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The Effects of Fatigue on the Reactive Agility Test: Looking at the Difference Between Normal Game Play and the Hurry-Up Offense in Football Game Simulations

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A thesis submitted in partial fulfillment of the requirements for the Master of Science degree in Kinesiology

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by

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Graduate Program in Kinesiology

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of the requirements for the degree of
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Abstract

Purpose: The purpose of this study was to assess the effects of fatigue on performance of the Reactive Agility Test (RAT) by University Football players. This test assesses the athlete's ability to change direction in response to a visual stimulus, somewhat like responding to the actions of an opponent in a game. Two fatiguing conditions were compared, simulations of normal game play and hurry-up offense in football. **Methods:** Following a warm-up and baseline RAT testing the athletes performed 10 high intensity, sprints on a specialized treadmill, with a 1:5 work to rest ratio to simulate regular game pace. This was followed by 10 repetitions of the RAT. The athletes repeated the interval sprints at a 1:2 work to rest to simulate a hurry-up offence and repeated the 10 repetitions of the RAT. The entire procedure was performed twice and data from the repeated trials averaged. **Results:** RAT time was significantly slower in the hurry-up condition (0.952sec$\pm$0.079) relative to the normal game play simulation (0.920sec$\pm$0.069, $p < 0.005$). Response time was also slower following the hurry-up fatigue protocol (0.094sec$\pm$0.078) relative to the normal game play simulation (0.062sec$\pm$0.063, $p < 0.005$). Power output during the interval treadmill sprinting declined in both conditions, but the hurry-up pace (1232watts$\pm$436.03) induced a significantly greater loss in power relative to the normal pace (1492.40watts$\pm$365.44, $p < 0.005$). Power output percentage significantly declined with hurry-up pace (78.4%$\pm$12%) relative to the normal pace (66.3%$\pm$8.6%, $p < 0.005$). **Conclusion:** The accelerated pace of the hurry up offense significantly slowed overall performance in the RAT and also the athlete's response time. This suggests that university football players should train using work to rest ratios appropriate to the pace of game play.

Keywords

American Football, Canadian Football, Change-of-direction, Power output, Sprints, HiTrainer, Conditioning

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Abbreviations

CODS – Change-of-direction speed

CFL – Canadian Football League

NFL – National Football League

RAT – Reactive Agility Test

Definitions

Agility – "a rapid whole body change in direction or speed in response to a stimulus" (Sheppard, Young, Doyle, Sheppard & Newton, 2006)

Anticipation – the expectation of a stimulus prior to the stimulus.

Change-of-direction speed (CODS) – "Ability to change initial direction to a predetermined location and space on the field or court" (Nimphius, 2014).

CODS baseline value – Four, pre-planned change-in-direction sprints (two left and two right) were performed to gather a baseline measure for the RAT. The four trials were averaged together to get one CODS baseline value to subtract from the RAT time.

Closed loop skills – Pre-programmed, predictable movements in a stable environment (Ives, 2014)

Fatigue – "the point where you can no longer maintain a given output of force" (Dupont)

Fatigue index – Calculated for the first and last sprint of each condition on the HiTrainer using the following formula:

> Fatigue Index = [(Highest 5second anaerobic power – Lowest 5second anaerobic power) / Highest 5second anaerobic power)] x 100.

Foot speed – quick and efficient movements of the feet.

Movement time – "the amount of time to actually produce a movement" (Vickers, 2007)

Open loop skills – Unpredictable and athletes need to adapt and change their movements and decisions continuously as game conditions change (Ives, 2014)

Peak power – "ideally measured in the first five-second interval of the Wingate test. It is measured in watts." (Sports Fitness Advisor)

Perceptual skill – “Ability of an athlete to interpret and react to a stimulus, such as an opponent, and be able to make at least one change-of-direction.” (Farrow, Young, & Bruce, 2005)

Power – Mechanical work performed per unit of time (Pincivero & Bompa, 1997)

Pro Agility (5-10-5) Test – The test "starts with the athlete in a crouched position, in between two cones which are 10-yards apart. From the crouched position, the athlete explodes to the right and touches the line with his right hand, he explodes out of this cut and sprints 10 yards, touching the line with his left hand, and then explodes back through the middle cone. After a short break the test is the repeated, but starts by going to the left first.” (Robertson, 2014)

Reaction time – “the amount of time to prepare a movement” (Vickers, 2007)

Reactive agility – “The term planned agility denotes the fact that participants are aware of the exact movement pattern required before the start of a test. This allows the distinction with a more recent definition of agility as a whole-body movement with a change of velocity or direction in response to a stimulus. This latter definition has been termed reactive agility, reflecting the requirement for participants to change direction in response to a given stimulus mid-test.” (Oliver & Meyers, 2009)

Reactive Agility Test (RAT) Time – Calculated from the moment the athlete broke the first beam to the time when the athlete correctly decided which gate, left or right, to run through. The computer recorded the trial number, direction of sprint (left or right) and the athletes’ 2-yard and 7-yard time. No calculation was needed to determine the value.

Response time (RT) – Response time included anticipation, reaction time and movement time, all of which could be affected by fatigue. The athlete’s response time was calculated using the RAT time and subtracting the CODS baseline value.

RT = (Reactive agility test time – CODS baseline value)

Speed – “Capacity to travel or move quickly from one point to another” (Pincivero & Bompa, 1997)

Three-cone drill – “Is a test performed by American football athletes at the NFL combine. It is primarily run to evaluate the agility, quickness and fluidity of movement of players by scouts, particularly for the NFL draft but also for collegiate recruiting. While not as highly regarded a test as the 40-yard dash, it is still an important barometer used by NFL personnel to compare players. Three cones are placed five yards apart from each other forming a right angle. The athlete starts with one hand down on the ground and runs to the middle cone and touches it. The athlete then reverses direction back to the starting cone and touches it. The athlete reverses direction again but this time runs around the outside of the middle cone on the way to the far cone running around it in figure eight fashion on his way back around the outside of the middle cone and finally finishing back at the starting cone. Athletes are timed for this whole procedure.” (Wikipedia, 2015)

Visual scanning – “Ability to process visual information in a competitive game.” (Young, James, & Montgomery, 2002)

Work-to-Rest Ratio – “Interval training is always expressed as a work-rest ratio. A classic example is the good old “sprint a lamp post / walk a lamp post.” If the sprint took 10 seconds and the walk took you 30 seconds, this would be expressed as a 1:3 ratio.” (Fitness First, 2014). The Canadian football game clock is 20 seconds, and game play generally lasts roughly 5 seconds … the normal game play simulation in this study had a 1:5 (25 seconds rest) and the hurry-up had a 1:2 (10 seconds rest)

Chapter 1

1 Introduction

Both open and closed loop skills are important in sport performance. Closed loop skills are pre-programmed, predictable movements performed in a stable environment, while open loop skills are unpredictable and athletes must adapt and change their movements and decisions continuously as game conditions change (Ives, 2014). Agility or the ability to change body position quickly and efficiently is a major component of both open and closed loop skills. In sport, however, it is often considered in the context of an open loop skill. Sheppard, Young, Doyle, Sheppard & Newton (2006) defined agility as "a rapid whole body change in direction or speed in response to a stimulus". Agility is "beneficial to attackers to evade their opponent's pressure or tackles and for defenders to reduce space on the field or court to limit attacking movements, or potentially achieve a turnover" (Young et al., 2015). Despite the importance of open loop skills in sports, the Canadian Football League and National Football League use the Pro Agility Test and three-cone drill (see appendix D), both closed loop skills as common standards for agility. The performance of these pre-programmed change-of-direction movements relies heavily on physical abilities such as strength, balance and speed; however, the cognitive or reactive component that is so valuable in an actual game situation is missing (Farrow, Young, & Bruce, 2005). An athlete may look great on paper but lack the necessary skills to react to their opponents in a game situation.

Only a select few studies have actually looked at using reactive agility, or the ability to change direction in response to a variable stimulus, as a reliable test of athletic performance. A study performed with Australian Rules football players showed that a reactive agility test (RAT) could distinguish the difference in skills between high and low-level performance athletes (Sheppard et al., 2006). Currently, no studies exist that investigated response time and fatigue in a true sport-specific setting. Decision time is the main factor in this differentiation in skill as shown in a study involving netball players reacting to an on-screen projection (Farrow et al., 2005). Decision time was determined by the "first definitive foot contact initiating the movement of the athlete in their final direction that they moved their body" (Farrow et al., 2005). In a study performed by Hüttermann and Memmert (2014), the relationship between exercise workload and activation levels indicated that an athlete's attention increased with higher levels of exercise intensity, however agility has been shown to decrease with fatigue (Mendez-Villanueva, Hamer & Bishop, 2008). Thus, the agility in sport is a complex interaction among physical condition, cognitive awareness and fatigue. A variety of terms will be used throughout the study including reaction time (the amount of time to prepare a movement), movement time (the total amount of time to actually produce a movement) (Vickers, 2007), and fatigue ("the point where you can no longer maintain a given output of force" (Dupont).

This study aims to examine the relationship between an athlete's response time and their fatigue levels in a sport-specific training task. We hypothesize that the response time of the athlete will increase, becoming slower as they become more fatigued. This study focuses specifically on collegiate football players. Normal football game play has a work-to-rest ratio of approximately 1:5 (five seconds of work to 25 seconds of rest) compared to hurry-up with a 1:2 (five seconds of work to 10 seconds of rest). Hurry-up offense (also referred to as no-huddle offense), is a strategy used by some teams to gain a competitive edge over their opponents. It can be run after each play by having the players line up in formation on the line of scrimmage immediately after the play is blown dead by the referee.

1.1 Purpose

In addition to speed and agility; anticipation, decision-making and quick reactions are important skills that football players need to maximize their performance on the field. The reactive agility test (RAT) is a combination of both physical (speed, agility) and cognitive (reaction, anticipation) skills. In this study, we looked at the affects of fatigue on football players' performance in the RAT by comparing two fatiguing conditions, one that simulates regular game pace and the other that mimics the hurry-up offense. The two conditions were compared to see if less rest in the hurry-up simulation would cause more fatigue and consequently slow the athlete's response time. We also looked at response time, or the difference between the RAT time and the time it took for the preplanned change of direction sprint. Fatigue was measured from the sprints and power data were collected on a motorized treadmill (HiTrainer). The results of the study will have implications on how to train football players in the future. For example, training methods that use work-to-rest ratios similar to those in game conditions, could delay fatigue and better preserve response time. This could provide better preparation to the athletes for the demand of the last quarter of a football game.

1.2 Research Hypothesis

The null hypothesis (Ho) states that there is no significant difference between the two groups. The alternative hypothesis (Ha) states that there is a difference between the groups.

Reactive Agility Test (RAT) time:

Ho: RAT time will remain constant across all trials in both conditions.

Ha: RAT time will increase (become slower) with fatigue. The higher work-to-rest (1:2) condition will induce more fatigue causing the movement time to slow.

Response time:

Ho: Response time will remain constant across all trials in both conditions.

Ha: Response time will increase (become slower) with fatigue. The higher work-to-rest (1:2) condition (simulating hurry-up) will induce more fatigue causing the response time to slow.

Fatigue:

Ho: Power output will remain constant across both trials on the HiTrainer.

Ha: Power output will decrease with fatigue. The higher work-to-rest (1:2) condition will induce more fatigue causing power output to decrease.

Chapter 2

2 Literature Review

There are two professional football leagues in North America, the Canadian Football League (CFL) in Canada and the National Football League (NFL) in the United States. These leagues use Canadian and American rules, respectively, that have evolved from a rugby-like game and that use many similar yet different approaches to the game. This paper will focus primarily on Canadian football but most studies involve NFL teams using American rules.

One of the biggest differences between the American and Canadian games is in the field of play. A Canadian field is 110 yards long, 65 yards wide and has two 20-yard end zones versus the American field that is 100 yards long, 53.5 yards wide and only has two 10-yard end zones. Further, the Canadian goalposts are located over the goal line whereas the American goalposts are on the end zone's farthest boundary line from the field of play, 10 yards behind the goal line.

Canadian teams have 12 players, while American teams use 11 players on the field per side. Both games have the same number of players required at the line of scrimmage, so the 12th player on a Canadian team plays a backfield position. The positions that require the most foot speed are linebackers (LBs), defensive backs (DBs), running backs (RBs) and receivers because they need to react to their opponents depending on the style of play.

2.1 Test Specificity

The NFL Combine consists of a series of tests performed over several days. The athletes participate in a 40-yard sprint, a 20-yard Pro Agility Test, a three-cone drill, bench press and both a vertical and broad jump. (MacLean). A figure of the Pro Agility Test, Reactive Agility Test and three-cone drill can be located in Appendix D. Testing is an important tool used by football coaches to compare, analyze and determine the extent to which their training protocols have a negative or positive effect on the players. Test specificity enables the coaches to focus on a particular trait and adapt the training as they see fit.

When running the Pro Agility Test, athletes perform preplanned movements. They learn how to perform the test precisely because they practice it. One of the benefits to the RAT is that it is open-skilled with unplanned change-of-direction. The downside is the use of generic cues because they may not be as effective a way to study athletes. Perceptual expertise is linked to increased visual search rates, specific search cues, and accuracy of domain specific responses (Sheppard et al., 2006). An athlete has no chance to anticipate the direction or timing of the appearance of a generic cue (Sheppard et al., 2006). In their respective sports, if the athletes are reacting to an opponent, they are able to recognize and attend to different cues earlier whether it is the opponent's torso position or foot placement (Sheppard et al., 2006).

2.1.1 Change-of-Direction

Change-of-direction is a movement without an immediate reaction to a stimulus; the direction or movement the athlete is performing is preplanned. Coaches pay particular attention to the battery of change-of-direction tests (5-10-5, three-cone) that are performed at the CFL and NFL Combine. In many sports, an athlete does not have enough time to achieve full acceleration before they have to decelerate to react and change direction to match their opponent. The improved ability to rapidly change direction will allow extra time for the athlete to react to their opponent.

In *High Performance Training for Sport* (2014), Sophia Nimphius assembled a table (see Table 1) breaking down the tests into three different categories. Change-of-direction speed requires one or two high or low velocity changes. Maneuverability requires three or more rounder versus sharp changes-of-directions. Reactive agility requires a response to a stimulus.

Table 1 Sample Tests for CODS and Agility

<table>
<tr><th>Change-Of-Direction Speed (CODS) Tests</th><th>Maneuverability</th><th>Reactive Agility Test (RAT)</th></tr>
<tr><td rowspan="2">Traditional 5-0-5 (high velocity)</td><td>t-test</td><td rowspan="2">RAT in response to an arrow or light</td></tr>
<tr><td>Illinois agility test</td></tr>
<tr><td rowspan="2">Modified 5-0-5 (low velocity)</td><td>L-run</td><td rowspan="2">RAT in response to a video</td></tr>
<tr><td rowspan="2">Three-cone agility test</td></tr>
<tr><td rowspan="2">Pro agility (low- and high-velocity)</td><td rowspan="2">RAT in response to a human stimulus</td></tr>
<tr><td rowspan="2">AFL agility test</td></tr>
<tr><td>10m shuttle (moderate- to high-velocity)</td><td></td></tr>
</table>

Gabbett, Kelly and Sheppard (2008) examined a variety of speed, change-of-direction and RATs that were used by coaches. They wanted to determine if there was a relationship between the variables and if the test could differentiate between athlete skill levels. The researchers determined there is a limitation in the L run, 5-10-5 and agility run test because they are/were based on preplanned movement patterns without a cognitive component. (Gabbett et al., 2008).

Young, James and Montgomery (2002) looked at the relationship between sprinting speed, leg strength and change-of-direction. 15 participants performed a drop jump, and 8m sprints with various changes in direction as well as leg concentric power. The time it took the athlete to complete the run increased as the number of directional changes increased and/as the angle became sharper (Yonge et al., 2002). This makes sense as the athlete would have to make adjustments. They determined the only significant relationship was between the drop jump and sprinting speed (Young et al., 2002).

2.1.2 Agility

Sheppard et al (2006) performed a study identifying the reliability and validity of a new test of agility that included a cognitive component. The athletes were divided into two groups (high performance and low performance) based on their level of play in the previous season to determine if the RAT would be able to differentiate between skill level (Sheppard et al. 2006). The athletes ran a 10m straight sprint, followed by an 8-9m drill for change-of-direction and reaction. The change-of-direction and reactive agility were set-up so it was similar distance covered and locations for changing direction. Within the RAT, there are four different possibilities that can occur; (1) step forward with right foot change-of-direction to left, (2) step forward with left foot change direction to right, (3) step forward with right, then left, and change direction to right, or (4) step forward with left, then right and change direction to the left (Sheppard et al. 2006). At the completion of 12 reaction trials, the mean of all trials to the left and right was used as the result. Sheppard et al. determined that the RAT was able to differentiate between athletes of varying skill level, while the sprint and CODS test were not.

In 2009, Young and Willey investigated the RAT by exploring the relationships between total time recorded and the different components that made it up including tester time, decision time (time taken for the athlete to respond to the stimulus) and response movement time (time taken for the athlete to change direction and sprint to the left or right). The athletes were required to react to the tester as the stimulus for changing direction. The greatest correlation was between the total time and decision time (Young & Willey, 2009). This study concluded that decision time had the most influential effect on performance; if the athlete could anticipate what the tester was going to do in the test, they were better able to react on the field (Young & Willey, 2009).

In 2001, Young, McDowell and Scarlett performed a study looking at the transference of sprint training to agility performance and vice versa. The tests consisted of a 30m straight sprint followed by six agility tests that included two to five various angles of changes in direction. As the agility task became more complex, the less speed training transferred. They determined speed training only affected speed. This study shows that the proper preparation of athletes requires the incorporation of both styles.

2.2 Fatigue and Response Time

2.2.1 Exercise

Since most studies found the relationship between exercise workload and attention as an inverted U curve, Huttermann and Memmert (2014) hypothesized that this was only true for non-athletes and disappeared for team athletes. 17 university students (nine with team sport experience and eight without) participated in the study looking at attention at three different exercise intensities. The results showed that non-athletes followed the inverted U curve, while athletes were better able to maintain their attention during physical exercise, especially under high intensities. (Huttermann & Memmert, 2014).

Junge et al. (2000) studied a group of 588 football players, with the following football-specific characteristics, including playing experience and positions played, style of play, number of training hours and games. It was their hypothesis that players of varying levels of ability might differ not only in their football skills but also in their way of playing football and with respect to psychological factors such as reaction time. The athletes' reaction time was tested twice - by having them press a button in response to a stimulus, first, without the influence of any physical exercise and second, immediately after a 12-minute run. Junge et al. (2000) observed a significant reduction in reaction time after physical exercise, i.e., after the 12-minute run, in players of all abilities; however, in high-level players, the reaction time immediately after the 12-minute run was significantly shorter than it was in low-level players.

2.2.2 Fatigue Calculations

Glaister et al. (2008) performed a study looking into the reliability and validity of multiple different ways of quantifying fatigue outcomes. The tests that the participants underwent were very similar to those performed in this study. The athletes performed two different 12 x 30m sprint trials with different recovery intervals, 35 seconds and 65 seconds. The best formula to calculate fatigue, as used in previous studies, is percentage decrement. (Glaister, Howatson, Pattison, & McInnes, 2008). In order to quantify fatigue relating to power output, the Fatigue Index formula was used.

Fatigue Index = [(Highest 5 second anaerobic power – Lowest 5 second anaerobic power)/Highest 5 second anaerobic power)] x 100.

2.2.3 Repeated Sprints and Power Output

Mendez-Villanueva, Hamer, & Bishop (2008) wanted to determine the relationship between maximum anaerobic, aerobic power, fatigability and the effects of neuromuscular activity during repeated-sprints. Athletes were asked to report to the laboratory for seven different sessions. During the last session they performed 10 x 6 second max sprints on a bike with 30 seconds recovery to determine peak and mean power output. A fatigue index was used to determine the percentage decline from the first to the last sprint (Mendez-Villaneuva et al., 2008). They hypothesized that athletes with a lower anaerobic power reserve would rely more on aerobic metabolism, developing less fatigue throughout the sprints (Mendez-Villaneuva et al., 2008). Peak power and mean power output decreased by 24.6% and mean 28.3%, respectively, over the course of the ten trials (Mendez-Villaneuva et al., 2008). This decrease was inversely related to the athlete's power output on the first sprint (Mendez-Villaneuva et al., 2008).

Gibala and McGee (2008) determined that six sessions of high intensity interval training (HIIT) over the course of two weeks (approximately 15 minutes total) could increase oxidative capacity in the muscles and endurance. This study could have a major implication as to how an athlete trains. In a study where they compared athletes either performing the HIIT protocol or 6 sessions of cycling (65% VO2max for 90-120 minutes), it was found that the HIIT protocol contained 90% less volume, but both attained similar adaptations to performance and muscle oxidative capacity (Gibala & McGee, 2008). In a similar study performed by Gibala and McGee (2008), athletes underwent a six-week training protocol, performing either four-six Wingate sprints with four and a half minutes' recovery for three days a week or 40-60 minutes at 65% VO2max of cycling for five days a week. There were no differences found amongst the groups in energy source utilization (Gibala & McGee, 2008). It is important for football players to train aerobically to aid in recovery. If athletes can become more efficient in training, this will improve their performance in sport and help aid in recovery without overtraining.

A study performed at McMaster University looked into muscle power and metabolic changes within the muscle. (McCartney, Spriet, Heigenhauser, Kowalchuk, Sutton, & Jones, 1986). Eight participants performed four 30-second all-out sprints on the bike followed by four minutes of recovery (McCartney et al., 1986). The authors determined that the highest peak power output and average power was produced in the first sprint, declined ~20% on the second sprint, declined another ~21% in the third sprint (~60% less peak power than first sprint) and maintained for the fourth sprint (McCartney et al., 1986).

2.3 Football

2.3.1 Game Play

A Canadian offense has only 20 seconds from the referee's whistle to initiate a play whereas an American offense has 45 seconds. Further, in Canadian football, a team has three downs to advance the ball ten yards, while in American football a team has four downs. With the NFL field being shorter and more compact, the players have more recovery time and need less stamina to perform. On the other hand, CFL players need greater skill and stamina to perform constantly under pressure.

Each team focuses their offense primarily on the run game, the pass game or a mix of the two. Chip Kelly, Head Coach of the Philadelphia Eagles of the NFL started a trend of speeding up practices. The purpose is to increase his player's stamina and decrease their recovery time to make faster plays on the field in a game situation. The practices are broken down into the different periods and have the players run multiple, high speed repetitions so that the second teams are given almost equal practice time to the first teams. Coach Kelly has said "You don't rise to the occasion; you sink to the level of your preparation." In order for the players to perform at high speed in a game, there is no better time to practice than at practice (Sheridan, 2014). There are many benefits to running a hurry-up offense style of play; however, there are a number of negatives as well. Table 2 found in the book *Coaching the No-Huddle Offense: By the Experts edited by Earl Browning* highlights the pros and cons of increasing the speed at which plays are made.

Table 2 Pros and Cons of a Hurry-Up Offense

Pros	Cons
• Drastically gain control of the game • Smaller package of plays • Can make other coaches do “uncharacteristic” things • Good vs. unconditioned or inexperienced teams • Good vs. better athletes (don’t like to think) • Can change the other teams’ tempo and approach	• Smaller package of plays • Mistakes are magnified • Often stresses out players and coaches • Be prepared to play defense!

Control of the game is the most important reason for utilizing a hurry-up offense. The tempo of the game does not have to be fast but the defense has to be prepared to react. This creates a sense of urgency in the defense, lack of strategy and opponents’ mistakes that forces them to use a time out.

2.3.2 Work-to-Rest Ratios

Rhea et al. (2006) wanted to create a sport-specific program that would mimic an actual football game. To do this, they analyzed 30 different American football games at each three levels of play (10 - high school, 10 - Division I college, and 10 - NFL) and collected data at each level based on length of play, rest time, series in a game and the number of stoppages per series. Work periods started at the snap of the ball and ended at the sound of a whistle calling the play dead while the rest time was the length of time between the sound of the whistle and the snap of the ball for the next play (MacLean). Examples of stoppages include penalties, timeouts, end of quarter or half, first-down measurements and injured players. The results at the Division I college level were that the average run and pass play took 5.13 ± 1.45 seconds and 5.96 ± 1.62 seconds, respectively, the average number of plays per drive was 6.26 ± 2.74 and rest time was 33.98 ± 4.19 seconds (no stoppages) (Rhea, Hunter, & Hunter, 2006). When comparing the work-to-rest ratios at the different levels of play, it was determined that the NFL had the longest work-to-rest ratio (1:6.2) followed by Division I colleges (1:6.1) and high school (1:5.5). These ratios are important for the athletes to adapt to in order to perform at maximum intensity in every play of the game.

In another study by Iosia & Bishop (2008), an analysis was completed of the work-to-rest ratios over the course of several televised NCAA Division I games, taking into account the style of play each team utilized whether it was running, passing or a combination of both. The average duration of play was 5.23 $\pm$ 1.7 seconds, and duration of rest was 46.9 $\pm$ 34 seconds (Iosia & Bishop, 2008). The time for the average duration of play is from when the snap of the ball to the end of the play because of an incomplete pass or a referee's whistle. Iosia and Bishop determined that run plays were statistically shorter in duration than pass plays but there was no difference in passing vs. combination. There were no significant differences found among styles of play and duration of rest between series (Iosia & Bishop, 2008).

Ferrauti, Pluim and Weber (2000) studied court sport athletes in order to identify the effect that recovery had on intermittent sprints, focusing on metabolism and coordination. The study consisted of 10 nationally ranked tennis players performing a passing shot-drill consisting of 30 strokes with two different rest times, subdivided by 6x5 sprints with a one minute recovery between series. They found that speed and stroke quality were dependent on recovery time (Ferrauti et al., 2000). The value of a coach understanding the appropriate work-to-rest ratios will aid the athlete in preparation for competition.

Chapter 3

3 Methodology

3.1 Participants

Twelve elite university and senior level athletes (mean$\pm$SD age 22 $\pm$ 2, height 71.5 inches $\pm$ 2.1 inches, weight 197.7 lbs $\pm$ 27.7 lbs) were recruited from Western University Football Team and the London Beefeaters. Specifically, linebackers, defensive backs, running backs, quarterbacks and receivers were recruited to participate in the study because of the high volume of sprinting they perform throughout a game. All of the participants in the study were injury free and had undergone prior strength and cardiovascular training. The cardiovascular training involved one hour of conditioning, twice a week instructed by Western University's Head Strength and Conditioning Coach. All subjects were volunteers and their participation in the study had no impact on their status on the team. The protocol was approved by The University of Western Ontario Research Ethics Board (Appendix A).

3.2 Facilities

TD Waterhouse Stadium encompasses a regulation CFL turf field and houses the Kirkley Mustang Training Center. The field was used to run the reactive agility test trials. The non-motorized treadmill (HiTrainer) used to simulate the game conditions and fatigue was located nearby in the Kirkley Training Center.

3.3 Instrumentation

3.3.1 Reactive Agility Testing Timing System

Zybek Sports (Boulder, Colorado) specifically created the R.A.T. Timing System to help athletes test and train repeatable, explosive movements. This system was utilized to test the athlete's reactive agility before and following the simulations of normal and hurry-up game play. It is composed of four timing gates, two set up at the start and 2-yard line and the other two separated by a light bar on the seven-yard line. Figure 1 is an illustration of the reactive agility testing procedure. Figure 2 shows the set-up of the R.A.T. Timing System on the field at TD Waterhouse Stadium. The athlete lined up with gate one at the start of the test. Once the athlete moved, they self-initatied the timing clock. The athlete sprinted from the first timing gate and once they had broken the beam at the 2-yard line, the light bar indicated which direction (left or right) the athlete should run. A computer randomly assigned the direction. The computer also records the athlete's initial two-yard burst time, and total movement time. There were two advantages to using the system for this study; a very quick and easy set-up allows the athletes to test at their convenience; and electronic timing eliminates potential errors from hand timing.

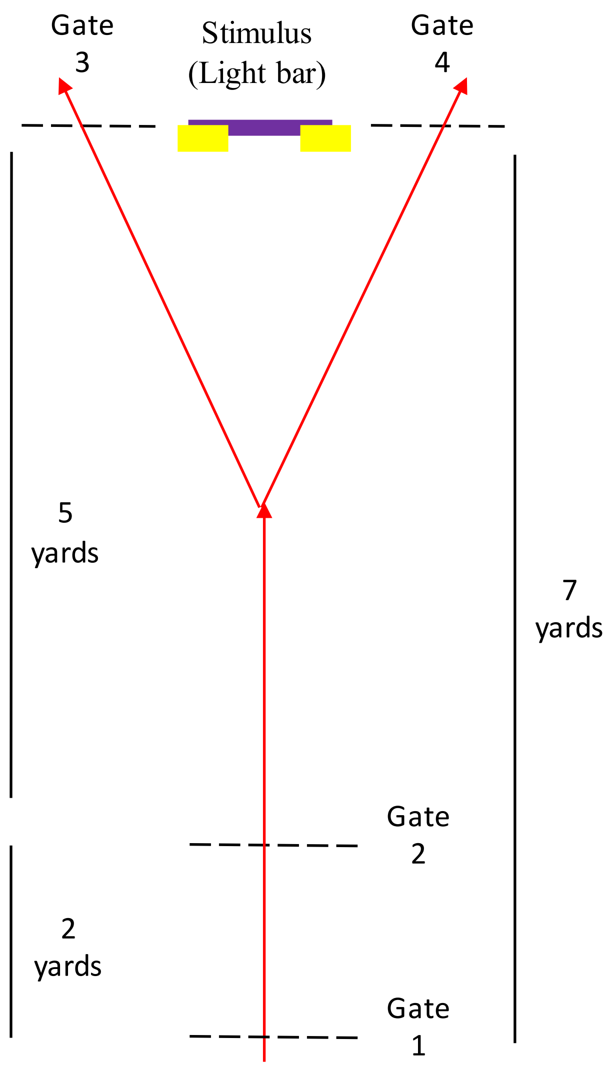


Figure 1 Visual representation of the RAT Timing System. The athlete starts the test at gate 1, runs through gate 2 triggering the light bar to provide a stimulus directing

the athlete to the left (gate 3) or right (gate 4). Gates 1 and 2 are 2 yards apart and the light bar is 5 yards away from gate 2.

Figure 2. Zybek RAT Timing System Set-Up on the field of TD Waterhouse Stadium.

3.3.2 HiTrainer Treadmill

The HiTrainer (Bromont, Canada) was used to fatigue the athletes and obtain their power output over the course of 10 intervals during the simulated game conditions. The device is a specialized, non-motorized treadmill designed primarily to decrease the amount of time athletes have to spend on cardiovascular training. It comes with preprogrammed high intensity training programs as well as the ability for the trainer to create their own protocol.

As shown in Figure 3, the HiTrainer has shoulder pads that hold the athlete in the acceleration position. This position is the safest for the athletes because they cannot over stride so it decreases the chance of injury. The HiTrainer displays and records real-time performance data including maximum speed, average speed, maximum power, average power and the differences between the left and right leg drive. It also allows you to review past performances. This feedback is important to evaluate how an individual athlete's training is progressing team, comparing different athletes, and modifying training protocols if there is a severe leg drive differentiation.

3(a) **3 (b)**

Figure 3a. (Left) is a front angle view of the athlete in correct acceleration position. Figure 3b. (Right) is a side profile looking at the athlete's acceleration position.

3.4 Procedure

Participants were required to come to TD Waterhouse Stadium for testing. The athletes needed to bring their cleats for running on the field and running shoes for the HiTrainer. Before any testing occurred, an experienced strength coach led a 10-minute dynamic warm-up with prescribed exercises (Appendix C) on the field. To obtain baseline measures for the RAT total movement time, four pre-planned change-in-direction sprints (two left and two right) were performed, followed by one-minute rest. To familiarize the athletes with the procedure, 10 reactive sprints (7.4 yards) were performed at 30-second intervals using the R.A.T. Timing System. The experimenter ensured the interval was properly maintained. The athlete had 3 minutes to change from their cleats into running shoes and re-locate to the HiTrainer on the second floor of the Kirkley Centre. On the HiTrainer, the athlete ran 10, five second sprints with a rest break of 25 seconds between each sprint. This took about five minutes and mimicked a normal style of game play that has about a 1:5 work to rest ratio. The athlete had three minutes to change shoes and return to the field where the RAT was repeated (10 reactive sprints on a 30-second interval). A 10-minute break was provided to the athlete for rest and water prior to repeating protocol again at a quicker interval. Following the break, 10 reactive sprints at a 15-second interval were performed on the RAT. The athlete had three minutes to change their shoes and re-locate to the HiTrainer. On the HiTrainer, the athlete ran 10, five second sprints with a rest break of 10 seconds. This took less than five minutes and mimicked a hurry-up style of offensive play that has a 1:2 work: rest ratio. 3 minutes later the athlete finally returned to the field where the RAT was repeated (10 reactive sprints, performed on at 15-second intervals). The actual sprints did not take long (about six minutes total), but they were intense. The total time for the entire study was one hour.

3.5 Reactive and Fatigue Measures

Reactive Agility Test Time. The reactive agility test time was calculated from the moment the athlete broke the first beam to the time when the athlete correctly decided which gate, left or right, to run through. The computer recorded the trial number, direction of sprint (left or right) and the athletes' 2-yard and 7-yard time. No calculation was needed to determine the value.

Change-Of-Direction. Four, pre-planned change-in-direction sprints (two left and two right) were performed to gather a baseline measure for the RAT. The four trials were averaged together to get one CODS baseline value to subtract from the RAT time.

Response Time. The athlete's response time was calculated using the RAT time and subtracting the CODS baseline value.

RT = (Reactive agility test time – CODS baseline value)

Power Output. Power Output values for the five seconds of the first and last sprint were directly recorded from the HiTrainer.

Fatigue Index. Fatigue index was calculated for the first and last sprint of each condition on the HiTrainer using the following formula:

Fatigue Index = [(Highest 5 second anaerobic power – Lowest 5 second anaerobic power)/Highest 5 second anaerobic power)] x 100.

3.6 Statistical Analyses

All statistical analyses were performed using the Statistical Package for Social Sciences. If the athlete selected the wrong gate to run through, as a result of fatigue and/or cognition error, descriptive statistics were calculated using the last observation carried forward.

Reactive Agility. A two-way ANOVA with repeated measures on both factors (condition x trial) was used to evaluate any between-condition and trial differences. Post hoc ANOVA and pairwise comparisons were used to detect which trials were significantly different.

Fatigue. Paired t-tests were used to determine the differences between the first and last trial of each condition, and fatigue index.

All results are reported in the text as group means $\pm$ standard deviations, and the level of significance was $p < 0.05$.

Chapter 4

4 Results

Four, pre-planned change-in-direction sprints (two left and two right) were performed to gather a CODS baseline measure for the RAT. There was no statistically significant difference between the left (0.863sec. ± 0.064) and the right (0.852sec. ± 0.064) CODS trials. The four trials were averaged together to get one CODS baseline (0.858sec. ± 0.058) value to subtract from the RAT time. Table 3 contains the descriptive statistics for the RAT Time and Response Time trials. The results are summarized below.

Table 3 RAT Time and Response Time.

	RAT Time		Response Time	
n = 24	Normal Condition	Hurry-Up Condition	Normal Condition	Hurry-Up Condition
Trial One	0.928±0.055	0.921 ± 0.062	0.070 ± 0.042	0.063 ± 0.064
Trial Two	0.937±0.064	0.933 ± 0.066	0.079 ± 0.061	0.075 ± 0.059
Trial Three	0.923±0.066	0.946 ± 0.079	0.066 ± 0.064	0.088 ± 0.084
Trial Four	0.933±0.068	0.952 ± 0.086	0.076 ± 0.055	0.094 ± 0.085
Trial Five	0.924±0.068	0.946 ± 0.080	0.066 ± 0.062	0.089 ± 0.069
Trial Six	0.909±0.083*	0.959±0.058*	0.051±0.058*	0.102±0.065*
Trial Seven	0.915±0.071*	0.968±0.087*	0.057±0.061*	0.110±0.079*
Trial Eight	0.903±0.08*	0.972±0.087*	0.045±0.078*	0.114±0.083*
Trial Nine	0.922±0.072*	0.968±0.095*	0.065±0.077*	0.110±0.102*
Trial Ten	0.907± 0.063*	0.955±0.083*	0.049±0.065*	0.097±0.076*

Values are mean ± standard deviation; *n* is the number of subjects. Times are displayed in seconds. Between condition differences * at the same time point following simple main effects and pairwise comparison respectively, are significant at $p < 0.05$.

4.1 Reactive Agility Test

4.1.1 RAT Time

The following tests were performed to ensure the five assumptions were met to perform the analysis. Movement time was normally distributed ($p > 0.05$) except for at the first two trials of the study ($p = 0.005$) and ($p = 0.008$), respectively, as assessed by Shapiro-Wilk's test of normality, and no outliers, as assessed no studentized residuals greater than ± 3 standard deviations. There was sphericity for the interaction term, as assessed by Mauchly's test of sphericity (p>0.05). There was a statistically significant interaction between condition and time on RAT time, $F\ (9,207) = 4.805$, $p < 0.001$. The main effect of condition showed a statistically significant difference in movement time between trials, $F\ (1, 23) = 13.336$, $p < 0.001$.

RAT time was not statistically different in trials one to five when the normal condition was compared to hurry-up. However, RAT time between the conditions was significant for trials six to ten. RAT time data is presented in Table 3 and Figure 4. Total movement time was statistically different in trial six in the normal condition (M = 0.909sec., SD = 0.08 sec.) compared to hurry-up condition (M=0.959 sec., SD = 0.058 sec.), $F\ (1,23) = 13.958$, $p< 0.001$, a difference of 0.051 sec., 95% CI [-0.079, -0.023]. Total movement time was statistically different in trial seven in the normal condition (M = 0.915 sec., SD = 0.071 sec.) compared to hurry-up condition (M=0.968 sec., SD = 0.087 sec.), $F\ (1,23) = 16.142$, $p< 0.001$, a difference of 0.053 sec., 95% CI [-0.081, -0.026]. Total movement time was statistically different in trial eight in the normal condition (M = 0.903 sec., SD = 0.083 sec.) compared to hurry-up condition (M=0.972 sec., SD = 0.087 sec.), $F\ (1,23) = 25.668$, $p< 0.001$, a difference of 0.069 sec., 95% CI [-0.098, -0.041]. Total movement time was statistically different in trial nine in the normal condition (M = 0.922 sec., SD = 0.072 sec.) compared to hurry-up condition (M=0.968 sec., SD = 0.095 sec.), $F\ (1,23) = 5.128$, $p< 0.05$, a difference of 0.045 sec., 95% CI [-0.087, -0.004]. Total movement time was statistically different in trial ten in the normal condition (M = 0.907 sec., SD = 0.063 sec.) compared to hurry-up condition (M=0.955 sec., SD = 0.083 sec.), $F\ (1,23) = 12.348$, $p< 0.05$, a difference of 0.048 sec., 95% CI [-0.075, -0.02].

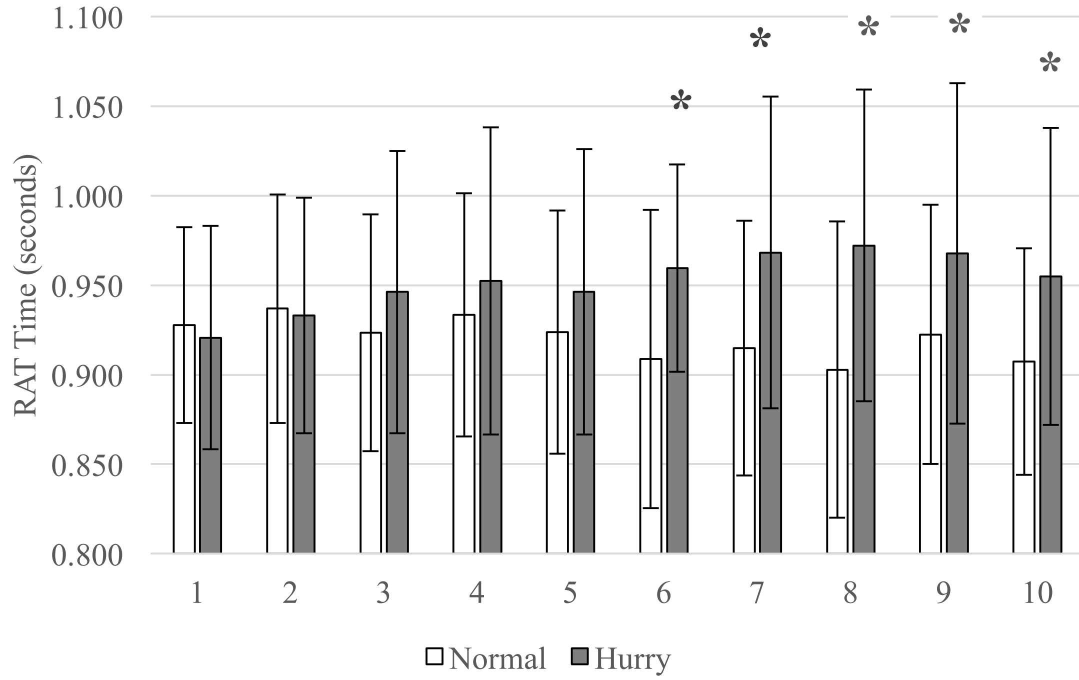


Figure 4 Reactive Agility Test Time across all 10 trials based on condition. Between condition differences * at the same time point following post hoc pairwise comparisons, respectively, are significant at *p* < 0.05.

4.1.2 Response Time

Response time was normally distributed ($p > 0.05$) except for the fifth trial in the hurry-up condition of the study ($p = 0.015$) respectively, as assessed by Shapiro-Wilk's test of normality, and no outliers, as assessed no studentized residuals greater than ± 3 standard deviations. There was sphericity for the interaction term, as assessed by Mauchly's test of sphericity (p>0.05). There was a statistically significant interaction between condition and response time, F (9,207) = 4.805, $p < 0.001$. The above tests were performed to ensure the five assumptions were met to perform the analysis. The main effect of treatment showed a statistically significant difference in movement time between trials, F (1, 23) = 13.336, $p < 0.001$. Therefore, simple main effects were run. Mean response time was not statistically different in trials one and five in the normal condition compared to hurry-up condition. However, response time was significantly different between the conditions for six to ten. Response time data is presented in Table 3 and Figure 5. Response time was statistically different in trial six in the normal condition (*M* = 0.909, *SD* = 0.083ms) compared to hurry-up condition (*M*=0.959, *SD* = 0.058ms), F (1,23) = 13.958, p= 0.001, a difference of 0.051ms, 95% CI [-0.079, -0.023]. Response time was statistically different in trial seven in the normal condition (*M* = 0.915, *SD* = 0.071ms) compared to hurry-up condition (*M*=0.968, *SD* = 0.087ms), F (1,23) = 16.142, p= 0.001, a difference of 0.053ms, 95% CI [-0.081, -0.026]. Response time was statistically different in trial eight in the normal condition (*M* = 0.903, *SD* = 0.083ms) compared to hurry-up condition (*M*=0.972, *SD* = 0.087ms), F (1,23) = 25.668, p= 0.0005, a difference of 0.069ms, 95% CI [-0.098, -0.041]. Response time was statistically different in trial nine in the normal condition (*M* = 0.922, *SD* = 0.072ms) compared to hurry-up condition (*M*=0.968, *SD* = 0.095ms), F (1,23) = 5.128, p= 0.033, a difference of 0.045ms, 95% CI [-0.087, -0.004]. Response time was statistically different in trial ten in the normal condition (*M* = 0.907, *SD* = 0.063ms) compared to hurry-up condition (*M*=0.955, *SD* = 0.083ms), F (1,23) = 12.348, p= 0.002, a difference of 0.048ms, 95% CI [-0.075, -0.02].

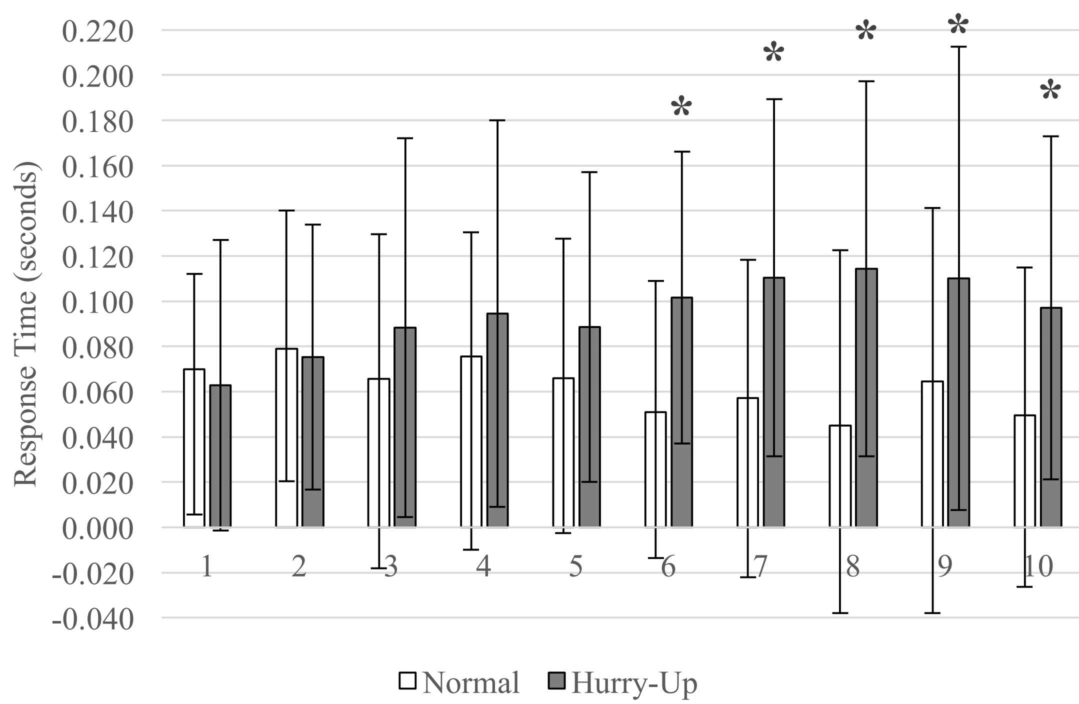
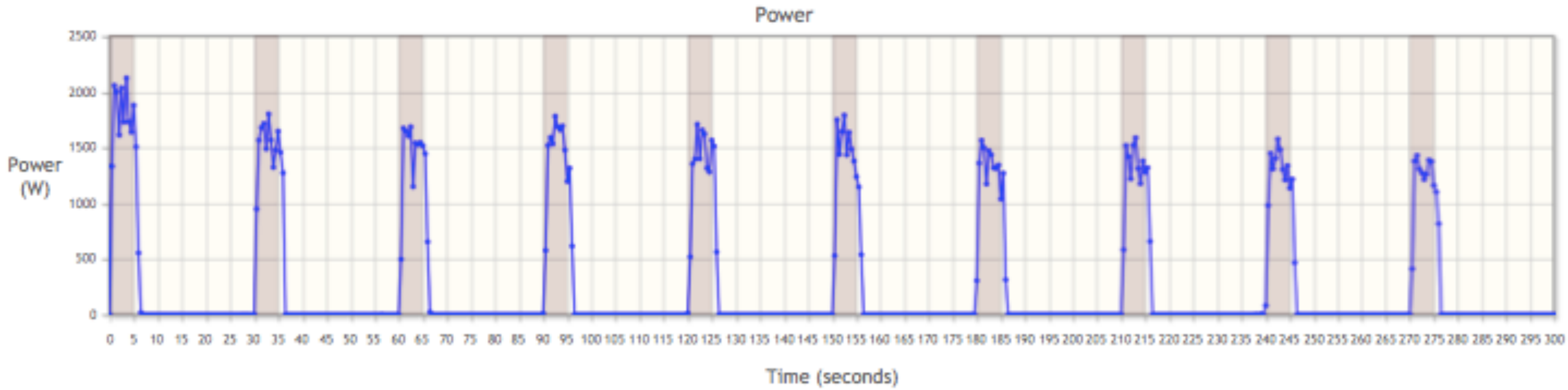


Figure 5 Reactive Agility Response Time across all 10 trials based on condition. Between condition differences * at the same time point following post hoc pairwise comparisons, respectively, are significant at *p* < 0.05.

4.2 Fatigue

Figure 7 is an illustration of one subjects Power Output taken from the HiTrainer. The power output declines in both conditions however it is more dramatic in the hurry-up condition (Figure 6b).

a)



b)

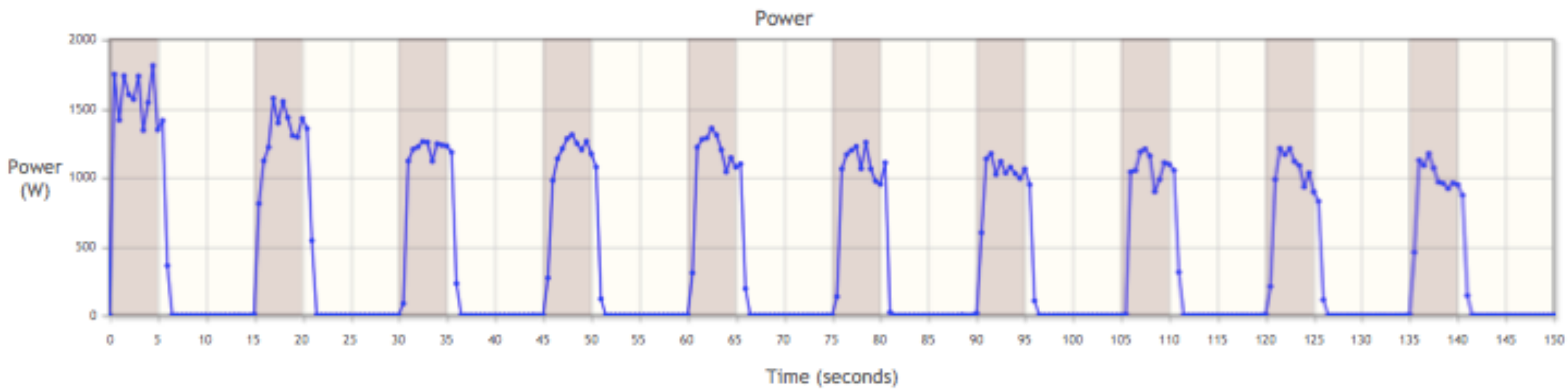


Figure 6 Example of the HiTrainer Power Output recordings illustrating the power decline across all 10 sprints. Figure 6a (Top) Normal (1:5) Condition. Figure 6b (Bottom) Hurry-Up (1:2) Condition. Power output in the first sprint is significantly higher than the last sprint in both conditions.

4.2.1 Power Output

Normal Condition. In the normal condition, the athletes produced a higher power output during the first sprint (M=1597 watts, SD= 328) as opposed to the last sprint (M=1387 watts, SD=373), a statistically significant mean decrease of 210 watts, 95% confidence interval [121, 299], t (54) = 4.736, $p < 0.001$, $d = 0.64$.

Hurry-Up Condition. In the hurry-up condition, the athletes produced a higher power output during the first sprint (M=1468 watts, SD= 394) as opposed to the last sprint (M=996 watts, SD=340), a statistically significant mean decrease of 471 watts, 95% confidence interval [365, 578], t (54) = 8.856, $p < 0.001$, $d = 0.64$.

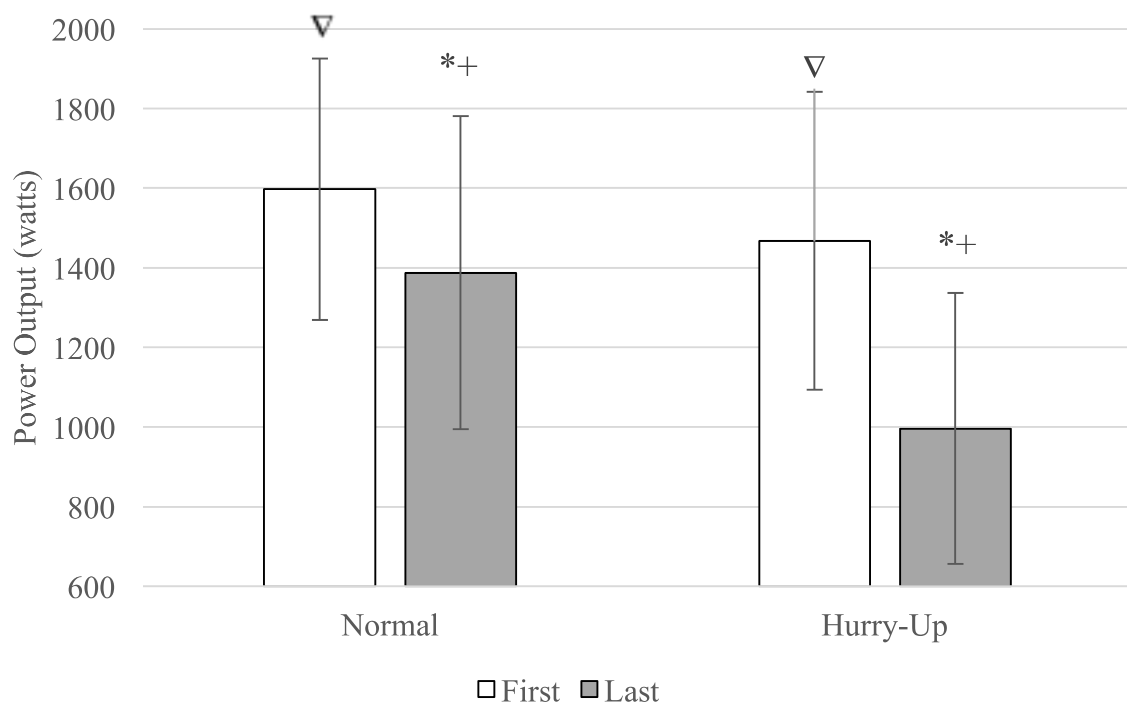


Figure 7 HiTrainer Power Output First and Last Sprint by Condition. * Last trial Power Output was significantly lower than the first trial in both conditions (p < 0.001). + Last trial Power Output was significantly lower in the hurry-up condition compared to the normal condition (p < 0.001). ∇ First trial Power Output was significantly lower in the hurry-up condition compared to the normal condition (p < 0.002).

4.2.2 Fatigue Index

The Fatigue Index. The athletes experienced a lower power output decline during the normal condition (M=66.3%, SD= 8.6%) as opposed to the hurry-up condition (M=78.4%, SD=12%), a statistically significant mean increase of 12 percent, 95% confidence interval [5, 19], t (10) = - 4.000, $p < 0.003$.

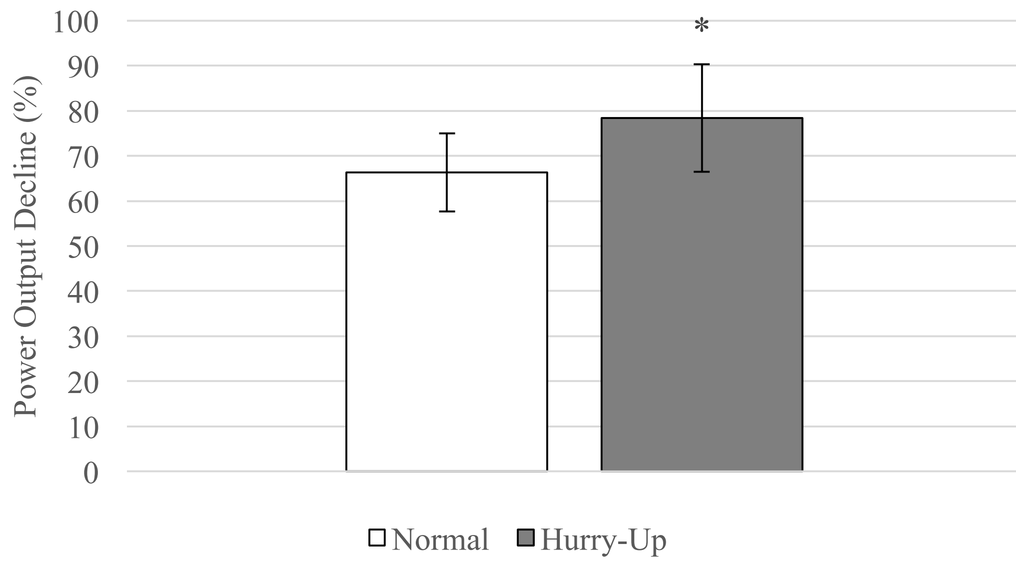


Figure 8: Fatigue Index. * Significant Power Output decline from normal condition to hurry-up condition (p < 0.003).

Chapter 5

5 Discussion

Anticipation, decision-making and quick responses are important skills that football players need to maximize their performance on the field. The dynamic warmup at the start of the study was designed to increase an athlete's mobility and heart rate, and to allow them time for mental preparation of the effort required. An athlete should never reach a "fresh, non-fatigued" state until after the study was complete. When a whistle signals the beginning of a football game/play, an athlete must be prepared for anything. If an offensive series is 10 plays long, the coach expects the athlete to have the same speed and response time regardless of whether it is the first, second or the tenth play. If the defense is playing strong and holds an opponent to a single series of downs, the offense needs to be fully prepared to take the field. The amount of rest that an athlete receives is dependent upon how much time they spend on the field of play. Nevertheless, an athlete will be in some sort of "fatigued" state throughout a game.

The purpose of this study was to observe how fatigue would affect a football player's performance on the RAT in two different game-like simulations. It was hypothesized that less rest in the hurry-up condition would cause more fatigue, slowing an athlete's total movement time and response time. To quantify fatigue, the athlete ran 10 trials with identical game-like work-to-rest ratios on the HiTrainer. It was hypothesized that decreasing levels of rest would result in greater decreases in power output.

5.1 Reactive Agility

5.1.1 RAT Time

Starting in a slight state of "fatigue", the continuous layering of trials was expected to have a negative impact on the following trial. In the normal condition simulation, the RAT trial took, on average, less than one second to run seven yards, allowing almost 24 seconds of recovery. The athlete's RAT time was consistent from trial one to five and then it decreased, speeding up at a faster rate from trial six to 10. Although there appeared to be some slight decrease in the normal condition in trials six to

10, it was not significant. The hurry-up condition did not have the same findings. The RAT time showed slight non-significant variations amongst all trials, decreasing on trial 10. Even though the RAT time to complete the trials was still on average less than a second, the shorter recovery period hindered the performance. This study found that even though both conditions followed different trends, the RAT time between trials six to ten was significant. A drop in 0.02 hundredths of a second in the normal condition compared to the addition of 0.05 hundredths of a second in the hurry-up condition can make a difference in the outcome of a game. This suggests that there is no physical advantage or greater fatigue effects if the drive is not prolonged (greater than five plays). The current study supports the hypothesis that less rest in the hurry-up condition causes more fatigue, slowing the athlete's total movement time.

These findings are similar to those found in previous studies. Young, McDowell and Scarlett (2001) investigated the transference of straight sprint training on agility performance and agility training on straight sprinting performance and concluded that there was no transference. This has important implications on an athlete's training regimen. An athlete may prepare with a lot of sprint training; however, if they cannot rapidly change direction or speed, they might be out-maneuvered by their opponent. The training that the athletes performed, prior to participating in this study, involved both agility and straight sprinting.

Sheppard, Young, Doyle, Sheppard & Newton (2006) were interested in identifying the reliability and validity of a new test of agility that incorporated a cognitive component. Set-up for the change-of-direction test and RAT was similar to this study. Sheppard et al. (2006) concluded reactive agility could differentiate between skill level while CODS and straight sprints could not. CODS and straight sprint tests are closed loop skills that can be trained, unlike the unpredictable, real-time sport situations.

Young & Willey (2009) were interested in evaluating a reactive agility test and the relationship between overall total time and the individual components of responding to an experimenter's movement time, decision time, and response movement time. This study was more realistic and specific to sport because it allowed an athlete to anticipate and react to the tester, as would be the case if they competed against an opponent on the field. Between all three variables, Young & Willey (2009) concluded that decision time had the strongest correlation to total time. Decision time in this study was measured from the time the tester planted his foot to change direction and the participant decided which direction the tester was going to move in. This study incorporated the anticipation and perceptual skill involved in sport.

5.1.2 Response Time

Multiple factors such as anticipation, reaction, previous fatigue may have had an influence on the difference between the RAT time and CODS baseline. The term response time encompasses all of these factors since they were not separated into the different components.

In the normal condition simulation, the athlete's response time stayed relatively consistent for trials one to five, and then decreased becoming quicker for trials six to eight, increasing becoming slower for nine and then decreasing again for trial ten. Since the athletes are used to receiving 25 seconds rest in a game situation, the response time was expected to stay relatively consistent. The hurry-up condition did not have the same findings. When rest time decreased to 10 seconds, response time in trial one increased becoming slower to trial eight then slightly decreased to trial ten. Over the course of the 10 trials, response time increased by 0.05 hundredths of a second. The current study supports the hypothesis that less rest in the hurry-up condition causes more fatigue, slowing the athlete's response time.

These findings are similar to those found in previous studies. Huttermann and Mermmett found that an athlete's attention increased with higher levels of exercise intensity. The speed-accuracy trade-off occurs when movement time increases as the accuracy of the response requirement increases. If the athlete is aware they are fatigued, they direct their focus to the accuracy of the task and movement time will increase. As shown in this study of 12 athletes, six made accuracy errors in the normal condition and none in the hurry-up condition; two made errors in the hurry-up condition; and four athletes ran all trials with no errors. These were not repeated but the results of the previous trial were carried forward. Both speed and accuracy were the goals for all trials.

In previous studies, the recovery time and exercise intensity played an important role on reaction time. This study agrees with results previously found by Junge et al. (2000) and Huttermann and Memmert (2014), in that reaction time decreased post-exercise. The difference between this study and Junge et al. is that the athletes performed roughly three minutes of maximum effort over the course of an hour, instead of a 12-minute run. This attempted to make the study more sport-specific by mimicking different game situations. Huttermann and Memmert found that even at high intensities of exercise, high-level athletes were able to maintain their reaction time whereas low-level athletes followed an inverted U curve. In this study, even though the athletes' response times differed across all ten trials, in the normal condition, response time actually decreased and improved by 0.02 hundredths of a second whereas, in the hurry-up condition it increased by 0.03 hundredths of a second. If a coach decides to run a hurry-up style offense, it is important for them to know if and when their player is fatigued so that they can call for a substitution. After five plays with little rest, a football player's response time appears to double.

5.2 Fatigue and Power Output

To quantify fatigue, the athlete ran 10 trials with game-like work-to-rest ratios on the HiTrainer. It was hypothesized that decreasing levels of rest would result in greater decreases in power output. Fatigue was calculated as the highest peak power output from the first five sprints and the lowest peak power output in the last five second sprints.

The Fatigue Index was used to quantify the drop in force performance. In the normal condition, the percent decline from sprint one to 10 was 66%. The hurry-up condition continued to decline by 12%. An overall 78% power reduction can provide insight on an athlete's recovery. If training for the appropriate work-to-rest ratios is performed, an athlete should be able to maintain their power output better.

In the normal condition, the athletes' power from the first sprint to the last sprint dropped a statistically significant amount of 210 watts; however, in the hurry-up condition, the athletes' power from the first sprint to the last sprint dropped a statistically significant amount of 471 watts.

These findings are similar to those found in previous studies. In the study performed by Mendez-Villaneuva, Hamer & Bishop (2008), peak power decreased by 24.6% and mean power output decreased by 28.3% over ten trials. In the RAT study, power output decreased by 66% in the normal condition and then 78% in the hurry-up condition. This greater decrease in power output may have to do with the multiple, repeated sprints. McCartney, Spriet, Heigenhauser, Kowalchuk, Sutton & Jones (1986) had their athletes perform a 30-second Wingate with four minutes of recovery and observed an approximate 60% power decline over four trials. This power output is similar to what was observed on the HiTrainer; however, the athletes only received 10 or 25 seconds recovery. The length of the sprint (30-seconds versus 5-seconds) may have an impact on how much power decline occurs. A 30-second Wingate is much different than a 5-second sprint. The RAT study utilized 5-second sprints based on the observations by Rhea et al (2006). Division I college level programs used an average run and pass play that took 5.13 ± 1.45 seconds and 5.96 ± 1.62 seconds, respectively, with an average number of plays per drive of 6.26 ± 2.74 and rest time of 33.98 ± 4.19 seconds (no stoppages) (Rhea, Hunter, & Hunter, 2006). When comparing the work-to-rest ratios at the different levels of play, it was determined that the NFL had the longest work-to-rest ratio (1:6.2) followed by Division I colleges (1:6.1) and then high school (1:5.5). These ratios are important for the athletes to adapt to in order to perform at maximum intensity throughout a game.

Control of the game is the most important reason for utilizing a hurry-up offense. The purpose of this study was to determine how fatigue affected a football player's performance in the RAT under the two different fatiguing conditions. Although there were no differences in the conditions until the sixth trial, it is important to consider the implications this may have in regards to the length of the drive. If an athlete is on the field for longer than five plays, their response time will start to decrease as well as their power output. By implementing the appropriate work-to-rest ratios for game play in practice and training sessions, coaches and trainers can effectively prepare players to outperform their opponents.

5.3 Limitations

Although this study found significance in the difference between response time, movement time and power output in the different conditions, it was not without limitations.

RAT Timing System.

Change of Direction Sprints. The RAT Timing System measured response time to an unknown stimulus. However, with a known stimulus, the path the athlete ran for CODS simulation may not have been identical to that in the RAT simulation. The athlete could have cheated and shortened the distance (ie. rounding corners) because they knew where they were going.

Reactive Agility. One of the limitations was the inability to record incorrect movement times. If the athlete ran through the wrong gate, the computer did not register the trial. These times would have helped to further identify the mean difference between the two conditions. The errors occurred in the final trials so total movement time may not have actually decreased to the same extent and response time may have increased more. Another limitation was the inability for the athlete to anticipate which direction they were supposed to run in. On the field during a game, the athlete is always observing their opponent for subtle cues that could give away or telegraph their movements. This decreased the sport-specificity. The final limitation was the inability to isolate the different perceptual components of the test (anticipation, reaction time, previous fatigue, etc.). There is the possibility that these variables may not be able to be separated because they may influence each other.

HiTrainer.

The biggest limitation with the HiTrainer was a glitch in the software for the first couple of athletes testing within both conditions. This meant that some of their sprints were cut short or missed completely. The glitch never affected the first or last trial. Once this was identified, the coach ensured that all sprints started and stopped on time. Both Zybek Sports and the HiTrainer Companies were helpful in identifying and correcting this problem as soon as it arose.

5.4 Significance of the Study

Determining the impact that fatigue has on response and RAT time will have a significant benefit to all those involved in sports. It can inform strength and conditioning coaches about modifications in training ratios that may be needed to properly prepare their athletes for game play.

The response time is important for the coach to know whether an athlete is fully prepared to play in the final part of a game. In the normal condition, response time actually decreased and later improved by 0.02 hundredths of a second whereas, in the hurry-up condition it increased by 0.03 hundredths of a second. An overall difference of 0.05 hundredths of a second is tremendously important in a sport like football, where yards and downs matter. This knowledge can help a coach make better decisions on who should be on the field and who needs more rest than would be the case if their information on response time is not as accurate. If an athlete is not adequately conditioned to the work-to-rest ratios needed in game play, they will not be able to perform at their best.

RAT time slowed by 0.05 hundredths of a second by trial eight in the hurry-up situation. This increase in time was statistically significant. If an athlete with this RAT time needed to make a play against an opponent that was better conditioned, their chances of success are much less likely.

5.5 Possible Directions for Future Studies

Future studies could examine the difference between left and right RAT time and compare it to the leg differentiation data from the HiTrainer. It would be interesting to see if an athlete's dominant leg on a treadmill was the same dominant leg they used in a game. For example, if an athlete is right leg dominant on a treadmill, will they change direction better to their left because the right leg is their plant leg.

An opponent gives off certain body cues that many athletes can recognize and use to their benefit. It would be interesting to design a study that is more sport-specific to an athlete, so instead of responding to a light bar, the athlete could instead respond to an opponent's movements.

A study designed to evaluate the conditioning of an athlete, pre- and post-offseason training would also be valuable to determine how much the different work-to-rest ratios impact their response time, RAT time and power output maintenance.

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Appendix A: Letter of Information and Consent

The Effects of Fatigue on Reaction Time: Looking at the Difference Between Normal Game Play and Hurry-Up Offense in Football Game Situations

Study Investigators

Dr. Greg D. Marsh	Associate Professor	Ph.D.
Kristine Walker	Graduate Student	B.A.

Introduction

You are being invited to participate in a research study comparing reaction time in a fatigued versus non-fatigued state.

Purpose of this Study

Reaction, anticipation and decision-making are important skills that football players need to fine-tune in order to improve their performance on the field. The CFL and NFL use the 5-10-5 and three-cone drill as a common standard for agility. The use of pre-programed change-of-direction movements can be trained but the cognitive component that is so valuable on the field is missing; an athlete may look great on paper but lack the necessary skills to react to their opponents. The RAT (RAT) is a combination of both physical and cognitive skills. Currently there are no studies that combine high-intensity interval sprinting with reactive agility. In this study, we want to correlate reaction time and fatigue by utilizing sport specific training methods to mimic the various types of work-to-rest ratios found in a football game.

You can participate in this study if you are a:

- Healthy male athlete 18-24 years' old
- Active participant on a varsity football team or men's competitive team

You CANNOT participate in this study if you:

- Any injuries that prevent the ability to change in direction quickly
- Have not performed any prior on-field running conditioning

Research Procedure

If you agree to participate in this study, you will be required to come to the Kirkley Training Centre at TD Waterhouse Stadium. On the field, a 10-minute dynamic warm-up with prescribed exercises and 3 accelerations to properly warm up the body will be lead by an experienced strength coach. 4 Change in direction sprints will be performed, followed by 1-minute rest. 10 reactive sprints (7.4 yards) will be performed on a :30-second interval that the athlete will be told by the tester. A 3-minute break takes place for the athlete to change from their shoes and re-locate to second floor Kirkley where the HiTrainer is located. The HiTrainer is a highly advanced treadmill that holds the athlete in the proper position for the constant drive phase of running. This helps eliminate any potential for hamstring injuries because the athlete will not be able to overreach. On the HiTrainer, the athlete will run 10x5 second sprints with a rest break of :25 seconds and a set resistance of 10. This will take 5 minutes and mimic normal game play that has a 1:5 work: rest ratio. A 3-minute break takes place for the athlete to change from their shoes and re-locate back to the field where the RAT is set-up. 10 reactive sprints (7.4 yards) will be performed on a :30second interval that the athlete will be told by the tester. A 10-minute break is given to the athlete to rest prior to repeating everything at a faster rate. 10 reactive sprints (7.4 yards) will be performed on a :15-second interval that the athlete will be told by the tester. A 3-minute break takes place for the athlete to change from their shoes and re-locate to second floor Kirkley where the HiTrainer is located. On the HiTrainer, the athlete will run 10x5 second sprints with a rest break of :10 seconds and a set resistance of 10. This will take 5 minutes and mimic a hurry-up style of offensive play that has a 1:2 work: rest ratio. A 3-minute break takes place for the athlete to change from their shoes and re-locate back to the field where the RAT is set-up. 10 reactive sprints (7.4 yards) will be performed on a :15second interval that the athlete will be told by the tester. The actual exercise will not take long (about 3 minutes), but it is intense. An experienced personal trainer will supervise the exercise session.

Risks and Discomforts

The HiTrainer is designed for high intensity interval training. With the intensity you are being asked to run at, this machine makes sprint training a lot safer. The angle will limit how far you can outstretch your leg decreasing your chances of a hamstring injury.

You may feel some muscle soreness and stiffness following the exercise protocol. This will be maximal about 48 hours after the exercise and should gradually subside. Although you will likely feel discomfort, you will be able to use your legs as you normally would.

Benefits

Participation in this research study may be of no direct benefit to you, although most subjects find that the knowledge they acquire during participation in research studies makes for a positive experience.

Voluntary Participation

Participation in this study is voluntary. You may refuse to participate, refuse to answer any questions, or withdraw from the study at any time with no effect on your future academic or employment status. The investigator has the right to withdraw you from the study at any time for reasons related to you (e.g., not following the study-related directions); or because the entire study has been stopped.

Privacy & Confidentiality

If the results of the study are published, your name will not be used and no information that discloses your identity will be released or published. Individual results will be held in strict confidence and all data will be placed in a locked cabinet. Only the investigators will have access to your records. You are encouraged to ask questions regarding the purpose of the study and the outcome of your test.

Compensation

You will not be compensated for your participation in this research study.

Legal Rights

You will be given a copy of this letter of information and consent form once it has been signed. You do not waive any legal rights by signing the consent form.

LETTER OF INFORMED CONSENT

The Effects of Fatigue on Reaction Time: Looking at the Difference Between Normal Game Play and Hurry Up in Football Game Situations

Principal Investigators: GD Marsh, PhD.
Kristine Walker, MSc Candidate

I have carefully read the "Letter of Information", have had the nature of the study explained to me and I agree to participate. All questions have been answered to my satisfaction.

____
Name (please print)

____
Signature

____
Date

____
Name of Person Obtaining Consent (please print)

____
Signature

Appendix B: Data Collection Form

Subject:

Change of Direction	Trial ID	Left	Right	Direction	2 YD	7.4 YD	Difference
	1						
	2						
	3						
	4						

Trial 1 - On-Field	Trial ID	Left	Right	Direction	2 YD	7.4 YD	Difference
	1						
	2						
	3						
	4						
	5						
	6						
	7						
	8						
	9						
	10						

HiTrainer 1:5		Trial ID	Power Output/sec	Speed/sec
Peak:		1		
Distance:		2		
Left Leg:		3		
Right Leg:		4		
		5		
		271		
		272		
		273		
		274		
		275		

Trial 2 - On Field	Trial ID	Left	Right	Direction	2 YD	7.4 YD	Difference
	1						
	2						
	3						
	4						
	5						
	6						
	7						
	8						
	9						
	10						

Trial 3 - On-Field	Trial ID	Left	Right	Direction	2 YD	7.4 YD	Difference
	1						
	2						
	3						
	4						
	5						
	6						
	7						
	8						
	9						
	10						

HiTrainer 1:2		Trial ID	Power Output/sec	Speed/sec
Peak:		1		
Distance:		2		
Left Leg:		3		
Right Leg:		4		
		5		
		136		
		137		
		138		
		139		
		140		

Trial 4 - On Field	Trial ID	Left	Right	Direction	2 YD	7.4 YD	Difference
	1						
	2						
	3						
	4						
	5						
	6						
	7						
	8						
	9						
	10						

Appendix C: Dynamic Warm-Up Routine

Pre-Run Dynamic Flexibility Warmup

The warm up drills progress from Slow tempo drills to Fast tempo drills.

All warm up drills are done over 10 yards, with perfect technique.

Slow Tempo Warm Up Drills— all drills done for 10 yards

1. **High Knee Walk and Grab**— grab knee and pull to chest, finish up on toes, switch sides
2. **Heel Up and Grab**— right hand grabs left foot, finish up on toes, switch
3. **Inch Worm**— walk hands out past pushup position, then walk each leg back keeping it straight towards hands, finish with heels flat and your quadriceps flexed
4. **Spiderman Crawl**— on hands and feet (four point stance), bring right knee up and to the outside of the right hand, make sure to keep the left straight and to drag it behind you to get a full stretch of the hip flexors, then repeat on the left side
5. **Backwards Lunge with a Twist**— backward long lunge with right leg, right hand to left ankle and left hand pulls right shoulder to left knee
6. **Forward Walking Toe Touch**— extending the left leg straight back and keeping the back flat, touch the ground in front of the right toe with both hands to the ground, stand straight up and repeat on the left side
7. **Forward Lunge Elbow to Instep/ Hamstring**— long forward lunge with right leg, drop right elbow into the in-step of the right foot, left leg stays straight with knee off the ground, then place both hands on each side of the right foot and raise hips up and try to straighten both legs into a hamstring stretch, repeat on left side
8. **Squat Shuffle**— in an athletic stance, squat and shuffle 5 yards leading with the right leg and then switch to leading with your left leg for 5 yards
9. **Walking Foot to Hip**— while walking forwards, grab your right foot and pull it up to your left hip, then switch sides
10. **Kung Fu Fighters**— abduct the right leg and extend it laterally, then complete the movement by sinking into a full squat
11. **Forward Atlas Lunge** with both hands reaching over same side shoulder— long forward lunge with right leg, twist and reach both hands up over right side, repeat on the other side
12. **Cross Behind Lunge**— right leg crosses behind left leg, sink into a squat

Fast Tempo Warm Up Drills — all drills done for 20 yards

13. **Leg Swing Skip**— alternating foot and toe touch plus a skip off the down leg
14. **Heel Ups**— butt kicks, heels up, toes up, fast turnover
15. **High Knee Skip** — pop off the ground powerfully and go for height
16. **Backwards Open Hip Skip**
17. **Backwards Reach Run**— not backpedal, you open up your stride to look like you are running forwards
18. **Forward High Knee Run**
19. **Backward High Knee Run**
20. **High Knee Carioca**— emphasize the high knee and leg crossover action
21. **Shuffle to a Sprint**— 10 yard shuffle to a sprint, both directions
22. **Jingle Jangle**— Sprint 5 yards ahead, touch line, sprint 5 yards back, touch line and sprint 10 yards ahead
23. **Fast High Knees to a Sprint**— 20 yards

Appendix D: Football Drills

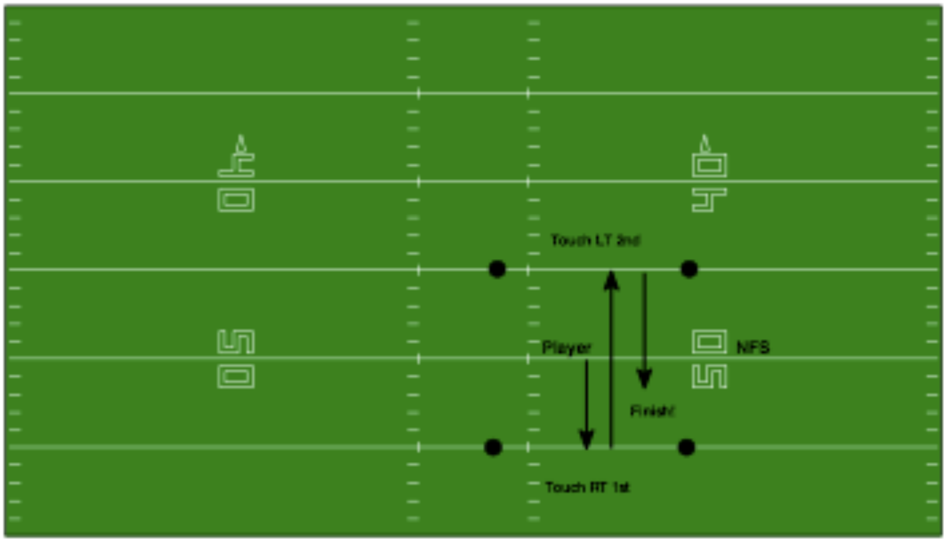

Figure 9 The Pro Agility Test (NFL)

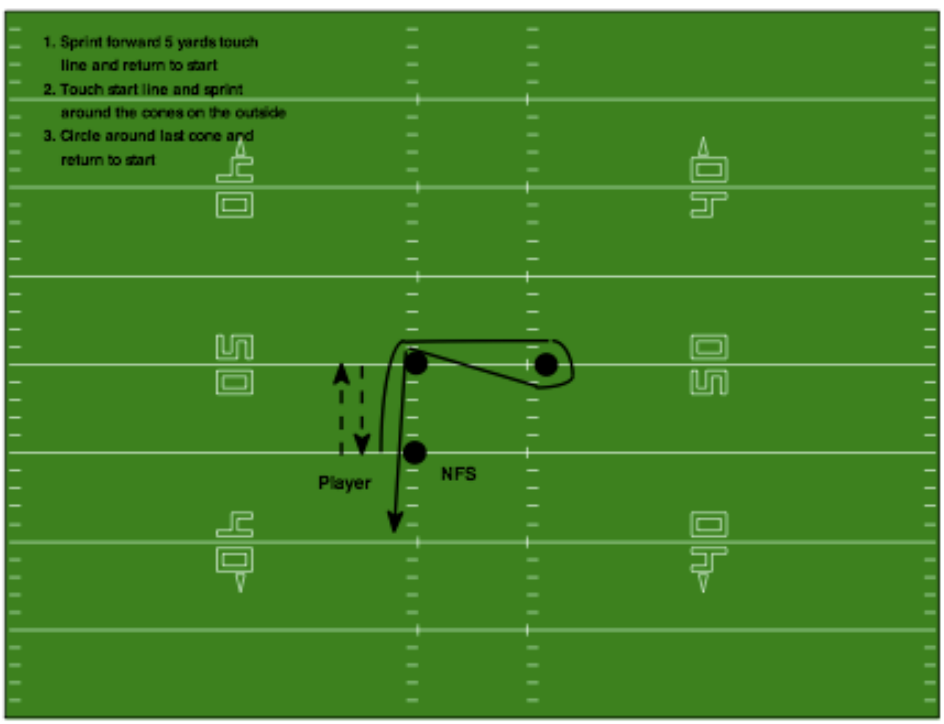

Figure 10 The Three-Cone Drill (NFL)

Curriculum Vitae

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	The University of Western Ontario London, Ontario, Canada 2013-2015 M.Sc.
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