THE GOOD-STORIE HOCKEY SPECIFIC TEST TO ASSESS ANAEROBIC POWER
AND FATIGUE IN ELITE AND NON-ELITE ICE HOCKEY PLAYERS

by

Michael L. Self

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Thesis Committee:

Dr. Jennifer L. Caputo, Chair

Dr. Vaughn W. Barry

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ABSTRACT

Sport specific testing and the collection of physiological data has become a common practice throughout sport. The Good-Storie Hockey Specific Test (HST) is an on-ice test used to assess the repeated sprint performance of hockey players. Anaerobic power output and fatigue were compared between the HST and the Wingate anaerobic test (WAnT) in a non-elite sample of players. Performance characteristics were also distinguished among previously studied elite samples and the current sample of non-elite players. The results demonstrated a high correlation ($r = .88$, $p < .001$) for peak power (W) and a moderately high correlation ($r = .69$, $p = .018$) for fatigue index (%) between the HST and WAnT. The non-elite players were significantly slower during 15 m. trial time (s) ($F [3, 62] = 12.4$, $p < .001$) and total trial time (s) ($F [3, 62] = 13.5$, $p < .001$) when compared to previously studied samples of elite players. Ultimately, the HST was able to delineate on-ice performance characteristics among skill levels and is a reliable, sport specific assessment of anaerobic power and fatigue for non-elite hockey players.

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CHAPTER I

INTRODUCTION

Coaches, general managers, and scouts may rely on physiological data for a multitude of reasons, including tactical decisions or the recruitment of prospects (Peterson et al., 2015a). However, having the ability to distinguish elite players from non-elite players or predict on-field performance through laboratory or off-field testing is often coveted (Peterson et al., 2015b; Peyer, Pivarnik, Eisenmann, & Vorkapich, 2011; Runner, Lehnhard, Butterfield, Tu, O'Neill, 2014; Tarter et al., 2009). Athletes that are better prepared to meet the physiological demands of their sport are crucial to the success of a team; therefore, performance testing is frequently conducted in sport (Peterson et al., 2015a). Specifically, in ice hockey, the validity of off-ice assessments to quantify on-ice performance have been questioned throughout the literature based on the various physiological demands of the sport.

In the literature, ice hockey has been described as a physically demanding sport combined with intermittent, high-intensity bursts of speed to result in an erratic pattern of play (Twist & Rhodes, 1993b). Ice hockey typically consists of three 20-minute periods with 15- to 18-minute intermissions. There are six players on the ice from two opposing teams with three forwards, two defensemen, and one goaltender, respectively. Forwards include a left wing, right wing, and center; while defensemen include a left and a right defender. Players are tactically grouped together on the ice in combinations known as

"lines," and rotate on and off the ice in "shifts" throughout the game. In the National Hockey League (NHL), an average shift lasted 45.5 seconds with a total of 6.8 shifts completed per period (Peterson et al., 2015a). Players complete shifts on the ice because of the intense physiological requirements of the game.

Rapid changes of direction and frequent bouts of contact require that players are agile and balanced. For optimal performance, a lean body composition is desired to keep up with the speed of the game, as well as high levels of upper and lower body strength and power (Montgomery, 1988; Twist & Rhodes, 1993b). Upper body strength and power are needed to deliver body checks, defend opposing forwards in front of the net, and dig pucks out of corners (Twist & Rhodes, 1993b). Skating mechanics require both lower body strength and power to accelerate and produce speed on the ice. While there are multiple physiological variables that can lead to success, repeated sprint ability (RSA) has been shown to be an important factor to on-ice performance (Peterson et al., 2015a).

Based on the average shift length on the ice, players are required to produce multiple bouts of power over a short period of time, thus relying on the cooperation of various energy pathways to produce adenosine triphosphate (ATP) for repeated, high-intensity sprints. The energy demand for ice hockey has been identified as 69% ATP-PC and anaerobic glycolysis and 31% oxidative (Montgomery, 1988). To produce power for explosive accelerations, players rely upon the rapid production of ATP (Twist & Rhodes, 1993b). The ATP-PC pathway can supply the immediate need for ATP, but is only able to sustain maximal intensity exercise for roughly 9- to 10-seconds with a recovery time of up to 5-minutes (Girard, Mendez-Vellanueva, & Bishop, 2011). The recovery time of this pathway and the utilization of phosphocreatine are not adequate to resupply the ATP

necessary to produce repeated sprints (Maughan, Gleeson, & Greenhaff 1997). Therefore, hockey players must rely upon other ATP generating mechanisms to fuel the muscular work needed to meet the physically intense demands of the game.

Anaerobic metabolism is able to sustain high-intensity exercise to an upward threshold of 120-seconds (Twist & Rhodes, 1993b). While this is an important component to sustaining power output during a shift, the inhibitory effects of hydrogen ion accumulation from anaerobic metabolism may limit a player's ability to repeat maximal-intensity actions required during ice hockey. This limitation in recovery time and metabolic waste may deter a player from chasing down an opponent or loose puck. Thus, it was suggested by Peterson and colleagues (2015a) that aerobic capacity may play an important role in determining RSA performance by enhancing the clearance of inhibitors and providing an aerobic ATP contribution for later sprints during repeated bouts. Ultimately, more research is needed to investigate the contributions of energy pathways to RSA and their relationship to on-ice performance. Researchers have attempted to quantify performance by conducting physiological testing; however, there are discrepancies in the literature as to which physiological variable is the most appropriate to predict on-ice performance.

Throughout the literature, vertical jump (VJ), broad jump (BJ), and sprint protocols have been examined in an attempt to predict on-ice performance and determine a relationship to on-ice speed and acceleration (Behm, Wahl, Button, Power, & Anderson, 2005; Burr et al., 2008; Runner et al., 2014). Some researchers suggest that anaerobic power is correlated to on-ice speed (Farlinger, Kruisselbrink, & Fowles, 2007; Potteiger, Smith, Maier, & Foster, 2010; Runner et al., 2014), whereas others conclude that while

anaerobic power is important, it may not be the key factor when determining on-ice

performance (Peterson et al., 2015b; Storie, 2015). At the elite level, the NHL combine

attempts to quantify on-ice performance through a battery of testing protocols. However,

in a review by Vescovi, Murray, Fiala, & VanHeest (2006), performance at the combine

did not accurately predict draft status for elite hockey players. Nevertheless, physiological

data are important when making informed decisions regarding tactical adjustments,

monitoring workloads, and recruiting prospects; however, discrepancies exist among data

collection methods and the sport specificity of some testing protocols.

The most popular assessment for anaerobic performance is the Wingate Anaerobic

Test (WAnT). According to a study by Ebben, Carrol, & Simenz (2004), 17 of 19 NHL

coaches surveyed used the WAnT to assess anaerobic capacity. While on-ice speed and

acceleration have been shown to correlate with peak power in the WAnT, it only provides

insight into the first shift on the ice because there is no assessment of repeated

performance (Janot, Beltz, & Dalleck, 2015; Peterson et al., 2016; Potteiger et al., 2010;

Storie, 2015). One group of authors suggested the use of a repeated WAnT protocol;

however, even though it was found as a reliable measure of power output and fatigue

index, it was researched in female ice hockey players and was not compared to an on-ice

assessment (Wilson, Snydmiller, Game, Quinney, & Bell, 2010). The WAnT's use in

hockey has often been questioned and argued in the literature based on its specificity to ice

hockey (Nightingale, Miller, & Turner, 2013; Peterson et al., 2016; Storie, 2015; Wilson

et al., 2010). According to Peterson et al. (2016), off-ice anaerobic power provides

valuable insight, but does not predict RSA in ice hockey, thus highlighting the need for an

on-ice test to assess performance.

Multiple on-ice tests have been developed to evaluate the performance of hockey players (Behm et al., 2005; Lariviere, Lavallee, & Shephard, 1976; Peterson, 2014; Reed, Hanen, Cotton, Gauthier, & Jette, 1979; Storie, 2015; Watson & Sargeant, 1986). Some skating patterns are limited in their ability to assess performance by consisting of only linear sprints, no agility based turns, and dissimilar work to rest ratios when compared to game analysis. Few researchers have attempted to incorporate sport-specific skating mechanics with RSA in a testing protocol to quantify performance (Peterson et al., 2015a; Storie, 2015). The Good-Storie Hockey Specific Test (HST) incorporates repeated, high-intensity sprints with a position specific skating pattern to evaluate on-ice performance. Relationships were found between the HST and WAnT and it was able to distinguish physiological differences among three elite groups. However, to date, the HST has not been examined in a non-elite playing population. Research is needed to further assess and expand the knowledge base on the HST and determine its potential application to performance testing.

Purpose

The purpose of this research was to evaluate the HST as a reliable, sport-specific test in hockey players. Specifically, the relationship between the HST and the WAnT in a non-elite population of male players was determined. Performance differences between elite (Storie, 2015) and non-elite players were evaluated, and the within-trials reliability for the HST was determined.

Research Questions

1. How are the HST and WAnT related as measures of power and fatigue in non-elite ice hockey players?

2. What is the within-trials reliability for the HST in non-elite ice hockey players?

3. How are the power, fatigue index, and HST trial velocities related among elite players and the current sample of non-elite players?

Significance of the Study

It is important to determine information regarding the HST to determine if it is a reliable and appropriate, sport-specific assessment for on-ice performance in hockey players. To promote a shift from the WAnT as the standard in measuring anaerobic performance in ice hockey players, this research answered questions with a non-elite population to provide insight on the applicability of the HST as a performance assessment tool. Information obtained from this research study expands knowledge on the HST and ultimately provided further information to a greater body of knowledge on the use of sport-specific measurement tools to quantify on-ice hockey performance.

CHAPTER II

LITERATURE REVIEW

Ice Hockey Statistics

According to statistics on athletic scholarships in 2014, 12% of boys that played

high school hockey in the United States went on to play at the National Collegiate Athletic

Association's (NCAA) Division I (DI), Division II (DII), or Division III (DIII) level

(*Scholarship Stats*, 2014). There are roughly 3,900 student-athletes participating in men's

ice hockey across 146 universities that sponsor it as an NCAA varsity sport; however,

there are 35,000 boys that participate in hockey at the high school level (*Scholarship Stats*,

2014). When compared to football in the United States, there are roughly 70,000 student

athletes participating at the NCAA DI, DII, or DIII levels and over 1.1 million playing at

the high school level (*Scholarship Stats*, 2014). In a professional league that is filled with

elite talent from nations around the world, the chance of making a National Hockey

League (NHL) active roster spot becomes even more difficult for prospective players.

Comprised of 31 teams, there are only 713 active roster players in the NHL with each

team having a maximum of 23 active roster spots (*NHL Hockey Operations Guidelines*,

2017).

Positions on the Ice

Hockey is played with six players on the ice from two opposing teams. Player

positions are categorized as forwards, defensemen, and goaltenders. On the ice, there are

three forwards, two defensemen, and one goaltender for each team. Forwards include a

left wing, a right wing, and a center; while defensemen include a left and a right defender. The shooting hand of the left and right wing players generally corresponds with that side of the ice, however, that is not always the case. Coaches strategically combine three forwards and two defensemen to create a "line" which rotates with other lines in bouts called "shifts" throughout the game. Players are not locked into these lines during the game and may be interchanged by the coach to fit a specific strategy. In the NHL, teams have four lines, however at the NCAA and high school levels, the number of lines may depend on the number of players per team. Players are unable to spend 100% of the game on the ice due to shift changes; however, a single defensemen may spend 50% of the game on the ice whereas a forward may only spend 35% of the game on the ice (Twist & Rhodes, 1993a). Time spent on ice, shift length, and shift frequency are representations of patterns of play.

Patterns of Play

Erratic change of direction, high intensity activity, and frequent checking are various characteristics of play over the course of a game lasting 60 minutes. Absorbing hits, crashing into boards, and sudden stops and starts are activities that occur on the ice (Twist & Rhodes, 1993b). At the high school level, games are played with three periods at lengths of 15 to 20-minutes and a 15-minute intermission between each period (*USAH Rule Book*, 2013). In the NCAA and NHL, games consist of three periods of 20-minutes each; however, the NHL allows an 18-minute intermission and the NCAA has a 15-minute intermission between periods.

Hockey is an intermittent sport where players come off the bench onto the ice in shifts. A shift can be described as a 30 to 80 second period of intense exertion (Burr et al.,

2008), rarely lasting more than 90 seconds (Cox, Miles, Verde, & Rhodes, 1995) and occurring every 3 to 5 minutes (Vescovi, Murray, & VanHeest, 2006). According to an analysis of NHL game data from 2009 to 2011, the average shift length for forwards was 45.5 seconds with an average rest interval of 73.4 seconds (Peterson et al., 2015a). Other research suggests that shift length at the NCAA level lasts 55 to 145 seconds, with an average of two stoppages of play lasting 27 seconds each; resulting in three bouts of approximately 26 seconds of play each (Noonan, 2010). Peterson and researchers (2015a) observed that the number of shifts per period in the NHL is 6.8, not including power plays. Motion-analysis of varsity level hockey games shows that a forward completes anywhere from 15 to 20 shifts per game (Noonan, 2010). Analysis of NHL game data also shows that players spend an average of 22.7 seconds per shift at maximal or near maximal intensity (Peterson et al., 2015a). The average time on ice for each player may be between 15- and 20-minutes per game; however, some players may average more than 25-minutes of ice time to meet the patterns of play (Montgomery, 1988). Defensemen may spend a considerable amount of time skating backwards to react to pressing forwards; and offensive players may spend significant time skating at high velocities to chase pucks and out maneuver the opposing defensemen (Twist & Rhodes, 1993a). An emphasis is placed on speed because of the 'flow' style of play with short shift lengths and frequent shift changes (Montgomery, 1988). Ultimately, intermittent skating, rapid changes in skating velocity, and frequent body contact are patterns of play that place various physiological demands on players (Twist & Rhodes, 1993b).

Physiological Demands of the Sport

Hockey is described as an intermittent collision sport where players have to meet certain physiological demands to be successful (Potteiger et al., 2010). Not only do players have to possess the skills of stick handling, passing, and shooting; they must demonstrate the ability of a figure skater, the swiftness of a speed skater, and the power of a football player to dig pucks out of corners and absorb hits at maximal speeds (Twist & Rhodes, 1993b). In addition to these skills, players must be fast and explosive skaters to win games (Peyer et al., 2011). One of the most important factors contributing to successful performance is skating ability; however, a multitude of attributes interact to contribute to overall hockey performance (Potteiger et al., 2010). Body composition, flexibility, agility, balance, muscular strength and power, as well as trained energy pathways, are relied upon during all aspects of the game.

Body composition. A lean body composition is desired by players to optimize performance. However, in the 1980s, Canadian hockey players were found to carry more excess fat weight compared to other elite athletes in endurance sports at the time (Montgomery, 1988). The excess mass may add protection during collisions as well as mass for body checking (Montgomery, 1988). Conversely, excess mass is detrimental to skating performance because it can alter skating efficiency by increasing the frictional resistance on the ice (Montgomery, 1988). During the propulsion and glide phase at maximal speeds, researchers argued that excess body mass can be supported by the skates so there would not be a decrease in skating performance. However, according to a study where the effect of excess mass on skating speed was measured, players that carried as little as 5% excess mass had an increased anaerobic performance time by 4%, resulting in

slower performance in the repeat sprint skate (RSS) test (Montgomery, 1988).

Researchers concluded that in players with greater mass, the amount of time that the

player can maintain a certain pace decreases because the energy required to skate at a

certain velocity increases, so energy systems are taxed maximally at slower speeds

(Montgomery, 1988).

Because of the added mass from the protective gear hockey players are required to

wear, excess fat mass could cause a detrimental effect on skating speed (Montgomery,

1988). According to a study in 2010, there is a moderately strong, negative relationship

between body fat percentage and on-ice skating speed (Potteiger et al., 2010). Players

must be aware of the negative implications that excess fat mass can have on performance.

Peterson and researchers (2015b) measured the body fat percentages of NCAA Division I

and Division III hockey players and found that DI players had a mean body fat percentage

of 11.46% compared to 14.36% in DIII players. Montgomery (1988) reported that

forwards and defensemen at the NHL level typically have a body fat percentage between

10-12% with defensemen having a slightly higher percent body fat to meet the physical

demands of the position. Overall, players are fairly lean to keep up with the speed and of

the game (Montgomery, 1988); however, flexibility is an important factor for producing

force on the ice.

Flexibility. Improved hip, groin, and quadriceps' flexibility will improve speed

and skating efficiency (Twist & Rhodes, 1993b). Hamstring flexibility plays a role during

skating because the rear leg must be extended or speed and power will be limited (Twist &

Rhodes, 1993b). A study by Wu, Pearsall, Russell, and Imanaka (2015) highlighted the

importance of hip, knee, and ankle extension for propulsion in forward skating.

Flexibility can play a role in puck handling, agility, and power; and is required by all

positions (Twist & Rhodes, 1993b). There is limited literature on flexibility in hockey

players; however, goalies were found to have better flexibility for trunk flexion and

shoulder extension than both forwards and defensemen (Montgomery, 1988). However,

forwards and defensemen were found to have similar flexibility scores to one another

(Montgomery, 1988). Ultimately, flexibility plays an important role for players and can

contribute to the ability to remain agile and balanced on the ice (Twist & Rhodes, 1993b).

Agility and balance. Remaining upright on ice skates and moving fluidly in a 360°

plane is a crucial requirement of the game (Peterson et al., 2015a). All dynamic

movements on the ice, including stops and starts, rapid turns, crossovers, zig-zags, and

changes in direction require agility (Twist & Rhodes, 1993b). Forwards must use agility

to handle the stick, control the puck, and make sudden movements in one-on-one

situations to out maneuver the opposition; whereas defensemen must keep their body

square to the opposition, effectively transition from forward to backward skating, and

demonstrate excellent footwork to stop opposing forwards (Twist & Rhodes, 1993a). All

players must change direction, make crossover steps, and produce quick lateral push-off

steps. During max effort skating, a stride consists of 82% single leg support and 18%

double leg support which requires players to be both balanced and agile in order meet the

patterns of play (Montgomery, 1988). Ultimately, Twist and Rhodes (1993b) concluded

that it is an agile and complex skating ability that separates elite and non-elite players.

Agility encompasses speed, acceleration, and importantly deceleration; however, strength

and power are physiological demands required to produce these quick linear and lateral

movements (Nightingale et al., 2013).

Muscular strength. Strength is necessary in all phases of the game. Requiring rough physical contact, hockey is described as the fastest game in the world played on two feet (Cox et al., 1995). Players can reach speeds up to 30 mph and shoot pucks as fast as 90 mph (Twist & Rhodes, 1993b). Strength is needed for defending against opponents, body checking, and enduring intense contact from other players (Twist & Rhodes, 1993b). Throughout the game, a player must be able to effectively deliver body checks as well as receive them (Twist & Rhodes, 1993b). Producing a lower center of gravity and increasing inertia through strength training is important for skating because it allows players to be dynamically stable so they are able to resist external forces from opponents (Twist & Rhodes, 1993b). Players rely on upper body strength for its contribution to puck control and shooting, and lower body strength for its contribution to acceleration and agility (Twist & Rhodes, 1993b). A strength demand is also placed on the leg abductors, adductors, and lower back due to the mechanics of skating (Twist & Rhodes, 1993b). Players are in slight back flexion during skating and endure continual isometric contraction of the back extensors as well as stressful twisting motions throughout a game (Twist & Rhodes, 1993b). Increased hand grip strength may contribute to improved stick handling during contact and may also improve shooting accuracy. However, Montgomery (1988) observed that there is a dominance in right handgrip strength over left and it may not be correlated with shooting 'handedness.' Montgomery (1988) also observed that professional players tend to have greater grip strength than university and junior players. Importantly, upper body strength is crucial in front of the net as defensemen force opponents out of the way and forwards fight to maintain position (Twist & Rhodes, 1993a).

During the 1980s, the hip flexor muscles were shown to be well developed in NHL players when compared to other muscles in the body; and hip flexor strength was related to skating ability (Montgomery, 1988). Gilenstam, Thorsen, and Henriksson-Larsen (2011) suggested that isokinetic lower body strength plays a vital role in acceleration and is found to be correlated with skating speed. However, one study determined that leg strength is only marginally associated with forward acceleration, backward acceleration, and skating speed on the ice (Runner et al., 2014). However, based off the majority of the literature, leg strength is an important component to overall skating ability in both forwards and defensemen.

Twist and Rhodes (1993a) suggested that forwards and defensemen are typically stronger than goaltenders; however, the strength difference between forwards and defensemen is becoming reduced due to strength and conditioning programs. Defensemen require greater absolute strength to keep stride with smaller, lighter forwards who require less force to move their mass across the ice (Burr et al., 2008). However, the patterns of play require explosive and dynamic movements from all positions throughout the game, and muscular strength also assists in the prevention of injuries that may occur during these movements (Twist & Rhodes, 1993b). By analyzing skating mechanics, Montgomery (1988) found that the quadriceps create the greatest contractile forces when the knee joint is extended in the skating thrust. Stabilization of the knee is supported by the hamstrings and gastrocnemius muscles when shifting weight and pushing off (Montgomery, 1988). An adequate strength ratio between muscle groups is important because an imbalance may lead to injury, so a hamstring/quadriceps strength ratio of 60% is desired in hockey players to reduce the risk of hamstring injuries (Twist & Rhodes, 1993b). Ultimately, hockey

players rely on strength to accelerate quickly, to maintain strong strides at max speed, and to deliver effective hits to opposing players (Twist & Rhodes, 1993b). Although strength is an important component in hockey, training the speed at which force can be applied is also a vital goal for performance (Runner et al., 2014).

 Muscular power. Power is an essential requirement for all actions on the ice. Players are required to propel their bodies and burst into action throughout the game (Twist & Rhodes, 1993b). The patterns of play require players to stop and start, as well as cut laterally, deliver a body check, and achieve top speed to chase down a puck (Twist & Rhodes, 1993b). Skating acceleration through forceful lower body movements and explosive upper body motions are crucial to hockey success (Twist & Rhodes, 1993b). According to Runner et al. (2014), lower body power is associated with on-ice linear speed and uniquely contributed to on-ice forward acceleration and backward acceleration. Montgomery (1988) characterized an elite hockey player by the capability to accelerate and exceed a velocity of 8 m/sec in four strides. Lower body power also contributes to the explosiveness of a body check when driving upwards from a squatted position (Twist & Rhodes, 1993b). Players rely on upper body power when sending a quick shot on goal or delivering a quick hit to an opponent in front of the net. Effective shooting and a forceful, quicker release of the puck is contributed to the overall explosive force a player is able to produce (Twist & Rhodes, 1993b). During slapshots, forwards and defensemen must rely on absolute power to forcefully rotate the trunk (Twist & Rhodes, 1993a).

 When describing differences among players at various collegiate levels, Peterson et al. (2015b) objectively quantified that NCAA DI hockey players produce more power than NCAA DIII players. Montgomery (1988) observed the power differences between

positions and found that defensemen have a greater mean power output than forwards and goaltenders, and forwards have a greater mean power output than goaltenders. A hockey shift requires players to produce intermittent bursts of speed and perform tasks at maximal effort; however, forwards and defensemen are on the ice for separate lengths and may have separate task requirements based off the position (Montgomery, 1988). Ultimately, both lower body and upper body power are a necessary requirement of the game and are described as some of the most important physiological factors in ice hockey (Twist & Rhodes, 1993b). However, it is suggested that the ability to produce repeated efforts of power may be the most important factor to on-ice performance (Peterson et al., 2016).

Repeated sprint ability. Hockey players must possess the physiological capability to perform repeated sprints with short bouts of recovery throughout a 60-minute game. The ability to produce high-power across multiple bouts with only brief rest periods gives a player an advantage during competition (Girard et al., 2011; Glaister, 2005), this ability is known as RSA (Peterson et al., 2015a). In regard to RSA in the literature, a 'sprint' is defined as maximal work that is maintained for ≤ 10 seconds (Girard et al., 2011). According to Girard et al. (2011) repeated sprints can be categorized as one of two types of exercise; intermittent-sprints or repeated sprint exercise (RSE). Intermittent-sprints ($\leq$ 10 seconds) have recovery bouts (60-300 seconds) between work that allow complete or near complete recovery of sprint performance; whereas RSE (≤ 10 seconds) has shorter recovery periods (typically ≤ 60 seconds) which results in a detriment to sprint performance (Girard et al., 2011). This is important in ice hockey because players perform both types of sprints. Each sprint type may have different factors contributing to fatigue (Girard et al., 2011).

Peterson (2014) suggested that hockey players have developed an intricate set of energy pathways to meet the physiological stresses of RSE. Montgomery (1988) stated that the energy demand in ice hockey is 69% ATP-PC and anaerobic glycolysis, and 31% oxidative. Ultimately, there is never a single energy pathway that is being used at a given time, and hockey players rely on each of these pathways to meet the energy demands of the sport and to contribute to overall RSA performance (Peterson, 2014). Muscle is fueled by energy known as adenosine triphosphate (ATP) and is approximately stored at 20-25 mmol/kg/dm (Gaitanos, Williams, & Boobis, 1993). Maximal, high-intensity exercise can be fueled by ATP alone for 1-2 seconds when at a peak turnover rate of approximately 14-15 mmol/kg/dm/sec (Glaister, 2005); however, as intracellular ATP stores decline, other metabolic pathways are utilized for its resynthesis (Peterson, 2014).

Phosphocreatine. A rapid supply of ATP is needed to supply the fast, explosive movements that occur in ice hockey (Twist & Rhodes, 1993b). Quickly jumping over the wall onto the ice during a line change requires an immediate source of energy. Phosphocreatine (PCr) is predominantly important during RSE when a high rate of ATP utilization and re-synthesis are required; it contributes instantly at the start of maximal exercise and serves as an immediate reserve for re-phosphorylation of ATP (Girard et al., 2011., Maughan et al., 1997). According to Girard et al. (2011), PCr instantly reaches a peak turnover rate at the start of maximal exercise of roughly 9 mmol/kg/dm/sec and has total intramuscular stores of approximately 80 mmol/kg/dm; therefore, stores would be rapidly consumed during one high-intensity bout on the ice. Researchers estimated that 50% of the total ATP production during a maximal 6-second sprint may be supplied by PCr (Gaitanos et al., 1993). The literature also illustrated that it may take up to 5-minutes

for complete recovery; therefore, a decrement in sprint performance may occur due to limited PCr availability during RSE when rest periods last ≤ 60 seconds (Girard et al., 2011). This is important during hockey because players are required to produce high-intensity sprints during erratic and unpredictable patterns of play with short periods of rest. Soon after the start of maximal exercise and after extended lengths of maximal exercise, intracellular PCr begins to decline and stores begin to deplete; therefore, PCr is unable to meet the entire demand for ATP during RSE (Maughan et al., 1997).

Anaerobic glycolysis. Players are required to perform various explosive activities on the ice (Vescovi, Murray, & VanHeest, 2006) and exert maximal, repeated effort over short distances, thus relying on anaerobic metabolism (Twist & Rhodes, 1993b). During a maximal effort 6-second sprint, anaerobic glycolysis supplies approximately 40% of the total energy demand (Gaitanos et al., 1993). Glycogen is broken down during glycogenolysis; and according to the literature, the ideal fuel during RSE is muscle glycogen (Spriet, Lindinger, McKelvie, Heigenhouser, & Jones, 1989). Gaitanos et al. (1993) suggested that the approximate resting intracellular concentration of glycogen is 300 mmol/kg/dm. Glycogenolysis begins at the start of high-intensity exercise and reaches a peak turnover rate of 6-9 mmol/ATP/kg/dm/sec at roughly 5 seconds (Gastin, 2001; Parolin et al., 1999). According to Twist and Rhodes (1993b), anaerobic ATP production has an upper threshold of 120 seconds (depending on intensity) and peaks at 30-45 seconds, and players must utilize both PCr and anaerobic glycolysis to provide the energy for activities during a shift. However, repeated bouts of high-intensity exercise on the ice may limit a player's ability to reproduce power because the availability of PCr is effected by recovery times and the accumulation of hydrogen ions (H^+) from anaerobic

metabolism promote inhibitory effects to muscular contraction. It is suggested by Peterson (2014) that the inhibitory effects from glycogenolysis may be limited by greater aerobic metabolism.

Oxidative. Twist and Rhodes (1993b) advocated that aerobic training not only prepares players for the recovery process on the ice, but also creates a base for the player to handle higher intensity anaerobic training. They also suggested that aerobic requirements depend on player position, skill level, and intensity of the game. Aerobic metabolism is slow to respond to the demands of RSE, however, it is suggested in the literature that it may play a crucial part in ATP production during maximal exercise (Peterson, 2014). Myoglobin (MbO_2) is the immediate source for oxygen during RSE, however, it is unable to keep up with the repeated sprint demands of sport (Peterson, 2014). Girard et al. (2011) stated that during a single sprint (≤ 10 seconds), the total energy contribution of the oxidative pathway is less than 10%; however, as sprints become repeated, aerobic ATP production may increase to 40% of total energy needs during the final bouts of RSE. This becomes an important mechanism when rest periods and metabolic waste from anaerobic glycolysis do not allow for the full replenishment of ATP. This may also lead to further insight and investigation of the aerobic pathway's contribution to RSA; and this increase in oxidative ATP production may improve RSA in hockey players. An athlete may reach his/her VO_{2max} (maximal oxygen consumption) during the last bouts of repeated sprints, which may inhibit an athlete's ability to maintain power in repeated exercise by limiting the aerobic contribution during RSE. Therefore, it is theorized that a higher VO_{2max} will allow for a greater aerobic contribution and may minimize fatigue (Girard et al., 2011). Peterson et al. (2015a) suggested that increased

oxygen utilization may improve RSA by increasing the speed of the fast and slow phase of PCr resynthesis, enhancing the clearance rate of inhibitors created during glycogenolysis and PCr breakdown, improving oxygen kinetics, and increasing the overall oxidative ATP contribution during maximal repeated sprints. This could allow for enhanced recovery between line shifts, which is critical to overall team performance (Laurent, Fullenkamp, Morgan, & Fischer, 2014). Peterson (2014) suggested that an increased VO_{2max} could also limit the demands on the PCr and glycolytic pathways by reducing the amount of inhibitors needed to be cleared from the muscle before the next high intensity sprint (Dupont, Millet, Guinhouya, & Berthoin, 2005). Ultimately, this mechanic would improve RSA and contribute to overall hockey performance. More research is needed to understand the contribution of the energy pathways during hockey and their relationship to on-ice performance.

Throughout the literature, ice hockey has been described as a physically demanding sport where players must possess the skill and tactical components of passing and shooting as well as the physiological ability to skate short, repeated bouts at near maximal intensities. A lean body composition is required for speed and efficiency; and the small surface area of the blades as well as the low friction of the ice requires players to demonstrate high levels of agility, balance, and flexibility (Behm et al., 2005). In addition to these skills, the physicality of the game requires players to demonstrate both strength and power. Lower and upper body strength is beneficial for digging pucks out of the corner and resisting external forces; whereas power is important for chasing pucks, delivering body checks, and performing slapshots. A key component of the game requires the ability to reproduce high-intensity sprints with brief periods of rest. The ATP-PC,

glycolytic, and oxidative energy pathways work together and contribute as a whole for successful on-ice performance. However, there is limited literature on RSA and ice hockey; therefore, these mechanisms are newly researched by Peterson et al. (2015a) through physiological testing.

Physiological Testing in Ice Hockey

Athletes that are best equipped to meet the physiological demands of their sport are crucial to the success of a team (Peterson et al., 2015b). Gaining insight on elite playing potential and on-field capabilities through laboratory or off-field testing is a common practice throughout sports (Peyer et al., 2011; Tarter et al., 2009). Coaches may use physiological testing data to pinpoint elite-level players, distinguish starters and non-starters, make tactical adjustments, and recruit prospective athletes (Peterson et al., 2015b; Runner et al., 2014). Performance testing is also used to identify areas of improvement, monitor an athlete's response to workloads during the season, and observe the effectiveness of a training program; as well as estimate an athlete's potential to perform at a greater level of competition (Peyer et al., 2011; Tarter et al., 2009). As sport advances with science, new means of evaluating and predicting athlete performance are being developed, thus the complexity of tests range from simply standing on a scale to performing elaborate fitness assessments (Peyer et al., 2011; Runner et al., 2014).

According to Burr et al. (2008), the utility of fitness assessments off the ice has been argued among scouts, coaches, strength and conditioning professionals, and physiologists at the elite hockey level. A different level of importance has been placed on test components with the belief that one test outcome may be more appropriate for predicting hockey playing potential than another (Burr et al., 2008). This debate over

which assessment/s to use may lead to the creation of new tests or the performance of

multiple tests on a single athlete. Some professionals believe that specific tests, in

combination with others or alone, are adequate to evaluate overall hockey playing

potential; and that there may be multiple measures of the same physiological characteristic

through multiple tests to please all viewpoints (Burr et al., 2008). Variations of tests in

hockey may include multiple protocols of the vertical jump (VJ) test to assess lower body

power because of its relationship to skating ability; for example, as a squat jump variation

or a countermovement variation may be used to assess jump height (Burr et al., 2008).

The single-leg lateral jump, a variation of the standing-broad jump (long jump), may also

be used to assess lower body power in hockey because of its similarity to a skating stride.

Much of the hockey related research is focused on the relationship of off-ice tests to on-ice

performance (Burr et al., 2008). Currently, the NHL Scouting Combine uses off-ice tests

to evaluate prospects and predict elite playing potential.

　　　　NHL combine testing. The NHL uses a wide range of physiological tests to

measure anthropometry, grip strength, upper body strength, lower body power, balance,

agility, aerobic capacity, and anaerobic capacity. Players perform maximal effort tests for

a total test time of approximately 2 hours (Vescovi, Murray, Fiala et al., 2006). Specific

tests during the combine may include: bod pod testing, bench press, push-ups, standing

broad jump, VJ, pro-agility, a cycle ergometer VO_2max test, and the Wingate anaerobic

test (Nightingale et al., 2013). However, limited and inconsistent data in the literature

suggest that the fitness tests used in the combine may hold little predictive value to on-ice

performance (Green, Pivarnik, Carrier, & Womak, 2006; Tarter et al., 2009; Vescovi,

Murray, Fiala et al., 2006). According to Tarter et al. (2009), some researchers failed to

take into account the covariance between tests when assessing the relationship between off-ice and on-ice performance. A "composite physical fitness index" (CPFI) was created by researchers to reduce 18 testing variables into one global index (Tarter et al., 2009). According to the CPFI, defensemen and forwards scoring in the 80th have a 70% and 50% probability, respectively, of playing five or more games within 4 years of the NHL draft (Tarter et al., 2009). While a global index of this nature may have value to coaches, managers, and performance staff, it is exhaustive to administer a complete testing protocol because of technology, time, and labor involved (Tarter et al., 2009). According to a review conducted by Vescovi, Murray, Fiala et al (2006), performance at the combine does not accurately predict draft status for elite ice hockey players. Similar scores have been found for players across tests such as the long jump, VJ, and medicine ball toss regardless of draft status (Vescovi, Murray, Fiala et al., 2006). One test that is seen as the "gold-standard" for assessing anaerobic performance in ice-hockey is the WAnT.

Wingate testing and its relationship to on-ice performance. The WAnT was developed by researchers at the Wingate Institute in Israel to measure absolute and relative peak and average power as well as a fatigue index across a 30-second maximal effort trial. Discrepancies in the literature exist between WAnT and on-ice performance, some researchers report significant relationships between peak power and skating speed, whereas other researchers have found no relationship between the variables (Farlinger et al., 2007; Nightingale et al., 2013; Potteiger et al., 2010). While discrepancies exist, the test has been used in numerous studies to assess the anaerobic performance in ice hockey players (Vescovi, Murray, Fiala et al., 2006). According to a study by Ebben et al. (2004), 17 of 19 NHL strength and conditioning coaches surveyed in 2004 used some variation of

the WAnT to assess anaerobic capacity. In a personal interview with the head strength and conditioning coach for men's ice hockey at a NCAA DI school, the WAnT is used during pre-season training camp to assess anaerobic performance (T. Rolinski, personal communication, August 5, 2016).

Data for off-ice testing has been reported in the literature; however, this may not be applicable to on-ice performance because there are no normative standards for elite hockey players (Vescovi, Murray, Fiala et al., 2006). Specifically, Blatherwick (1983) found that fatigue curves produced with on-ice anaerobic tests have been replicated in the WAnT. However, the sport specificity of the on-ice tests can also be questioned as appropriate assessments for hockey based of their work to rest ratios and linear, one bout protocols. One study found that a low-moderate correlation ($r = -.48$) was found between the percent power drop in the WAnT and fastest 54m skate time (Poetteiger et al., 2010). The same study also found a low-moderate correlation ($r = -.43$) between relative peak power in the WAnT and average 54m skate time (Poetteiger et al., 2010). In another study, Janot et al. (2015) assessed the relationship between off-ice tests and various on-ice skating tests in DIII ice hockey players with a mean age of 20.5 ± 1.4 years ($N = 26$). When comparing the WAnT to on-ice tests, the researchers concluded that percent power drop was the best predictor of on-ice performance when using regression analysis (Janot et al., 2015). The on-ice tests conducted during the study were S-turn agility, 6.1m acceleration, 44.80m speed skate, 15.2m full speed skate, and a modified Reed Repeat Sprint Skate (RSS) (Janot et al., 2015). The relationship between WAnT relative peak power and the various on-ice tests ranged from low to moderate; whereas the relationship between WAnT percent power drop and the various on-ice tests were reported as low

(Janot et al., 2015). The researchers stated that off-ice tests were not effective predictors

of on-ice performance in the 6.1m acceleration, 15.2m full speed skate, and the S-turn

agility test, and suggested that more specific off-ice tests should be identified in further

research to predict these areas of skating performance (Janot et al., 2015). However, the

problem with the aforementioned statement lies with the suggestion to identify more

specific off-ice tests; and while off-ice testing has certain benefits, the skill and energy

system requirements of skating performance should be evaluated with specific on-ice

testing.

　　　Limitations to off-ice testing. Limitations in off-ice testing exist when the

physiological demands of ice hockey are investigated. According to Bracko (2004),

skating is believed to be the most important skill in ice hockey. It is suggested in the

literature that the same muscle mass may not be recruited and there is an inconsistency in

the mechanics between on-ice skating and off-ice tests (Durocher, Guisfredi, Leetun, &

Carter, 2010; Nightingale et al., 2013; Peterson, 2014). Peterson (2014) stated that

cycling has been found to have a related muscle recruitment pattern to speed skating;

however, the mechanical and physiological demands between hockey players and speed

skaters were found to be different. According to Tidman (2015), skating strides found in

hockey players are more narrow with large anterior-posterior skate separation, but in

speed skaters the strides are wider with less anterior-posterior skate separation. Therefore,

speed skaters may not be a good population to derive conclusions when determining the

effectiveness of a cycling protocol in hockey players (Peterson, 2014). Research

conducted by Farlinger et al. (2007) found that horizontal leg power was a requirement at

top speeds during skating, which was suggested to be easier to replicate with sprinting

protocols. The 40-yard dash has been found to be significantly correlated with maximal skating speed; however, Marino (1997) argued that hockey players are required to displace force laterally during skating rather than posteriorly in running-based activity (Behm et al., 2005). A study by Buckeridge, LeVangie, Stetter, Nigg, and Nigg (2015) showed significant kinematic differences between skating and running; and Pearsall, Turcotte, LeVangie, & Forget (2000) found that leg muscle activity and posture are altered during skating when compared to field sports. Therefore, the effectiveness of off-ice assessments to predict on-ice anaerobic power are unclear in the literature, thus making off-ice tests difficult to establish as reliable and valid measures for hockey players.

Bracko (2001) stated that hockey players are required to produce power to overcome air, ice resistance, and support weight; whereas cyclists have a reduced power requirement because body weight is supported. Bracko (2014) has also suggested that efficient skating is contributed to smooth and coordinated abduction and adduction of the hips and shoulders. Not only is the weight supported during the WAnT, the arms are stationary; whereas in skating the arms are used to assist in balance and forward momentum (Bracko, 2001). The WAnT has also been questioned as a valid assessment to measure anaerobic performance in intermittent based sports, such as ice hockey, which require a repeated ability to produce high intensity sprints (Nightingale et al., 2013). Some researchers have suggested the use of a repeated WAnT to assess intermittent anaerobic performance; however, differences between cycling and skating may yield unclear results based off mechanical limitations (Wilson et al., 2010). In a study by Marino and Drouin (2000), skating mechanics were analyzed and shown to be significantly different between a fatigued and non-fatigued state. The researchers

concluded that a fatigued skater is unable to position the support leg in an optimal spot on the ice to begin the next thrust, which inhibits the skater from producing equal velocities and stride rates (Marino & Drouin, 2000). Therefore, off-ice protocols seem to create a mechanical limitation or disadvantage to hockey players that are accustomed to performing specific movements related to skating. Force production and repeated sprint requirements during ice hockey may lead to reasons why there is variance in off-ice testing data. Even though the WAnT is a popular assessment for anaerobic capacity, it has been often questioned; therefore, on-ice anaerobic tests have been suggested in the literature (Bouchard, Taylor, Simoneau, 1991; Peterson, 2014; Reed et al., 1979; Storie, 2015; Watson & Sargeant, 1986).

On-ice testing for anaerobic performance. A test that is specific to ice-hockey is needed to assess on-ice performance and ultimately evaluate playing potential. In the literature, there have been various on-ice protocols proposed to evaluate hockey playing potential. While replicating the physiological and mechanical demands of a game is a difficult task, the ultimate goal of sport-specific testing would be to replicate these demands as closely as possible. However, discrepancies exist among sport-specific assessments based on their ability to replicate game demands. Nonetheless, to assess anaerobic performance, various on-ice tests ranging from simple sprints to repeated skates have been suggested in the literature (Behm et al., 2005; Lariviere et al., 1976; Reed et al., 1979; Peterson, 2014; Storie, 2015; Watson & Sargeant, 1986).

One of the first on-ice tests to assess anaerobic performance was developed by Reed et al. (1979) and is known as the Reed Repeat Sprint Skate Test (RSS). The protocol requires players to perform six 54 meter sprints every 30 seconds. Anaerobic capacity, a

speed index, and a fatigue index are calculated by using the total sprint time and the time to skate one sprint (Montgomery, 1988). The average time to complete one bout of the RSS was 14 seconds and was found to be significantly correlated ($r = .82$) to the WAnT when relative peak power was assessed (Cox et al., 1995). Differences in trial time, power, and anaerobic capacity were found between elite and non-elite women's hockey players when the RSS was used (Bracko, 2001). According to Power, Faught, Pryzsucha, McPherson, and Montelpare (2012), the RSS has the highest reliability compared to the Sargent Anaerobic Skate Test and the 18.3-meter Sprint Test. However, the researchers suggested that the RSS was too exhausting and is criticized as a good representation of anaerobic performance because players are unable to complete the test or perform it at a maximal level. Based off the exhaustive nature of the RSS, the researchers suggested that it was ineffective at providing a reliable assessment (Power et al., 2012). Watson and Sargeant (1986) developed an on-ice test known as the Sargeant Anaerobic Skate Test (SAS40). The protocol consisted of a continuous 40-second, maximal effort skate from one end of the ice to the other where total distance covered was measured (Watson & Sargeant, 1986). It was reported by Watson and Sargeant (1986) to have high test-retest reliability. Anaerobic capacity was also found to be significantly correlated ($r = .73$) with the WAnT (Watson & Sargeant, 1986). While both the RSS and the SAS40 are more sport-specific than the WAnT, they are limited in skating mechanics based off the linear nature of the protocol. Power et al. (2012) criticized the exhaustive nature of both the RSS and SAS40, so researchers developed an on-ice test known as the Repeat Ice Skating Test (RIST).

The RIST was used as an assessment of anaerobic performance in adolescent hockey players and was validated against the WAnT, VJ, and Margaria-Kalamen Stair Test (Power et al., 2012). The protocol required players to perform six 49 meter sprints with 10 seconds of recovery between each (Power et al., 2012). The researchers found that the RIST had strong test-retest reliability with intra-class correlation scores ($r = .98$ and $r = .99$) for average relative peak power and average absolute peak power, respectively. The RIST was correlated with the WAnT ($r = .86$), VJ ($r = .86$), and the Margaria-Kalamen Stair Test ($r = .66$); and based off these correlations, researchers concluded that it was a valid and reliable on-ice anaerobic test for hockey players ages 11-16 years (Power et al., 2012). The skating pattern created a "U" shape consisting of a sprint from the midline into a single turn around the net finishing with a sprint through the midline. While the RIST is correlated to off-ice assessments, it was validated using adolescent hockey players and has a skating pattern that is not as specific to game demands, which may not be suitable for elite level players.

Hulka, Belka, Cuberek, and Schneider (2014) developed a more specific RSA test that required participants to perform twelve 80 meter sprints that consists of accelerations, stops, changes of direction, and backwards skating. Researchers measured course time, calculated a fatigue index, and also reported a high test-retest reliability for total time ($r = .98$), best time ($r = .96$) and fatigue index ($r = .74$; Hulka et al., 2014). Hulka et al. (2014) concluded that the test is a good indicator of RSA based on the high test-retest reliability and intraclass correlation coefficient ($r = .98$) for the best time score. However, peak and average power were not calculated and other physiological measures were not assessed to validate it against off-ice measures. Recently, more specific repeated sprint tests have

been developed to incorporate the physiological and mechanical demands of ice hockey

(Peterson et al., 2016; Storie, 2015).

Peterson et al. (2015a) developed an on-ice test with a skating pattern that

replicated specific movements seen in games as well as mimicked shift frequency,

duration, and intensity. The test was created by analyzing data from the NHL database

and is known as the On-Ice Repeated Shift Test (Peterson et al., 2015a). According to

Peterson et al. (2015a), the average shift length by a NHL forward is 45.5 ± 3.9 seconds,

the average shift frequency per period is 6.8 ± 1.1, with a rest interval of 73.4 ± 16.6

seconds. The On-Ice Repeated Shift Test requires the participant to skate 8 maximal bouts

with 90 seconds of rest between each (Peterson et al., 2015a). Acceleration (seconds),

max speed (seconds), fastest course time (seconds), and fatigue indexes were measured;

however, only acceleration, max speed, and fastest course time were found to be

significantly correlated with VJ, WAnT relative peak power, and WAnT relative mean

power (Peterson et al., 2016). Peterson and colleagues (2016) suggested that a player's

performance during the first shift of each period may more likely be contributed to off-ice

anaerobic power. According to their research, the On-Ice Repeated Shift Test validated

the use of VJ and WAnT for measuring peak and mean power in hockey players; however,

these off-ice assessments were not examined against a WAnT fatigue index. While off-ice

measures of anaerobic power have been shown to contribute to on-ice acceleration and

velocity, they did not predict the ability to reproduce high intensity sprints, which is

ultimately why an on-ice test is needed to assess the repeated bout nature of ice hockey

(Peterson et al., 2016).

Various researchers have advocated the need for a sport-specific test to evaluate the on-ice performance of ice hockey players (Hulka et al., 2014; Lariviere et al., 1976; Peterson, 2014; Power et al., 2012; Reed et al., 1979; Storie, 2015; Watson & Sargeant, 1986). Relationships have been found between off-ice measures of anaerobic power and on-ice acceleration, velocity and agility, respectively, but these measures have not been able to predict repeated sprint performance (Behm et al., 2005; Farlinger et al., 2007; Peterson et al., 2016; Runner et al., 2014; Storie, 2015). There are limited data for an on-ice test that replicate game demands as well as examine the specific physiological and mechanical requirements of ice hockey in skating pattern. Peterson and colleagues (2016) assumed that weak on-ice testing parameters are due to limited specificity between anaerobic power and RSA. The researchers stated that prominence should be placed on assessing a player's RSA instead of deeming anaerobic power as the most important factor for success in ice hockey (Peterson et al., 2016). To assess the repeated anaerobic performance of ice hockey players, Storie (2015) developed an on-ice test that mimicked game demands known as the Good-Storie Hockey Specific Test (HST).

Good-storie hockey specific test. An on-ice, anaerobic test was created and compared to the WAnT in elite level players in a study by Storie (2015). The HST was created to assess anaerobic properties as well as fatigue in elite hockey players (Storie, 2015). Storie also compared the HST amongst three separate groups of elite hockey players consisting of: The United States National Team Development Program (U17), NHL development players (DP), and NHL veteran players (NHL). The protocol consists of six maximal effort bouts that last on average 23-seconds, 30-seconds of rest is also given between each trial (Storie, 2015). The trial length was consistent with another on-

ice test using NHL data where the average time a player spent at maximal, or close-to-maximal intensity during a shift was 22.7 seconds (Peterson et al., 2015a). The participants also skated a pattern unique to their positions; defensemen performed backwards skating from blue line to blue line, as well as around cones; whereas forwards continued with forward skating the entirety of the test (Storie, 2015). The pattern was mechanically specific to hockey with tight turns, straight sprints, accelerations, and decelerations.

Relationships were found between the HST and WAnT, and significant differences were found in the HST among elite groups (Storie, 2015). Significant correlations between absolute peak and mean power, and post-exercise blood lactate during the HST and WAnT were reported. Strong relationships between trial time, relative mean power, mean speed, and trial fatigue index and the HST, respectively, were also reported (Storie, 2015). However, when the fatigue index was analyzed, no relationship was found between the HST and the WAnT (Storie, 2015).

Constant acceleration, peak heart rate (HR), and post-exercise blood lactate (BLa) were used as indicators of maximal effort to validate the HST as a true anaerobic test (Storie, 2015). Post-exercise blood lactate measures (10-12 mmol) were similar to those of a previous study that assessed the BLa of hockey players during a game (Noonan, 2010). According to Storie (2015), the high percentage of max HR and high BLa values of the HST compared to the WAnT were indicators to conclude that the glycolytic pathway was sufficiently stressed during the HST. Storie (2015) also assessed the anaerobic differences between forwards and defensemen during the study. Even though both positions skated different patterns, there were no significant differences found

between positions on any variables during the HST or the WAnT. However, when HST variables were compared amongst groups, significant differences were found among the NHL, DP, and U17 players (Storie, 2015). There are limited data on NHL caliber hockey players and the HST was able to distinguish differences among the three elite groups, showing that the NHL veterans were superior in all components of the test (Storie, 2015). In other research, biomechanical differences were found between high caliber and low caliber level hockey players during skating analysis, which further supports the argument and need for an on-ice test to assess hockey performance (Bukeridge et al., 2015; Turcotte & Pearsall, 2008). Similar to the exhaustive nature of other on-ice tests such as the RSS and SAS40, the HST may be better suited for elite level hockey players given it sufficiently taxed the glycolytic pathway in this population as well incorporated a hockey specific skating pattern.

Similar to other studies, the properties of the HST were examined to establish construct validity against the WAnT (Storie, 2015). However, as the literature expands, there may be a shift from the WAnT as the "gold-standard" for assessing athletes in a sport that encompasses an array of mechanical and physiological factors that affect performance. Predicting elite playing potential and on-ice performance with off-ice assessments is placing a limitation on players, thus providing unreliable data to coaches, general managers, and support staff. The ability to reproduce power is a crucial component to success in ice hockey; however, off-ice assessments, particularly the WAnT, do not provide a clear evaluation of on-ice performance for coaches to make data-driven decisions. While anaerobic power is still an important aspect in hockey, the slow rate of phosphocreatine resynthesis (3 – 5 minutes) inhibits the player's ability to produce

power in repeated, high-intensity shifts (Peterson et al., 2016). The time needed for PCr to recover may suggest why off-ice tests of anaerobic power have little to no relationship to on-ice performance, thus providing stronger evidence as to why an on-ice test is needed to assess hockey players (Baker, McCormick, & Robergs, 2010; Peterson et al., 2016; Storie, 2015). The HST assessed the anaerobic characteristics of elite level hockey players, while distinguishing characteristics of speed, acceleration, and RSA among three different elite level groups (Storie, 2015). However, the HST needs to be examined in a non-elite population to assist in validating it as a reliable sport-specific test in hockey players. To date, there has been no research conducted on the HST in a non-elite, hockey population.

Overall Summary

Ice hockey is a physical game that is played with three 20 minute periods at the NHL level. With erratic patterns of play, quick changes of direction, and multiple collisions, ice hockey demands an array of physiological attributes. Players must be lean to keep up with the speed of the game as well as demonstrate the ability to remain balanced and agile on a low-friction surface. The average shift frequency per period in the NHL was recorded at 6.8, with an average shift length of 45.5 seconds, and a near-maximal intensity per shift at 22.7 seconds, thus requiring players to exhibit multiple efforts of strength and power to be successful (Peterson et al., 2015a). Players must exhibit the ability to repeat short bursts of high-intensity efforts over the course of a game. It is important for teams to assess the RSA of players or prospects when evaluating on-ice performance.

The NHL is comprised of 23 active roster spots, with athletes from all over the world competing for a slot on a team. Off-ice assessments are used at the NHL Combine

and have been used by collegiate and professional teams to evaluate players. While some studies have found a relationship between off-ice anaerobic power and on-ice acceleration or velocity, it is also clear that off-ice tests have physiological limitations, protocol limitations, and overall inconstancies for hockey players; and, therefore, should be limited when coaches are making tactical and team decisions. Multiple studies have used the WAnT when evaluating anaerobic performance; however, this design does not replicate game demands nor is it specific to ice hockey. Researchers have also found that anaerobic power may not be as important of a factor to on-ice performance as previously assumed, and that RSA should be further assessed to define on-ice performance (Peterson et al., 2016). An on-ice test that assesses RSA gives players an ideal advantage to demonstrate their skating ability instead of being limited by off-ice protocols. Various on-ice assessments such as the RSS, SAS40, RIST, The On-Ice Repeated Shift Test, and the HST have been tested. While each of these tests attempts to define on-ice performance using skating protocols, only the HST was developed by researching highly elite level hockey players. The HST incorporates a sport-specific design to assess anaerobic properties and RSA in elite hockey players and distinguished performance differences among elite hockey groups. However, to date, it has not been assessed in a non-elite population. To assist in evaluating the HST as a reliable, sport-specific test in hockey players, the purpose of this research was to test for a relationship between the HST and the WAnT in a non-elite population of male ice hockey players, determine the within-trials reliability of the HST in a non-elite sample, and distinguish performance differences between elite and non-elite players.

CHAPTER III

METHODOLOGY

Participants

Male hockey players ($N = 11$), aged 18-28 years, playing club level hockey at a

NCAA DI school participated in this study. All players were cleared for participation in

exercise by the university physician. Club level hockey at the collegiate level defined this

group as non-elite when compared to NHL veterans (NHL), NHL development players

(DP), and United States National Team Development Program U17 players (U17).

Goaltenders were excluded because of the physiological demands specific to that position.

All participants received information on testing procedures and risks and provided written

informed consent. Participants were asked to refrain from alcohol consumption and

caffeine use 12 hours before testing, as well as heavy exercise 24 hours before testing.

Instrumentation

Blood lactate. A portable blood lactate (BLa) analyzer (Lactate Pro, Cycle Classic

Imports, Inc., Hurtsville, NSW, AUS) was used to assess maximal BLa immediately after

the WAnT and immediately after the last HST trial. One BLa sample was taken from the

participant's fourth proximal finger of the right hand. This assessment was used as an

indirect marker of maximal effort.

Heart rate. Polar HR monitors (Polar Team^2, Polar Electro, Inc., Lake Success,

NY, USA) were used to record HR immediately after the WAnT and the last trial of the

HST. This measurement was used as an indirect marker of maximal effort.

Wingate anaerobic test. A Monark cycle ergometer (894E Peak Bike, Health Care International, Inc., Langley, WA, USA) was used to conduct the WAnT. Participants performed the WAnT in workout clothing. Monark ATS software was used to obtain absolute peak power (APP) in watts (W), relative peak power (RPP) in watts per kilogram (W/kg), absolute mean power (AMP) in watts (W), relative mean power (RMP) in watts per kilogram (W/kg), and the fatigue index. A standardized 30-second WAnT protocol was used with flywheel resistance set to 0.075 kg per kg body mass. Seat height was adjusted accordingly to participant's comfort. At the beginning of the WAnT, participants were given a 5-second countdown and instructed to increase revolutions per minute (RPM) so that at "1" they were at maximal RPMs. At the end of the countdown, the coordinator said "GO" and pressed a button to release the weight cage, applying the 0.075 kg per kg of body mass resistance to the flywheel. The participant was encouraged to pedal for maximal effort against the resistance for 30-seconds.

Good-storie hockey specific test. For the on-ice assessment, the participants wore full hockey gear including the stick during the Good-Storie Hockey Specific Test (HST). Wireless timing lasers (TC Timing System, Brower Timing Systems, Draper, UT, USA) were used to record acceleration time and total trial time. The timing system were set at waist height so participants did not break the plane with their stick. Cones were provided as markers for participants to make tight maneuvers around. Regulation size hockey goals were attached to the ice so participants could skate around the net as part of the skating pattern. The protocol included six bouts of 152-meter sprints with 30-seconds of rest between each bout. The participant was notified when 10-seconds were left during the rest period, as well as received a 5-second countdown to "Go." To measure acceleration,

the wireless timing lasers were placed 15 m. from the starting line. This distance was chosen as a representation of peak power based on previous research by Storie (2015). The timing lasers were also placed at the finish line of the test to assess total trial time. The skating pattern included accelerations, decelerations, turns, tightknit maneuvers around cones, and sprints (Storie, 2015). The participant started to the right of the net, next to the boards, with his front skate behind the goal line. When he was ready, he accelerated as fast as possible to the center red line. Once he reached center ice, he made a sharp turn to his left to maneuver quickly around two cones. The first cone that the participant had to skate around was set on the center red line directly across from the neutral zone face off spot. The second cone was set on the blue line directly in line with the hash marks on the near face-off circle. Once he made his second turn, he skated towards the right post of the opposite goal, around the net, sprinted maximally towards the left post of the opposite goal, skated around the net, and finished with a sprint through the first blue line. Only defensemen transitioned to backwards skating at the first cone turn and at the final blue line to blue line skate (Storie, 2015). Participants were instructed to skate each rep at a maximal speed.

Procedures

Participants completed two testing sessions. Testing took place across two days with off-ice assessments the first day and the on-ice assessment the second day. Each test took approximately 10 minutes per participant. This research followed the same procedures as Storie (2015).

Off-ice assessments. At the start of session one, participants, in workout attire with shoes off, had their height (cm) and body mass (kg) measured with a stadiometer (Seca

213, Seca North America, Chino, CA, USA) and scale (160KL, Health O'Meter, McCook, IL, USA). Height (cm) will be measured to the nearest millimeter and body mass (kg) will be measured to the nearest gram, this data will be used to build a physiological profile for this population. Body mass (kg) will also be used to determine the appropriate flywheel resistance in the WAnT. After anthropometric measurements, the participant put on the HR monitor and warmed-up lightly on a separate cycle ergometer at 70 RPM's for 3- to 5-minutes. Following the warm-up, seat height was adjusted on the Monark 894E Peak Bike accordingly for comfort. The player then performed a 30-second WAnT protocol with a flywheel resistance of 7.5% of body mass. Immediately following the WAnT, one BLa measurement was taken at the fourth proximal finger on the right hand and post exercise HR was recorded. Participants then performed a 10- to 15-minute cooldown on a separate cycle ergometer.

On-ice testing. Day two testing took place at the hockey arena where participants performed the HST. Participants were instructed to wear full hockey gear including their stick as well as the Polar HR monitor. Each participant was given 8- to 10-minutes to conduct his typical pre-game warm-up on the ice. Only one participant performed the HST at a time. After the last trial of the HST, participants skated towards the researchers at the bench to have post exercise HR and BLa recorded. The BLa sample will be taken from the participant's fourth proximal finger on the right hand. These procedures ensured that the study followed the same testing protocol as Storie (2015). The HR and BLa assessments were used as indirect markers of maximal effort (Storie, 2015).

Data Analysis

All data analyses were performed using SPSS software (IBM, vr. 24.0). Mean (*M*)

and standard deviations (*SD*) were calculated for all variables. Pearson's correlation

coefficients were calculated to determine associations between the WAnT and HST

variables in the non-elite sample. Intra-class correlation coefficients for 15 m. and total

trial times were calculated to determine the within-trial reliability for each participant.

One-way analysis of variance (ANOVA) were performed to compare on-ice performance

variables among non-elite and three samples of elite players. WAnT and HST data from

elite players were obtained from a previous study by Storie (2015). Trial times were

converted to velocity (m/s) to remain uniform in comparison to the elite ice hockey

population.

Results

Eleven collegiate ice hockey players performed the WAnT and HST on two

separate days. Descriptive statistics for participants can be found in Table 1. There was a

significant, strong correlation for absolute peak power between WAnT and HST (refer to

Table 2). A moderately high relationship was also observed for relative peak power

between the WAnT and the HST. Power output from all six trials was significantly

correlated with the WAnT in regard to absolute peak power; however, only trial one ($r =$

.67, $p < .05$) and trial two ($r = .69, p < .05$) demonstrated a moderately high relationship

Table 1

Participant Descriptive Statistics (*N* = 11)

Participant characteristic	*M*	*SD*
Age (years)	20.9	2.6
Height (cm)	179.8	6.5
Body mass (kg)	79.2	9.3

Table 2

Pearson Product Correlations Between WAnT and HST ($N = 11$)

Variable	r	p
Peak power (W)	.88	< .001
Peak power (W/kg)	.78	.005
Fatigue index (%)	.69	.018
Post-exercise peak HR (bpm)	.73	.012
Percent of APMHR (%)	.50	.118
Blood lactate (mmol/dL)	.12	.734

Note. HR = heart rate. APMHR = age-predicted max heart rate. bpm = beats per minute. Post-exercise peak HR and blood lactate were assessed immediately after the WAnT and the final HST trial.

to the WAnT for relative peak power. When comparing peak and mean power outputs

from the WAnT to mean HST 15 m. times (s), there was a moderately high correlation for

relative peak power ($r = -.75$, $p < .05$) and relative mean power ($r = -.66$, $p < .05$).

However, no significant relationships were observed for average total trial times in regard

to peak or mean power output from the WAnT. When evaluating individual 15 m. trial

times, only trial one ($r = -.64$, $p < .05$) and trial two ($r = -.69$, $p < .05$) demonstrated

relationships to WAnT RPP.

Two fatigue indexes (%) were calculated from the HST by means of peak power

output and total trial power output. A moderately high correlation was demonstrated

between WAnT fatigue index ($M = 50.1\%$, $SD = 6.4$) and HST peak power fatigue index

($M = 14.2\%$, $SD = 5.2$); however, there was no significant correlation between the WAnT

fatigue index and the HST total trial power fatigue index. WAnT and HST results for the

sample can be found in Table 2. Intra-class correlation coefficients revealed a moderately

high reliability ($r = .72$, $p < .001$) for 15 m. time (s), and a high reliability ($r = .95$, $p <$

$.001$) for total trial time (s). When comparing the current sample to three previously

studied elite samples using the HST, significant differences were observed for almost all

HST variables among the samples. Specifically, there were significant differences among

groups for HST peak power ($F [3, 62] = 24.6$, $p < .001$), HST total trial power ($F [3, 62] =$

43.3, $p < .001$), 15 m. times (s) ($F [3, 62] = 12.4$, $p < .001$), and total trial times (s) ($F [3,$

$62] = 13.5$, $p < .001$). Results of the HST for the non-elite players are displayed in Table

3.

Table 3

HST Results for the Non-Elite Players (*N* = 11)

Variable	M	SD
Peak power (W)	3853.5*	474.2
Peak power (W/kg)	48.7*	2.0
Total trial power (W)	4392.6*	539.3
Total trial power (W/kg)	55.5*	2.5
Fatigue index (%)	14.2	5.2
15 m. time (s)	3.2*	0.1
Total trial time (s)	26.9^	1.2
15 m. velocity (m/s)	4.9*	0.2
Total trial velocity (m/s)	5.7*	0.3
Post-exercise peak HR (bpm)	176.7	5.6
Percent of APMHR (%)	89.0	2.1
Blood lactate (mmol/dL)	11.0	1.5

Note. HR = heart rate. APMHR = age-predicted max heart rate. bpm = beats per minute. Peak power and total trial power represent all six HST trials. Post-exercise peak HR and blood lactate were assessed immediately after the final HST trial. *Significantly different than three elite samples including the United States National Team Development Program U17 players, National Hockey League development players, and National Hockey League veteran players ($p < .05$). ^Significantly different than National Hockey League veteran players ($p < .05$).

CHAPTER IV

DISCUSSION

The HST was evaluated to determine if it is a reliable, sport-specific assessment of anaerobic power and fatigue for non-elite hockey players. The HST and WAnT were correlated for peak power, fatigue index, and post-exercise peak HR. A significant correlation was found between mean 15 m. times (s) and WAnT RPP and RMP. However, no significant relationship was found between mean total trial times (s) and WAnT power. Interestingly, various individual trials (s) demonstrated a significant correlation to WAnT power. The HST also demonstrated strong within-trials reliability for 15 m. and total trial times. To date, this was the first study comparing the HST among elite and non-elite ice hockey players.

When evaluating the trials individually, only trial one and trial two displayed a correlation to the WAnT for peak power. The same was also demonstrated for the HST trial times, where only the first two 15 m. times demonstrated a correlation for WAnT RPP and mean power; and the first three total trial times were correlated to WAnT RMP. However, no significant relationship existed between the mean of the six HST total trial times and WAnT power. When converting trial times to on-ice speed (m/s) there was a significant relationship between mean 15 m. velocity and WAnT RPP as well as mean total trial velocity and WAnT RMP. A moderately high correlation also existed between the first two 15 m. trials (m/s) and WAnT RPP, and the first three total trials (m/s) and WAnT RMP. Thus, giving insight into the inability of the WAnT to provide consistent and adequate data about the RSA of non-elite ice hockey players.

Similar to previous research conducted by Storie (2015), APP was found to be highly correlated between the HST and WAnT. However, RPP demonstrated a moderately high correlation between the HST and WAnT which is in contrast with Storie's study (2015) where there was no correlation for this variable. Previous studies also demonstrated on-ice speed to be correlated with peak power in the WAnT, however multiple researchers concluded that it only provided insight into the first shift because there is no assessment of repeated performance (Janot et al., 2015; Peterson et al., 2016; Potteiger et al., 2010; Storie, 2015). Similar findings were observed within this study as WAnT peak power was only correlated with the first two 15 m. trial velocities, thus giving credibility to the need for an on-ice repeated sprint assessment such as the HST. Fatigue index (%) between the HST and WAnT was also found to be significantly correlated for the current sample of non-elite players, which was not found in Storie's study (2015) where fatigue index between the HST and WAnT showed no correlation for the elite players. Ultimately, the dissimilarities between this study and Storie's (2015) in regard to correlations for RPP and correlations for the fatigue index may be due to the sport-specificity of the HST and the elite players' ability to perform significantly better on the HST.

Multiple performance differences distinguished the current sample of non-elite players from the three previously studied elite samples (U17, DP, and NHL). Interestingly, there were no significant differences for WAnT peak and mean power among the current sample of non-elite players and the previously studied U17 players (Storie, 2015). However, when comparing the non-elite and U17 groups on the ice there were significant differences for APP, RPP, and total trial power (Storie, 2015). The U17

players produced greater power and were faster than the non-elite sample (Storie, 2015).

This finding lends credibility of using the HST to distinguish anaerobic power output

between skill levels whereas this was not possible using the WAnT.

Overall, the non-elite players produced significantly less power and were slower

when compared to the elite samples (Storie, 2015). However, only the NHL veteran

players were significantly faster for every bout than the non-elite when 15 m. times and

total trial times were compared (see Table 4; Storie, 2015). The U17 and DP samples

were not significantly faster than the non-elite players until trial five of the HST for 15 m.

times (Storie, 2015). This observation could be due to pacing strategies conducted by the

elite players, which was listed as a limitation in Storie's study (2015). The lack of

differences in total trial times among the non-elite, U17, and DP groups is possibly due to

the difference in rink size (Storie, 2015). Storie (2015) used an NHL regulation rink with

the dimensions of 200 ft. x 85 ft. where the total distance covered during one HST trial

was 166 m. In this study, the rink available had dimensions of 185 ft. x 85 ft., where the

total distance covered during one HST trial equaled 152 m. However, when comparing

the mean 15 m. velocity and mean total trial velocity among the non-elite players and the

other elite players, the non-elite players were significantly slower than the U17, DP, and

NHL players regardless of rink size (Storie, 2015). Analyzing the trials individually may

give further insight into the RSA differences among the elite and non-elite players.

There were no statistically significant differences for APP between the non-elite

and U17 players until HST trial three (Storie, 2015). There were also no differences in

RPP or 15m. velocity among the non-elite, U17, and DP players until HST trial five

(Storie, 2015). However, the non-elite sample was significantly slower than each elite

sample in total trial velocity for all six HST trials (Storie, 2015). The same was also

observed for total trial power where the non-elite group produced significantly less

absolute and relative power for all six HST trials. The differences among groups for total

trial velocity and power may be due to the inability of the non-elite sample to effectively

generate ATP via the ATP-PC and anaerobic glycolysis energy systems; ultimately

hindering their ability to maintain anaerobic power output across the six trials. Also, the

rest between HST bouts (30-seconds) may limit the non-elite players' ability to produce

repeated efforts of anaerobic power due to inhibitory effects to muscular contraction from

anaerobic metabolism and PCr recovery times (Girard et al., 2011). Therefore, the

requirement for ATP cannot be adequately supplied through these energy pathways alone

(Maughan et al., 1997). These observations may lead to questions about the role that the

oxidative system plays in repeated sprint performance based on previous research

conducted by Peterson et al. (2015a). The elite level players may have a more effective

oxidative pathway in which their ability to generate ATP during trials and recover

between trials is enhanced. Nonetheless, these observations demonstrate the need for a

repeated bout on-ice test rather than a single bout off-ice assessment to evaluate on-ice

performance characteristics and differences among skill levels.

When comparing fatigue across trials, the non-elite sample demonstrated a greater

HST fatigue index (%) however, there were no significant differences for this variable

among the non-elite and the three elite groups, respectively (Storie, 2015). Interestingly,

the same observation was made for the WAnT fatigue index (%); therefore, the HST and

WAnT did not detect statistically significant differences in skill level in regard to fatigue.

However, practical significance may play a greater role than statistical significance for this

variable in which the non-elite players have displayed a greater power decrement across repeated sprint trials. In contrast, a fatigue index may not be the separating factor among the non-elite and elite samples; from the results of this study the ability to accelerate quickly on the ice and ultimately produce greater repeated efforts of power may be the key performance indicators among the players. In regard to independent variables used as indicators of maximal intensity exercise, there were no significant differences among skill levels for HST post-exercise peak HR or HST blood lactate (Storie, 2015). When compared to the WAnT, there was a high correlation for post-exercise peak HR, however there was no correlation for blood lactate. Interestingly, the HST elicited a greater average blood lactate than the WAnT. Similar to Storie's study (2015), these observations lend credibility to the HST as a maximal intensity assessment that sufficiently taxed the anaerobic energy pathway for the non-elite sample.

In summary, the HST and WAnT had a significant relationship for peak power, fatigue index, and post-exercise HR; however, only HST trials one and two were related to peak power. A similar relationship for trials one and two was also observed between 15 m. time (s) and both WAnT RPP and WAnT mean power, respectively. In regard to total trial time, a significant correlation existed between each of the first three trials and WAnT RMP; however, there was no relationship between the average of the six total trials and WAnT power output. Similar observations also existed for 15 m. velocity (m/s) and total trial velocity (m/s) in regard to WAnT power; however, the need for a sport-specific ice test such as the HST is supported with this study. The WAnT was unable to adequately delineate performance characteristics between the U17 and non-elite players, as well as demonstrate a consistent relationship between power output and repeated bouts of sport-

Table 4

HST 15 m. Trial Times for the Non-Elite Players ($N = 11$)

Trail	*M* (s)	*SD*
1	2.75*	0.17
2	2.86*	0.19
3	3.05*	0.18
4	3.13*	0.26
5	3.26*^	0.14
6	3.21*^	0.16

Note. *Significantly different than National Hockey League veteran players ($p < .05$). ^Significantly different than United States National Team Development Program U17 players and National Hockey League development players ($p < .05$).

specific, on-ice sprints (Storie, 2015). In contrast, the HST distinguished performance

characteristics for all on-ice variables among groups (Storie, 2015). Each previously

studied elite samples (U17, DP, and NHL) produced greater power and displayed greater

velocity than the current sample of non-elite players (Storie, 2015). Although not

statistically significant, a greater fatigue index (%) was observed for the non-elite players

when compared to the elite samples (Storie, 2015). Ultimately, the HST was able to detect

the ability of a non-elite sample to produce power and resist fatigue in repeated sprint

exercise.

 The HST is a reliable, sport-specific assessment of anaerobic power and fatigue in

non-elite hockey players. Although limitations and future implications for research do

exist within this study. While not measured during this research, the HST may provide

insight into the effect the oxidative pathway has on RSA due to its 1:1 work to rest ratio.

A future study may be needed to assess the oxidative capacity during the HST with means

of a portable metabolic unit to determine any significant effects on trial times and fatigue

index. In regard to HST rest time between bouts, 30-seconds does not necessarily

represent the time between shifts according to previous research nor does it represent the

time necessary to recover from maximal anaerobic exercise (Peterson et al., 2015a).

Therefore, a greater rest interval (up to 75-seconds) may elicit greater anaerobic power

outputs and allow the HST to become more sport specific. The calculation of body mass

on the ice was also a limitation to this study; however, to conduct similar research to

Storie (2015), body mass with gear was not taken into account during the power

calculations.

When compared to the WAnT, the HST is an inexpensive test only requiring timing gates and cones, and resembles a specific skating pattern observed in ice hockey. This assessment can be utilized to meet the various demands of a coaching staff in regards to player recruitment and development. The HST is able to delineate on-ice performance characteristics among skill levels which could assist in the identification of prospects. Strength and conditioning coaches as well as Sport Scientists could also utilize the HST as a performance monitoring tool to evaluate the effectiveness of a training program as well as determine the players' ability to perform repeated, high-intensity bouts during the pre-season. In regard to tactical decisions, the HST could play a role in line pairings, whereas the WAnT is unable to do so as an off-ice, single effort test. Even though the WAnT is recognized as the "gold standard" and is used at the NHL Combine, a case can be made to promote the HST as a new standard to evaluate anaerobic performance on the ice.

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APPENDIX

APPENDIX A

IRB LETTER OF APPROVAL

IRB
INSTITUTIONAL REVIEW BOARD
Office of Research Compliance,

010A Sam Ingram Building,

2269 Middle Tennessee Blvd

Murfreesboro, TN 37129

IRBN001 - EXPEDITED PROTOCOL APPROVAL NOTICE

Tuesday, November 08, 2016

Investigator(s):   Michael Self; Dr. Jennifer Caputo; Dr. Vaughn Barry

Investigator(s') Email(s): mls9f@mtmail.mtsu.edu; jenn.caputo@mtsu.edu

Department: Health and Human Performance

Study Title: The Good-Storie Hockey Specific Test Compared Between Elite
and NonElite Ice Hockey Players

Protocol ID: **17-2086**

Dear Investigator(s),

The above identified research proposal has been reviewed by the MTSU Institutional Review Board (IRB) through the **EXPEDITED** mechanism under 45 CFR 46.110 and 21 CFR 56.110 within the category *(4) Collection of data through noninvasive procedures* A summary of the IRB action and other particulars in regard to this protocol application is tabulated as shown below:

IRB Action	APPROVED for one year from the date of this notification		
Date of expiration	<mark>11/30/2017</mark>		
Participant Size	40		
Participant Pool	University of Tennessee - Hockey Club		
Exceptions			
Restrictions			
Comments			
Amendments	**Date**	**Post-approval Amendments**	

This protocol can be continued for up to THREE years (<mark>11/30/2019</mark>) by obtaining a continuation approval prior to <mark>11/30/2017</mark>.   Refer to the following schedule to plan your annual project reports and be aware that you may not receive a separate reminder to complete your continuing reviews.   Failure in obtaining an approval for continuation will automatically result in cancellation of this protocol. Moreover, the completion of this study MUST be notified to the Office of Compliance by filing a final report in order to close-out the protocol.

Continuing Review Schedule:

Reporting Period	Requisition Deadline	IRB Comments
First year report	11/30/2017	
Second year report	11/30/2018	
Final report	11/30/2019	

The investigator(s) indicated in this notification should read and abide by all of the post-approval conditions imposed with this approval. Refer to the post-approval guidelines posted in the MTSU IRB's website. Any unanticipated harms to participants or adverse events must be reported to the Office of Compliance at (615) 494-8918 within 48 hours of the incident. Amendments to this protocol must be approved by the IRB. Inclusion of new researchers must also be approved by the Office of Compliance before they begin to work on the project.

All of the research-related records, which include signed consent forms, investigator information and other documents related to the study, must be retained by the PI or the faculty advisor (if the PI is a student) at the secure location mentioned in the protocol application. The data storage must be maintained for at least three (3) years after study completion. Subsequently, the

researcher may destroy the data in a manner that maintains confidentiality and anonymity. IRB reserves the right to modify, change or cancel the terms of this letter without prior notice. Be advised that IRB also reserves the right to inspect or audit your records if needed.

Sincerely,

Institutional Review Board

Middle Tennessee State University