0.5	0.6	0.533
0.4	0.433	0.433	0.333	0.3	0.266
0.5	0.5	0.433	0.5	0.467	0.534
0.367	0.533	0.5	0.534	0.5	0.433
0.433	0.533	0.33	0.433	0.466	0.5
0.466	0.643	0.6	0.533	0.433	0.466
0.366	0.433	0.366	0.366	0.566	0.3
0.4	0.6	0.567	0.467	0.5	0.433
0.6	0.5	0.6	0.467	0.9	0.566
0.367	0.367	0.333	0.3	0.367	0.367
0.336	0.433	0.4	0.467	0.4	0.4
0.367	0.401	0.367	0.367	0.434	0.334
0.367	0.4	0.366	0.4	0.5	0.367
0.4	0.534	0.467	0.444	0.5	0.367
0.366	0.366	0.334	0.333	0.4	0.433
0.566	0.534	0.733	0.5	0.5	0.433
0.466	0.5	0.4	0.433	0.533	0.434
0.466	0.397	0.433	0.533	0.5	0.533
0.5	0.666	0.467	0.467	0.467	0.534

LINEAR FORWARD, LATERAL AND LINEAR BACKWARD TIME

LIN F PRE	LIN F POST1	LIN F POST2	LATPRE	LAT POST1	LATPOST 2	LIN B PRE	LIN B POST1	LIN B POST2
1.769	1.978	2.02	6.133	9.8	6.7	2.612	3.364	2.925
1.904	2.015	1.905	5.927	6.633	6.138	2.527	2.897	2.839
1.733	2.148	1.875	6.234	6.767	6.5	2.534	3.264	2.735
1.836	2.012	1.978	6.166	6.834	6.633	2.93	3.133	3.168
2.144	2.584	2.106	6.832	7.8	7.5	2.634	3.196	2.839
1.94	2.115	1.836	6.233	7.501	6.366	3.037	3.43	3.009
1.838	2.014	2.046	6.066	6.533	6.4	2.436	2.767	2.698
1.833	1.967	1.867	6.201	6.8	6.367	3.033	3.1	2.8
1.833	2.667	2.066	6.067	8.2	6.834	2.667	3.766	3.1
1.667	1.8	1.7	5.433	5.933	5.633	2.333	2.5	2.4
1.733	1.867	1.766	5.367	5.6	5.7	2.467	2.833	2.534
1.638	1.911	1.796	5.367	5.6	5.597	2.504	2.5	2.514
1.585	1.682	1.908	5.4	5.967	5.834	2.35	2.568	2.335
1.534	1.633	1.667	6.466	5.967	5.666	1.8	2.6	2.267

1.743	1.841	1.911	5.267	6.3	6.2	2.183	2.804	2.86
1.6	1.767	1.933	6.167	6.533	6.467	3.1	3.067	2.9
1.7	1.914	1.914	5.599	5.9	5.7	2.576	2.597	2.596
1.824	2.195	2.134	5.066	6.367	6.4	2.996	3.351	3.1
1.639	1.815	1.845	5.767	6.566	6.233	2.591	2.729	1.845