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The Relationship Between On-Ice Aerobic Capacity and On-Ice Power Output

A THESIS

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The Relationship Between On-Ice Aerobic Capacity and On-Ice Power Output

Abstract

There is debate if a high aerobic capacity will improve recovery from repeated bouts of sprinting, which primarily taxes the anaerobic energy systems. The relationship between aerobic capacity and repeat sprint ability in ice hockey players is not well established; moreover, the relationships that have been examined involved off-ice testing protocols, which lack specificity to the ice hockey. **Purpose:** The purpose of this study was to examine the relationship between on-ice aerobic capacity (VO_{2peak} and V_{IIT}) and repeated on-ice sprint ability (RISA) via percentage of power output decrement (%DPO), and other measurements of on-ice power output (OPO). **Methods:** 11 male professional ice hockey players, recruited from an American Hockey League team, participated in two maximal effort on-ice tests. Aerobic capacity was tested via the 30-15 Intermittent Ice Test. Gas exchange was measured directly measured via an Oxycon portable O_2 analyzer in four of the participants. OPO was measured via the Repeat Ice Skating Test. The relationship between these variables for nine of the participants was then analyzed via Pearson's correlational testing. **Results:** There was no significant relationship between V_{IIT} or VO_{2peak} to %DPO (r =-.036 and .197 respectively; $p > .05$) or any other measurement of RISA. **Discussion:** The results from this study suggest that aerobic capacity was not related to RISA. While the results were not statistically significant, likely due to a small sample size, the effect size for %DPO and aerobic capacity (V_{IIT} and VO_{2peak}) was small, indicating that the relationship was nearly negligible. Elite level ice hockey players may not have a better RISA resultant from a higher aerobic capacity.

Chapter One: Introduction

Significance

Ice hockey can be characterized as a high-intensity, contact sport, typically consisting of intermittent periods of sprinting, followed by periods of "coasting" (Montgomery, 1988). The typical "shift" during a game generally lasts anywhere from 45-70 seconds, with ~30 seconds of that time being characterized as "skating time," and the remaining time being, "non-skating time" (Horrigan & Kreis, 1994). After a player's shift, he/she will return to the bench and rest for approximately three to five minutes (Montgomery, 1988).

There is a prevailing idea amongst many fitness professionals who work alongside ice hockey players that a high aerobic capacity (often measured as relative VO_{2max}) is necessary for players to recover more rapidly from repeated bouts of anaerobic skating (Montgomery, 1988; Twist & Rhodes, 1993). This can be attributed to increased reoxidation of lactate via slow-twitch muscle fibers, and increased oxidative energy system contribution during high-intensity exercise, which could spare glycogen and phosphocreatine stores (Tomlin & Wenger, 2001; Twist & Rhodes, 1993). While there is debate as to whether or not that is true, the belief that a high aerobic capacity is necessary for optimal performance is prevalent within the sport (Bishop, Lawrence, & Spencer, 2003; Carey, Drake, Pliego, & Raymond, 2007; Green, Pivarnik, Carrier, & Womack, 2006; Montgomery, 1988; Nagasawa, 2013). Existing evidence supports the notion that VO_{2max} is related to repeat sprint ability up to a certain point. It appears that in untrained subjects there is a correlation between the two variables; however, the relationship in trained subjects appears to be nebulous (Bishop et al., 2003; Tomlin & Wenger, 2001).

One major problem with fitness testing for ice hockey is that the testing is often not specific to the sport itself, and usually takes place off-ice (Montgomery, 1988, 2006; Quinney et al., 2008). Likewise, testing for aerobic capacity often involves continuous submaximal workloads, which does not reflect the intermittent natures of many sports, including ice hockey (Buchheit, 2008). Therefore, results comparing off-ice aerobic capacity to on-ice repeated sprint ability should be interpreted with caution, as the testing is often not specific enough to the sport itself (Behm, Wahl, Button, Power, & Anderson, 2005; Durocher, Jensen, Arredondo, Leetun, & Carter, 2008a; Montgomery, 1988).

Some researchers have compared off-ice VO_{2max} to on-ice anaerobic performance and/or recovery, but it appears that there has not been any research that has compared the relationship between on-ice aerobic capacity and power output (PO) during repeated bouts of on-ice sprinting (Carey, et al., 2007; Roczniok et al., 2012). Additionally, it has been suggested that there is a need for further testing of multiple on-ice aerobic testing protocols using professional hockey players and direct gas exchange measurement. (Leone, Leger, Lariviere, & Comtois, 2007; Buchheit Lefebvre, Laursen, & Ahmaidi, 2011). The dearth of such evidence reflects the need for further investigation regarding this topic. Moreover, conditioning protocols for hockey players are often prescribed by hockey coaches who have little to no educational background regarding energy system utilization (Twist & Rhodes, 1993). The evidence from the current investigation could provide strength and conditioning professionals, as well as ice hockey coaches, a practical view of how to incorporate conditioning protocols for their players. With professional hockey coaches placing a premium on the ability to sustain high performance throughout the duration of a game, it is important to prioritize appropriate and specific conditioning protocols to adequately prepare players (Montgomery, 1988; T. Nelson, personal communication, October 8, 2014; Twist & Rhodes, 1993).

Purpose

The purpose of this study was to test for the relationship between on-ice aerobic capacity (VO_{2peak} and/or final skating velocity during the 30-15 Intermittent Ice Test*)* and repeated on-ice sprint (RISA) ability via a % decrement in PO (%DPO), peak PO (PPO), relative PO (RPPO), mean PO (MPO), and relative mean PO (RMPO) in elite ice hockey players.

Hypothesis

$H_{0:}$ The null hypothesis states that there would not be a significant relationship between on-ice aerobic capacity (VO_{2peak} and V_{IIT}) and on-ice PO (%DPO, PPO, RPPO, MPO, and RMPO) in elite ice hockey players.

H_A: The researcher's hypothesis was in agreement with H_0 in that there would not be a significant relationship between on-ice aerobic capacity and on-ice PO (%DPO, PPO, RPPO, MPO and RMPO) in elite ice hockey players (Carey et al., 2007; Nagasawa, 2013).

Assumptions

The researcher assumed that the participants put forth maximal efforts during testing. It was also assumed that the participants were in similar physiological conditioning states, as they have similar lifestyles and similar physiological stressors. The researcher also assumed that VO_{2peak} taken during the 30-15 Intermittent Ice Test ($30\text{-}15_{IIT}$) would have a strong correlation to the final skating velocity (V_{IIT}) achieved during the test.

Limitations

Limitations of this study included: the indirect estimation of PO, the small sample size of the subjects (n = 11 total; n = 9 for correlational testing), and the time constraints related to ice-time and participant availability. Additionally, OPO was estimated using the Repeat Ice Skating Test (RIST), which is a field test, and lacks the improved accuracy that may improve via direct measurement (ACSM, 2010). The participants likely had better skating performances while skating on their preferred side of the ice during the RIST, which may have skewed the results. Moreover, not all of the participants were able to utilize the direct gas exchange measurement that were taken during $30\text{-}15_{\mathrm{IIT}}$ testing, meaning that V_{IIT} was used in comparison with OPO, which was also an indirect estimation of aerobic capacity. Additionally, the distance skated was an estimate taken from the average of skating tracks in the ice left after testing.

Lastly, there are a limited number of subjects that could not participate in this study due to a variety of factors including, but not limited to: injuries and recalls by the clubs' NHL affiliate, which further reduced the sample size of this study.

Delimitations

Delimitations of the study included: only male professional hockey players between the ages of 18 and 35 were used, and the exclusion of goaltenders participation due to the different physiological demands of their position (Besson, Buchheit, Praz, Dériaz, & Millet, 2013). The aformentioned delimitations resulted in normally distributed data, improving the validity of the study.

Definitions

- Fatigue Index (FI): Used to describe a decrease in repeated sprint ability by calculating the drop off from best to worst performances (Oliver, 2009).
- Mean power output (MPO): Average of power output during the Repeat Ice Skating Test (Oliver, 2009).
- Peak power output (PPO): The highest power output measurement observed during RIST trials (Carey et al., 2007). This will also be measured in watts.
- Percent decrement of power (%DPO): The percent decrease in power output observed over subsequent RIST trials (Oliver, 2009). Calculated via the following equation: %DPO= ((PPO – MPO) / PPO) x 100 (Oliver, 2009).
- Power output (PO): The amount of work (force * distance) that can be performed over a period of time. Power = ((Force*Distance) / Time). This will be measured in watts (ACSM, 2010).
- Repeat ice skating test (RIST): An on-ice test used to measure anaerobic PO of hockey players (Power, Faught, Przysucha, McPherson, & Montelpare, 2012).
- V_{IIT}: Final skating velocity completed during the $30\text{-}15_{IIT}$. A multifactorial variable for measuring aerobic capacity (Buchheit et al., 2011).

Summary

There is conflicting evidence pertaining to the relationship between aerobic capacity and measurements of RSA, especially in ice hockey players (Carey et al., 2007). The purpose of this study was to examine the relationship between on-ice aerobic capacity (VO_{2peak} and/or V_{IIT}) and RISA (%DPO, PPO, RPPO, MPO, and RMPO). The results of this study will help to clarify the relationship between the aforementioned variables, and could possibly shed light on training protocols for fitness professionals in order to further optimize on-ice performance.

Chapter Two: Review of Literature

The intent of this section is to further the reader's understanding of ice hockey, the physiological demands of the sport, and the importance of the research question. The evidence from this study could be used to help prioritize training protocols for elite ice hockey players. Moreover, this section will familiarize the reader with the background and physiological demands of ice hockey, as well as the roles of: high aerobic capacity; anaerobic power output; anaerobic recovery; the conflicting evidence in relationship between aerobic capacity and measurements of RSA; and the need for more specific testing for ice hockey players.

Background Information

Ice hockey is a sport that is played in an oval-shaped "rink." Plastic boards and Plexiglas enclose the rink. Between the boards is a sheet of ice on which the game is played. There are six players on the ice, per team, during "even-strength" play (three forwards, two defenseman, and one goaltender). Players wear ice hockey skates, full protective gear, and utilize an ice-hockey stick to pass, shoot, and defend the puck. The puck is a small, short, cylindrical piece of vulcanized rubber, which is the equivalent of balls in other sports. The objective of the sport is to have scored more goals than the other team after the completion of the three 20-minute periods of play. The sport is played at a rapid pace, and involves full-body "checking" (full-body contact, similar to "hitting" in American football; Bracko, 2004).

Physiological Demands

Ice hockey is a high-intensity sport, which relies heavily on anaerobic substrate utilization (Montgomery, 1988). The typical "shift" during a game generally lasts anywhere from 45-70 seconds, with ~30 seconds of that time being characterized as "skating time," and the remaining time being, "non-skating time" (Horrigan & Kreis, 1994). These time frames are congruent with those in which anaerobic metabolism is the primary energy provider; however, a high aerobic capacity is considered by many to be requisite to playing ice hockey at an elite level (McArdle et al., 2010; Montgomery, 1988; Twist & Rhodes, 1993). To a certain degree this seems to be true. The mean VO_{2max} of 853 elite level junior hockey players was 57.4 ml/kg/min, putting the mean of said players in the "superior" category for aerobic capacity relative to age and gender (ACSM, 2010; Burr et al., 2008). This suggests that there may be an inherent need for a high aerobic capacity to compete in the sport at a high level, which may be important when considering its high-intensity intermittent nature.

Because of the physiological demands of the sport, elite level ice hockey players need well-rounded physical fitness levels encompassing multiple variables including: anaerobic power production, aerobic capacity, muscular strength, muscular endurance, and flexibility (Nightingale, Miller, & Turner, 2013). While these variables are often related to measurements of on-ice success, the skill involved in playing the sport is of greater importance to coaches and players than off-ice fitness measurements (Bracko, 2004; T. Nelson, personal communication, October 8, 2014).

Benefits of a High Aerobic Capacity

According to McArdle et al. (2010), increasing cardiorespiratory endurance (i.e. aerobic capacity) can lead to an increase in: oxygen supply to working muscles, mitochondrial density, capillary density, aerobic enzyme activity, and type II muscle fiber transformation to type I. All of these are positive factors if the person's goal is to increase his/her ability to sustain submaximal workloads over an extended period of time (Buchheit & Laursen, 2013a). Twist and Rhodes (1993) stated that increasing aerobic capacity could increase lactate reoxidation in type I muscle fibers, which may be beneficial in fatigue avoidance. Brooks (2009) also found that mitochondria are able to metabolize lactate, which implies that increasing mitochondrial density could result in improved metabolism of lactate on an intracellular level. Since lactate accumulation is accompanied by an increase in acidity (resulting in a decrease in muscle pH), which limits binding of calcium ions to the troponin within a sarcomere (resulting in muscular fatigue), theoretically, increasing aerobic capacity could result in the ability to sustain higher workloads over a longer period of time (Brooks, 2009; McArdle et al., 2010).

However, improving aerobic capacity is not synonymous with low-intensity, long duration training. In fact, Buchheit and Laursen (2013a, 2013b) stated that training at supramaximal VO_{2max} levels leads to greater improvements in aerobic capacity than training at lactate threshold (LT). Of importance, LT is lower than VO_{2max}, but is highly dependent on training status (McArdle et al., 2010). This type of training could theoretically improve aerobic capacity, LT, and sustained power output (Buchheit & Laursen, 2013a, 2013b). Moreover, high lactate accumulation, which is common during hockey games, combined with improved mitochondrial density could result in greater lactate metabolism in hockey players (Brooks, 2009; Buchheit & Laursen, 2013a; McArdle et al., 2010). It should be noted that the aforementioned training protocols are more similar to the demands of a hockey game as opposed to low-intensity, steady state cardiorespiratory endurance training (Buchheit et al., 2011).

Benefits of an Improved Anaerobic Power Output

McArdle et al. (2010) stated that there are three main improvements that occur via anaerobic training (which are the primary energy systems utilized in ice hockey): Improved levels of anaerobic substrates:

1. PCr, glycogen stores, and ATP stores
2. Improved threshold levels of glycolytic enzyme activity (i.e. phosphofructokinase) in type II muscle fibers
3. Higher blood lactate levels occurring during maximal exercise

Higher blood lactate levels are indicative of increased glycolytic activity, which implies that the body is metabolizing energy at a rapid pace (McArdle et al., 2010). This is beneficial for multiple sprint sports (i.e. ice hockey) because the body needs to quickly generate energy; at a sustained pace for longer periods of time than ATP-PCr (McArdle et al., 2010; Montgomery, 1988). As previously stated, training outlined by Buchheit and Laursen (2013a, 2013b) can lead to increases in anaerobic PO as well as mitochondrial density. The latter improvement is resultant to an individual's ability to metabolize lactate as energy within the muscle, as opposed to delayed metabolism by the heart, brain, or the liver in the Cori cycle (Brooks, 2009; Buchheit & Laursen, 2013b; McArdle et al., 2010). This type of training can also improve muscle glycogen storage, which could be extremely important, as ice hockey players can deplete up to 70% of their muscle glycogen stores after approximately 10 shifts (Durocher, Leetun, & Carter, 2008b).

Durocher, Leetun, et al. (2008b) found that collegiate ice hockey players' mid-season skating velocity at LT were significantly higher than pre-season ($p < .01$). This further substantiates the theory that lactate can be utilized as energy by the muscles, which could increase LT. Additionally, Bishop et al. (2003) recruited 14 elite level female field hockey players and compared the relationship between VO_{2peak} (mean: 55.7± 3.2 ml/kg/min), H^+ ion concentration, and RSA using a cycle ergometer. The authors found that H^+ ion concentration was more related to RSA ($r = .63$; $p < .05$) than VO_{2peak} ($r =.3$; $p > .05$). These findings suggest that LT (represented by the H^+ accumulation) might be a better indicator of RSA than aerobic capacity (in this case, VO_{2peak}). Improved anaerobic substrate utilization may actually be a positive adapation for hockey players, as opposed to a negative one (Brooks, 2009).

Benefits of Improved Anaerobic Recovery

There are multiple physiological measurements that can be utilized to track recovery from anaerobic work such as: heart rate, blood lactate, oxygen consumption, etc. (Besson, et al., 2013); however, the ability to maintain PO during repeated sprints is a specific indicator as to how well an individual can recover from repeated bouts of anaerobic work (Carey et al., 2007; Oliver, 2009). The ability to maintain power during a hockey game may also lead to improved play (Farlinger, Kruisselbrink, & Fowles, 2007; T. Nelson, personal communication, October 8, 2014). Theoretically, a powerful athlete who can maintain his/her power from shift-to-shift or sprint-to-sprint may be able to benefit his/her team more than an athlete who cannot (T. Nelson, personal communication, October 8, 2014).

Aerobic Capacity and Anaerobic Recovery

There has been ample research comparing the relationship between aerobic capacity and anaerobic recovery (often measured via RSA testing). Despite the large body of evidence pertaining to this subject, the literature itself is conflicting; moreover, there is a lack of empirical evidence, which compares the two aforementioned variables in a sport specific manner for ice hockey, much less in elite level players.

For example, Green et al. (2006) found that off-ice VO_{2max} was a significant predictor of scoring chances throughout a season in collegiate hockey players *(r* = .41, *p* < .03). This study indicated that a higher aerobic capacity is correlated to greater chances of scoring in a game. However, the same researchers found that VO_{2max} was not significantly related to minutes played throughout the season (*r* = .20; *p* > .05). These researchers also found a significant relationship between blood lactate levels and minutes played throughout the season (*r* = .41; *p* < .03). While it does appear that aerobic capacity could result in greater scoring chances, the reliance on anaerobic metabolism was more important for minutes played during an ice hockey game. This could further substantiate speculation that aerobic capacity is not requisite to anaerobic recovery due to a higher reliance on glycolytic metabolism.

Roczniok et al. (2012) recruited 21 elite level male hockey players from the Polish U20 national team and found significant relationships between off-ice VO_{2max} (mean: 57.88 ± 4.94 ml/kg/min) with skating agility and stop-and-start skating time (*r* = -.68 and -.62 respectively; *p* < .05); however, aerobic capacity was measured via off-ice testing, which lacks the aforementioned specificity of testing. The authors also found a significant relationship between relative anaerobic PO (watts/kg; measured via a Wingate cycle ergometer test) and skating agility and stop-and-start skating time (*r* = -.58 and -.57 respectively; *p* < .05). Again, this test was not as specific as an on-ice test, but the results still suggest that anaerobic PO can result in improved on-ice performance. That notwithstanding, aerobic capacity did have a stronger relationship to on-ice skating performance than that of anaerobic power, although both relationships were significant ($p < .05$).

McNeely, Millette, Brunet, and Wilson (2010) recruited 21 male NCAA Division I ice hockey players and compared the relationship between off-ice aerobic capacity, an on-ice FI, and lactate removal following repeated on-ice sprints. The authors found that off-ice VO_{2max} (mean: 59.6 ± 5.48 ml/kg/min) was significantly and inversely related to on-ice FI and lactate removal ($r = -.455$ and -.49 respectively; $p < .05$). This implies that a higher aerobic capacity is related to lower fatigue in elite ice hockey players. However, the Reed Repeat Sprint Test (on-ice repeat sprint used in this study), is known for being especially difficult (Buchheit et al., 2011). This could have resulted in pacing effect in some of the subjects, which may have skewed the FI data (Oliver, 2009; Power et al., 2012; Watson & Sargeant, 1986). Additionally, FIs have been shown to have a high coefficient of variability, meaning that if a FI was not calculated properly or slightly skewed by pacing, the data would strongly skewed, especially considering the relatively low magnitude of sprint times compared to those of PO in watts (Oliver, 2009).

Peterson and colleagues (2015) recruited 45 male college and elite level junior hockey players and compared the relationship between on-ice aerobic capacity and RISA. The participants were asked to complete a maximal effort aerobic capacity test, on a synthetic skating treadmill to establish the participants' VO_{2peak}. The participants were then asked to engage in an on-ice shift simulation skating test to examine their RISA. This test involved multiple changes of direction, and lasted approximately 23 seconds with 90 seconds of rest in between each repetition. Eight total repetitions were completed. The authors then calculated a time decrement score similar to that of other FIs (% Decrement Score = (100 x (Total Sprint Time ÷ Ideal Sprint Time) – 100). There were three timing points set-up throughout the skating course. A decrement score was calculated for each (gate one, gate two, and total course). It was found that VO_{2peak} was not significantly related to gate one fatigue, nor total course fatigue (r = -.11 and -.17 respectively; $p > .05$); however it was significantly related to gate two fatigue (r = -.31; p < 05). It was also stated that the number of stages completed on the aerobic capacity test was significantly related to RISA for gate two fatigue ($r = .46$; $p < .01$) and total course fatigue ($r = .32$; $p < .05$), but not gate one fatigue ($r = -.21$; $p > .05$). The authors attributed the significant relationship between VO_{2peak} and gate two fatigue to an increase in glycolytic metabolism at this time (10-25 seconds into the sprint), resulting in a lower muscle pH. They hypothesized that players with a higher aerobic capacity would be able to buffer H^+ ions more efficiently, thus improving RISA via an improved reliance on aerobic metabolism. They also theorized that gate one fatigue was not significantly related to VO_{2peak} because the half-life of PCr restoration is about 21 seconds, meaning that the participants may have been more proficient at the beginning of the test because PCr was likely the primary fuel source. It was also stated that the relationship between the maximum number of stages completed during the aerobic capacity test and the other decrement scores was indicative of higher skating proficiency in these participants, meaning that better skaters would use less energy than inefficient skating.

While these results are intriguing, they should be interpreted with caution for numerous reasons. For example, the aerobic capacity test was performed while skating, which would imply that the test was specific to the sport; however, skating treadmills use synthetic plastic, which may increase the friction of the skating surface. Additionally, this test was performed in a continuous fashion, which does not mirror the intermittent nature of the sport itself. It should also be noted that the participants skated at an incline for the duration of the test, which may have been unfamiliar to them. The authors did not mention if the participants completed this test in full hockey gear, which also may have skewed their results. The test also likely took place in a setting with a warmer temperature than those of an ice hockey rink, which may have caused the participants to become uncomfortable and further disassociated them from their natural skating habits. The RISA test also lent itself to higher fatigue accumulation by gate two because there were multiple stops and starts before skating in a full circle, followed by a half circle, and another sprint to finish the course. While this test was specific to a shift simulation, the multiple changes in direction may have cause higher lactate accumulation (Besson et al., 2013).

Yoshida and Watari (1993) clearly demonstrated that males with a high aerobic capacity (n = 5; mean VO_{2max}: 73.6 ml/kg/min) had significantly ($p < .05$) lower PCr restoration times in comparison to a healthy male control group (n= 6 mean; VO_{2max} : 46.6 ml/kg/min); however, these findings may suggest that training status is more related to measurements of anaerobic recovery than aerobic capacity itself. While the authors did not mention the training volume of the participants recruited for this study, one could deduce that the high-aerobic capacity group likely had more training time than that of the control group. These findings could also illustrate the point that aerobic capacity can improve recovery via increased O_2 supply to working muscles, mitochondrial density, capillary density, aerobic enzyme activity, and type II muscle fiber transformation to type

I, but this may only be beneficial up to a certain point, which may be after an "aerobic base" has been established (Bishop et al., 2003). Conversely, there is also evidence that suggests that O_2 supply to the working muscles is not as important to RSA as O_2 supply to the central nervous system (Smith & Billaut, 2010).

Tomlin and Wenger (2001) reviewed multiple scholarly articles and concluded that aerobic capacity was an essential element in an individual's ability to recover from anaerobic work. However, the authors did not mention if markers of anaerobic performance were also related to the ability to recover, as it was outside of the scope of their review. Perhaps these two variables would be more related to each other than aerobic capacity and anaerobic recovery (Nagaswa, 2013). Additionally, Tomlin and Wenger (2001) stated that studies that utilized participants with a higher aerobic capacity had nearly no relationship between aerobic capacity and anaerobic recovery.

Despite the aforementioned empirical evidence that aerobic capacity is related to anaerobic recovery, and/or skating ability, there is also sufficient experimental data demonstrating that the inverse are true. For example, Carey et al. (2007) found a non-significant, moderate, inverse relationship ($r = -.422$; $p > .05$) between off-ice aerobic capacity and an on-ice FI in female collegiate hockey players. However, these results should be interpreted with caution as aerobic capacity was measured off ice, and female subjects tend to self-select lower intensity levels during repeated sprints (Durocher, et al., 2008a; Laurent, Vervaecke, Kutz, & Green, 2014). Moreover, females appear to rely more on aerobic energy systems when compared to males (Billaut, Giacomoni, & Falgairette, 2003; Laurent et al., 2014). As previously mentoined, a FI can have a high coefficient of variability (if the average is not taken into considertion), which could skew this data even further (Oliver, 2009). While these results are intriguing, they may not apply to this study, as all of the participants were males, both measurements will be conducted on-ice, and a FI was not used.

Durocher et al. (2008a) compared the on-ice aerobic capacities, lactate thesholds, and ventilatory thresholds of male (n = 10) and female (n = 10) Division III collegiate ice hockey players. The researchers found that VO_{2max} was significantly higher in males when compared to females (52.7 ± 1.3 and 40.1 ± 1 ml/kg/min respectively; $p < .01$). However, the authors found that LT was not significantly different (when represented as $\%HR_{max}$ and $\%VO_{2max}$), but the female group had a significantly higher ventilatory threshold when compared to the male group (67.3 ± 4% and 52.7 ± 3.2% respectively; $p < .02$). The authors speculated that this might have been a compensatory mechanism in females to overcome their lower aerobic capacities and still play the sport at a high level. These results further substantiate the reasonable concern behind the findings of Carey et al. (2007), when trying to apply their findings to the participants of this proposed study.

Hoffman, Epstein, Einbinder, & Weinstein (1999) compared the relationship between VO_{2max} and anaerobic recovery from repeated sprints on a basketball court and the Wingate cycle ergometer test (measured via a fatigue index) in 20 male national-level bastketball players (age: 19. 0 ± 1.7 years, mean VO_{2max}: 50.2 ± 3.8 ml/kg/min). The authors found a moderate correlation between VO_{2max} and MPO on the Wingate test ($r = .57$; $p < .05$); however, no significant relationship was found between VO_{2max} and FI for the repeated sprints and the Wingate tests ($r = .01$ and -.23 respectively; $p > .05$). The authors suggested that there might be a certain threshold where VO_{2max} does not relate to anaerobic recovery. While these results are intriguing the use of a FI means that the results should be interpreted with caution (Oliver, 2009).

Cooke, Petersen, and Quinney (1997) recruited 21 male participants to determine if aerobic capacity could predict PCr recovery rates. The participants were seperated in high-aerobic capacity (n = 10; mean: 64.4 ± 1.4 ml/kg/min) and low aerobic capacity groups (n = 10; mean: 46.6 ± 1.1 ml/kg/min) and engaged in a two-minute bout of intense exercise involving the calf musculature. Aerobic capacity was not a significant predictor ($p > .05$) of PCr recovery rates of the calf musculature following intense exercise. However, the testing for this study was performed 48 hours after baseline measurements of calf musculature strength was established, which is when delayed onset muscle sorness can peak, possibly skewing their results (Schoenfeld & Contreras, 2013). While PCr recovery rates are important for recovery from bouts of anaerobic work, muscle reoxygenation rates are another important factor in recovery (Tomlin & Wenger, 2001).

Kime et al. (2003) recruited seven healthy males (mean age: 29 ± 3 years) to compare the relationship between muscle reoxygenation and PCr restoration following isometric exercise involving the hands. The participants were instructed to contract their hands (isometric; maximally) for 10 seconds. Muscle reoxygenation rates and PCr restoration rates were monitored after the testing was performed. There was a significant positive relationship between muscle reoxygenation rates and PCr restoration rates ($R^2 = .939$; $p < .001$), indicating that highly oxidative muscles took longer to restore PCr. While these results are intriguing, the protocol used for testing this relationship involved a short isometric contraction, which may not be indicative of the relationship between aerobic capacity and anaerobic recovery in whole-body, dynamic movements, like those utilized in ice hockey.

Nagasawa (2013) found that muscle reoxygenation rates were significantly slower in the long distance runners (highest VO_{2max}) compared to sprinters (middle VO_{2max}; $p < .05$) and a control group (lowest VO_{2max}; $p < .01$) following an anaerobic cycling test. Amongst all subjects there was a significant, positive, relationship between VO_{2max} and muscle reoxygenation half-life rates ($r = .75$; $p < .01$), meaning that as aerobic capacity increased, so did muscle reoxygenation time. Reoxygenation rates were the longest in the long distance runners, which indicates that aerobic capacity does not improve anaerobic recovery after bouts of anaerobic exercise.

Smith and Billaut (2010) recruited 13 male collegiate soccer and rugby players (age: 23.6 ± 3.7 years) and compared muscle O_2 saturation and prefrontal cortex O_2 saturation during repeated sprints on a cycle ergometer under normoxic and hypoxic conditions. The participants completed 10 sets of 10-second maximal effort sprints followed by a period 30 seconds of rest under normoxic and hypoxic states on separate testing days. The researchers found no significant difference ($p > .05$) in muscle O_2 saturation between the two states; however, prefrontal cortex O_2 saturation, measured by the presence of deoxygenated hemoglobin content, was significantly ($p < .05$) higher under hypoxic conditions when compared to baseline measurements. Additionally, the presence of deoxygenated hemoglobin was found to be negatively correlated with mechanical work over the 10 sprints in both normoxic and hypoxic states ($R^2 = .81$ and .85 respectively; $p < .05$), whereas muscle O_2 saturation did not have a significant main effect on normoxic or hypoxic states ($p > .05$). These findings suggest that a lack of oxygen supplied to the central nervous system has more of an affect on RSA than the ability of the human body to provide oxygen to working muscles (i.e. aerobic capacity).

Based on this body of literature there is clearly conflicting evidence on this subject. While some researchers have found a relationship between aerobic capacity and measurements of RSA there are other researchers that have shown the opposite (Carey et al., 2007; Cooke et al., 1997; Hoffman et al., 1999; McNeely et al., 2010; Tomlin & Wenger, 2001; Yoshida & Watari, 1993).

Physical Fitness Testing

In 1988, Montgomery, called for more specific physical fitness tests for ice hockey players. Off-ice measurements of aerobic capacity show mixed results when compared to on-ice aerobic capacity. For example, Besson et al. (2013) demonstrated that off-ice aerobic capacity was higher than on-ice aerobic capacity (VO_{2peak}: 62.7 ± 4 and 60 ± 7 ml/kg/min respectively; $p = .02$) in 10 semi-professional hockey players. The subjects also had significantly ($p < .01$) larger blood lactate accumulation on-ice when compared to off-ice, which the authors attributed to the hypoxic environment created by the seated position of the skating stride. However, this could also be related to hockey players' propensity to accumulate and utilize lactate as energy, which appears to be a positive adaptation for the sport (Brooks, 2009; Durocher et al., 2008b).

Additionally, Petrella, Montelpare, Nystrom, Plyley, and Faught (2007) recruited 406 ice hockey players (male and female) between the ages of nine and 25 years old to establish aerobic capacity normative data for the on-ice *Faught Aerobic Skating Test* (FAST). The primary objective of this study was to establish predicted VO_{2max} for the FAST via a multiple linear regression equation, which would be compared to the participants' off-ice aerobic capacity. The authors found that age, weight, height, and maximum completed lengths of the FAST were significant predictors of VO_{2max} (adjusted $R^2 = .387$; Standard Error = ± 7.25 ml/kg/min; $p < .0001$). The authors also found mean predicted on-ice aerobic capacity was not significantly different than mean off-ice aerobic capacity via dependent *t* testing ($t(405) = .077$; $p < .05$; $\alpha = .01$); however, there was a significant, moderate, positive relationship between predicted (on-ice) and actual (off-ice) VO_{2max} ($r = .77$; $p < .01$). These findings are contrary to those of Besson et al. (2013), and suggest that there is no difference in testing aerobic capacity on- and off-ice, meaning that either might be a viable option; however, FAST is a continuous skating test, which does not replicate the intermittent sprinting nature of ice hockey (Buchheit, 2008).

Leger, Seliger, and Brassard (1979) showed that 10 male ice hockey players had similar on-ice aerobic capacities when compared to off-ice (mean VO_{2max}: 59.9 ± 7.4 and 61.4 ± 6.3 ml/kg/min respectively; $p > .05$). However, the hockey players were 15.9% more mechanically efficient during skating and 7.9% less mechanically efficient when running, which implies that on-ice testing might be more specific to the sport itself.

Conversely, Durocher, Guisfredi, Leetun, and Carter (2010) recruited 10 male collegiate ice hockey players and compared on-ice and off-ice aerobic capacity. The authors found that on-ice VO_{2max} was significantly higher than off-ice (46.9 ± 1 and 43.6 ± .09 ml/kg/ min respectively; $p < .05$). The authors also found that no relationship existed between the two variables ($r = -.002$; $p = .99$). This suggests that measurements of aerobic fitness should be performed in a more sport specific manner.

Additionally, Leone et al. (2007) established a predicted on-ice VO_{2max} using 30 elite youth hockey players (age: 14.7 ± 1.5 years) for the skating multistage aerobic test

(SMAT). Additional testing involving 112 elite male (age: 14.2 ± 1.3 years) and 21 elite female (age: 14.0 ± 1.2 years) youth hockey players recruited to compare the predicted VO_{2max} of the SMAT to the validated predicted VO_{2max} of the 20-m shuttle run test (off-ice). The authors found that predicted VO_{2max} was significantly higher in males during SMAT when compared to the 20-m shuttle run test (53.4 ± 6.34 and 48.5 ± 5.27 ml/kg/min respectively; $p < .05$); however, the authors found no significant difference in aerobic capacity during SMAT and the 20-m shuttle run test in the female participants (44.5 ± 5.1 and 42.9 ± 5.17 ml/kg/min respectively; $p > .05$). As previously mentioned, findings regarding female participants may not apply to the current study; however, these findings could be used to legitimize the findings of Carey et al. (2007) as off-ice aerobic capacity was not significantly different from on-ice in these participants. With that being said, these participants were youth hockey players, and there is still evidence suggesting that the FI used by Carey et al. (2007) may have skewed their results.

The aforementioned results suggest that off-ice testing is not reliable for measuring aerobic capacity in hockey players. While Besson et al. (2013) found that there was not a significant difference in on-ice and off-ice aerobic capacities (using participants similar to those of the current study), other researchers have shown the opposite. Anecdotally, off-ice testing may put a participant in an environment that they may not be comfortable with (Leger et al., 1979; Montgomery, 1988). Not all subjects may be as comfortable or efficient on a cycle ergometer or running as they may be ice-skating (Leger et al., 1979). This is further validation that aerobic capacity testing should be conducted in a sport-specific manner (Montgomery, 1988).

Off-ice power measurements have been shown to be significantly related to measurements of skating ability; however, if specificity is optimal for testing physiological adaptations, on-ice power output testing may be a better option than off-ice PO (Bracko & George, 2001; Farlinger, et al. 2007; McArdle et al., 2010; Montgomery, 1988). For example, Watson and Sargeant (1986) recruited 24 junior hockey players and compared PO between two on-ice tests and a maximal Wingate cycle ergometer test. The authors found significantly ($p < .05$) higher OPO compared to the Wingate cycle ergometer test (off-ice), which is used as a standard off-ice PO test within multiple professional hockey organizations (Burr et al., 2008; Tarter et al., 2009). These findings further substantiate the idea that on-ice testing would be more specific for PO testing than off-ice PO testing.

Additionally, Farlinger et al. (2007) compared multiple measurements of off-ice fitness variables (e.g. broad jump, 30m sprint, Wingate mean PO, etc.) in 36 competitive youth hockey players (males and females; age range: 15 - 22 years) to two tests of on-ice skating agility and skating velocity. The authors found that horizontal jump and a 3-hop jump test were the most highly correlated off-ice tests to skating times ($r = -.59$ and -.53 respectively; $p < .001$). These findings suggest that off-ice tests are related to on-ice performance; however, it should be noted that the two on-ice skating tests were the most highly correlated ($r = .70$; $p < .001$), suggesting that on-ice testing is more specific and more related to one another.

Power et al. (2012) designed a study to compare the interclass correlation of the RIST to other traditional power output tests, which were measured off-ice. While the objective of their study was not to determine whether or not the RIST resulted in higher relative POs compared to the Wingate cycle test, the Margarita-Kalamen Stair Test, and Vertical Jump, the RIST OPO was much higher than traditional off-ice PO tests (47.9 ± 3.8; 6.4 ± .53; 13.7 ± 2; and 37.9 ± 4.7 watts/kg respectively). These findings are congruent with those of Watson and Sargeant (1986).

On-ice physical fitness testing is more specific to the nature of the sport than off-ice testing (Bracko & George, 2001; Farlinger et al., 2007; Montgomery, 1988). Since specificity is prefferable during physical fitness testing (due to activation of the trained musculature) it has been suggested that future researchers should strive to compare on-ice variables to one another (McArdle, et al., 2010; Montgomery, 1988).

Summary

Ice hockey is a sport that relies on a multitude of different physical fitness variables in order to compete at an elite level (Montgomery, 1988). While it has been stated that ice hockey relies mainly on anaerobic substrate utilization (69%) compared to aerobic metabolism (31%), some would argue that aerobic metabolism is beneficial to improving performance in ice hockey players (Montgomery, 1988; Twist & Rhodes, 1993). It could easily be deduced that a high aerobic capacity is requisite to playing the sport at a high level based on the findings of Burr et al. (2008). Improving aerobic capacity might be beneficial as it would allow physiological adaptations to occur that would improve in-game performance, including: improved mitochondrial density, capillary density, O_2 delivery to working muscles, and type I fiber hypertrophy/transformation, which could utilize lactate as energy, thereby bypassing the Cori cycle of the liver (McArdle et al., 2010; Twist & Rhodes, 1993).

Ice hockey players might also benefit from improving anaerobic PO as it may increase lactate utilization of the muscles during an ice hockey game, as shown by Durocher et al. (2008). Additionally, Bishop et al. (2003) found that increased H^+ accumulation, which is indicative of the presence of lactate in the body, was positively related to RSA, meaning that hockey players that rely heavily on anaerobic substrate utilization may, in fact, demonstrate better RSA.

Regarding the relationship between aerobic capacity and RSA or FI, the literature is quite conflicting. While McNeely et al. (2010) used a group of NCAA Division I ice hockey players (mean VO_{2max}: 59.6 ± 5.48 ml/kg/min) and found a significant, moderate, inverse relationship between aerobic capacity, FI and lactate removal, Hoffman et al. (1999) used a group with a comparable aerobic capacity (mean VO_{2max}: 50.2 ± 3.8 ml/kg/min) and found no significant relationship between VO_{2max} and the FI for a repeat sprint test and the Wingate test. Yoshida & Watari (1993) found that males with a high aerobic capacity (mean VO_{2max}: 73.6 ml/kg/min) had significantly faster ($p < .05$) PCr restoration rates when compared to a healthy control group (mean VO_{2max}: 46.6 ml/kg/min), Cooke et al. (1997) found that aerobic capacity (high-aerobic capacity mean VO_{2max}: 64.4 ± 1.4 ml/kg/min; low aerobic capacity mean VO_{2max}: 46.6 ± 1.1 ml/kg/min) was not a significant predictor ($p > .05$) of PCr recovery rates. Tomlin and Wenger (2001) have argued that aerobic capacity is related to RSA or FIs, but this seems to be true only in individuals with a relatively low aerobic capacity (Hoffman et al. 1999). Additionally, the majority of the data that compares these two variables utilize a FI, which has a high coefficient of variability, suggesting that some results should be interpreted with caution (Oliver, 2009).

While the literature is nebulous regarding the relationship between aerobic capacity and RSA, it also unclear as to whether or not off-ice measurements of aerobic capacity are specific enough to ice hockey (Leger et al., 1979; Montgomery 1988). Petrella et al. (2007) found that an on-ice predicted VO_{2max} using a continuous on-ice skating protocol was not significantly different from actual off-ice VO_{2max} in 406 ice hockey players ($t(405) = .077$; $p < .05$; $\alpha = .01$); however, Besson et al. (2013) demonstrated that off-ice VO_{2peak} was significantly different from on-ice VO_{2peak} in 10 semi-professional ice hockey players (VO_{2peak}: 62.7 ± 4 and 60 ± 7 ml/kg/min respectively; $p = .02$). Further convoluting this subject, Leger et al. (1979) found no significant difference in on-ice aerobic capacity and off-ice aerobic capacity in 10 male ice hockey players (mean VO_{2max}: 59.9 ± 7.4 and 61.4 ± 6.3 ml/kg/min respectively; $p > .05$), whereas Durocher et al. (2010) found that off-ice aerobic capacity was significantly higher than on-ice (mean VO_{2max}: 46.9 ± 1 and 43.6 ± .09 ml/kg/ min respectively; $p < .05$) and no significant relationship between the two variables ($r = -.002$; $p = .99$).

The lack of clarity in the existing literature generally ceases to exist regarding OPO. Watson & Sargeant (1986) found that two different skating tests yielded significantly higher POs when compared to those accrued via the Wingate cycle ergometer test ($p < .05$). Additionally, while Power et al. (2012) were not comparing differences in POs between tests, OPO via the RIST was higher when compared to the Wingate cycle test, the Margarita-Kalamen Stair Test, and Vertical Jump tests (47.9 ± 3.8; 6.4 ± .53; 13.7 ± 2; and 37.9 ± 4.7 watts/kg respectively).

While there are theoretical advantages of improving both aerobic capacity and anaerobic PO, there is a clear need to determine the relationship between these two theoretically advantageous physiological adaptations in a sport-specific manner. While off-ice testing may be a viable option for analyzing aerobic capacity, there has been a call to utilize sport-specific on-ice testing, which utilizes direct gas exchange measurement in elite ice hockey players (Buchheit, 2008; Leger et al., 1979; Montgomery, 1988). Examining the relationship between these two variables could only further the scientific community's understanding of the application of underlying physiology in elite level ice hockey, thus encouraging coaches at all levels to apply the data which is collected via this study in the field. Based on the existing literature, it is clear that further investigation on this topic is needed, especially considering the lack of specificity of testing for aerobic capacity and PO in ice hockey players. (Besson et al., 2013; Buchheit et al., 2011; Montgomery, 1988).

The purpose of this study was to compare on-ice aerobic capacity (VO_{2peak} and/or V_{IIT}) via the *30-15*$_{IIT}$ (Besson et al., 2013; Buchheit et al., 2011) and OPO measured via the *RIST* (Power et al., 2012), in nine elite level ice hockey players recruited from an American Hockey League (AHL) team.

Chapter Three: Methodology

The purpose of this chapter is to familiarize the reader with the study design, participants, instrumentation, test selection, and statistical analyses that were performed with the data. The design of this study had to consider the competition schedule of the participants, in addition to the ice-time availability necessary to perform the testing. This study was observational in nature. The aim of this study was not to establish cause and effect, but rather to observe the relationship between on-ice aerobic capacity and RISA (correlational).

Participants

Based on the research of Peterson et al. (2015), a sample size of 45 participants would be needed to find statistical significance between on-ice aerobic capacity and RISA. However, Nagasawa (2013) found a significant relationship ($r = .75$; $p < .01$; ES = .52) between aerobic capacity and PCr recovery rates (ES = .86) in 11 participants. Conversely, Carey et al. (2007) found a non-significant relationship between off-ice aerobic capacity ($r = -.422$; $p > .05$) and RISA in 11 participants (ES = .19). Based on these findings, it seemed necessary to recruit 10-15 participants (ES = .13 to .22) for this study to have a similar *p*-value to that of Peterson et al. (2015) and Carey et al. (2007). In actuality, 11 professional ice hockey players (AHL; seven forwards and four defenseman) were recruited (mean age = 23.10 ± 2.66 years); however, correlational analyses were only conducted for nine of the eleven participants, as two were dropped from the study due to in-season recalls by the club's National Hockey League affiliate. As previously mentioned, there have been multiple studies comparing off-ice testing to on-ice testing, and additional studies that have analyzed repeated sprint ability (Carey et al., 2007; da Silva, Guglielmo, & Bishop, 2010; Mendez-Villanueva, Hamer, & Bishop, 2008; Montgomery, 1988). The authors of the aforementioned studies were able to yield valid, and oftentimes, significant results with ≤ 12 subjects.

Instrumentation

The Oxycon portable O_2 analyzer, created by CareFusion, is essentially a backpack that can be worn along with a gas exchange mask during exercise that can not be monitored using a traditional metabolic cart, due to its lack of portability. This device has been shown to be a valid and reliable tool for measuring aerobic capacity remotely (Akkermans, Sillen, Wouters, & Spruit, 2012). Some of the participants (n = 4) wore this mobile gas analyzer with their full hockey equipment during the $30\text{-}15_{IIT}$, and direct measurement of VO_{2peak} was determined.

The Speedtrap 2, created by Brower Timing systems, is a wireless photocell timing system that was used for the RIST. The timing device was set up on the red-line of the ice, which was both the starting and finishing point for the participants during the RIST (Figure 1). This device reduced the probability of user error during the timing of sprint trials (Hetzler, Stickley, Lundquist, & Kimura, 2008).

A Tanita BWB-800S Digital Physician Scale was used to obtain the bodyweight of the subjects prior to testing, as well as the weight of the subjects in full hockey gear. A pair of Harpenden skinfold calipers were used to assess body fat percentage of the subjects. Body fat percentage (%BF) was calculated via the Yuhasz formula in accordance with National Hockey League (NHL) combine standards (Burr et al., 2008; Yuhasz, 1962). Six skinfold sites were utilized: pectoral, subscapular, triceps, suprailliac, abdomen, and thigh.

Test Selection

Because testing was performed in-season it was of the utmost importance that the tests would not cause undue fatigue on the participants (T. Nelson, personal communication, October 8, 2014); additionally, the tests had to be valid and reliable, which presented a unique problem. While it was important that that data were reliable and valid, the subjects still needed to be able to perform at a high-level following the testing protocols (T. Nelson, personal communication, October 8, 2014). The performance of their jobs could not be sacrificed for the sake of the data (T. Nelson, personal communication, October 8, 2014). With that being said, there were tests available that are both reliable and valid for measuring both on-ice aerobic capacity and on-ice PO, but would not cause undue fatigue on the participants (Besson et al., 2013; Buchheit et al., 2011; Power et al., 2012).

The 30-15_{IIT} has been shown to be a highly specific and reliable method for assessing on-ice aerobic capacity in hockey players (Buchheit et al., 2011). Of the athletes that participated in the off-ice version of this test, 70% perceived it as less physically taxing than other submaximal, continuous effort tests (Buchheit et al., 2011). These characteristics made the 30-15_{IIT} the most appropriate test for measuring in-season VO_{2peak} in the subjects.

There are many on-ice tests that have been used to measure anaerobic recovery, but oftentimes these protocols result in extreme physical exhaustion. For example, the Reed Repeat Sprint Test (RSS) has been shown to be the most reliable on-ice test for measuring repeated sprint ability (Nightingale, et al., 2013); however, this protocol has caused some participants to become physically incapacitated following testing (Power et al., 2012). The RIST does not cause nearly as much fatigue, and can measure PO (watts) throughout repeated sprints (Astorino, Allen, Roberson, & Jurancich, 2012; Power et al., 2012). This test has also been shown to be a reliable and valid method for measuring OPO (Power et al., 2012). The RIST is also highly specific to the sport since the major skating components of the test are forward skating, and crossovers, which are some of the most common components of skating during a hockey game (Bracko, 2004). Off-ice laboratory testing with similar work-to-rest ratios (utilizing maximal efforts), yielded high lactate accumulation levels, suggesting that an on-ice test of a similar nature (like the RIST), could sufficiently tax the anaerobic system (Bishop et al., 2003). Data obtained from this test was then used to calculate a %DPO.

While there is concern regarding the use of a FI as a measurement of repeated sprint performance, Wilson, Snydmiller, Game, Quinney, and Bell (2010) demonstrated a FI to be a reliable variable for measuring anaerobic recovery. Oliver (2009) stated that FIs should be interpreted with caution when time was used as a variable, but nothing was mentioned regarding the reliability and validity of PO being used as the variable for %DPO. Moreover, since the numbers for PO should be markedly higher values than sprint times (e.g. ~ 1000 watts vs. ~7 seconds) there should be less coefficient variability in percentages (Oliver, 2009). However, the concerns regarding %DPO cannot be ignored (i.e. a less power in the first trial will result in a lower %DPO). Considering this evidence it seemed appropriate to include MPO and PPO in the statistical analyses as well. It also seemed appropriate to include relative measurements of OPO, as this offered additional insight to the role of body mass on power production and decrement.

Procedures

Prior to the collection of data, Institutional Review Board (IRB) of the University of Central Oklahoma was requested and received (Appendix A). Upon IRB approval, participant recruitment began on January 20, 2015. The participants were recruited by the Co-PI in a group presentation within the clubs' dressing room. Prospective participants were encouraged to sign an informed consent with the PI in the following week (Appendix B). The participants were reminded that their participation in this study was voluntary and that their results would not be shared with anyone in the organization. Players that did not meet the inclusion criteria (Appendix D) were not allowed to be present during the meeting and were not allowed to participate in the study. Reasons for exclusion included: musculoskeletal injuries (sprains, strains, and fractures), acute illness, chronic illness, neurological deficits, psychological deficits, and sociological deficits (as determined by the athletic trainer and medical staff). Goaltenders were excluded from participation in the study as their physiological adaptations may differ from those of the other players (Buchheit et al., 2011).

On February 3, 2015, OPO testing was conducted, and on-ice aerobic capacity testing was completed on February 18, 2015. It should be noted that due to injuries, two of the participant completed OPO testing at a later date (April 20, 2015). These participants were cleared by the team Athletic Trainer to play in games at the time of testing, meaning that they were medically eligible to participate in the testing. Aerobic capacity (VO_{2peak}) was intended to be measured directly via the Oxycon portable O_2 analyzer during the $30\text{-}15_{IIT}$; however, due to malfunctions with the equipment and ice time limitations, the V_{IIT} was used as a determinant of aerobic capacity in all participants

(Buchheit et al., 2011). OPO was measured via the RIST (Power et al., 2012). A %DPO was also calculated based on the PO of the six sprints for each subject. MPO and PPO were also calculated. Body weight (with and without hockey equipment), %BF, sprint times, and playing position were all used as descriptive statistics. Body weight and %BF were measured prior to testing.

It should be noted that a Certified Athletic Trainer was present during all testing. The team Athletic Trainer medically cleared all of the participants prior to participation in this study (in conjunction with the team medical staff). Two practitioners were present in the facility during all testing, namely the primary investigator (PI) and a University of Central Oklahoma faculty member. The PI was on the ice while the faculty member collected data off the ice in the scorekeeper's box.

RIST (Power et al., 2012). Prior to testing the participants were instructed to avoid coffee and to go through a general off-ice warm-up prior to testing (Appendix F). The primary investigator (PI) was responsible for setting up the testing course. The *Speed Trap 2 Timing System* was situated along the center ice long, on the same line as the neutral zone faceoff dots. The PI was also responsible for placing the cones of the course in the proper place. The first cone was placed three meters on the outside of the neutral zone faceoff dot. The second cone was placed three meters to the outside to in-zone dot closest to the net. The third cone was placed one and a half meters away from the boards, in line with the previous two cones, and on the goal line. The fourth cone was placed behind the net, one and a half meters away from the start of the start of the trapezoid line (which begins on the goal line). The other four cones were placed in the exact same positions on the ice, but on the opposite side. Pucks were placed on each dot to help the participants visualize the width that they had to stay in during testing (a depiction of the cone set-up for the RIST can be seen in Figure 1).

After their off-ice warm-up, they were weighed while wearing all of their hockey gear (body mass in hockey equipment; BMHE). On the ice, the participants began skating with their skates perpendicular to the center ice line, with the toe of the hockey stick on the line, but not crossing the beam of the *Speed Trap 2 Timing System*, which was placed along the center ice line. Once on the ice, they were instructed to take 4 laps around the ice to warm-up their legs before the test. The participants were given one familiarization repetition before the first repetition began. They were instructed to skate at 70% of their perceived maximal effort, and given sixty seconds of rest prior to their first repetition.

Once the participant started the first repetition, the beam of the timing system was broken by the shaft of the hockey stick, signaling the commencement of the repetition. The participants then skated as quickly as possible around the goal, in an elliptical pattern, ending at the opposite end of the center ice line (Figure 2). As they crossed the line, the on-ice practitioner counted the participants' 10 seconds of rest from a stopwatch. Participants would stop at the near blue line, past the center ice line, change directions, and prepared for his next sprint in the opposite direction, all within the 10 seconds of rest. Once the rest period was over, the participants repeated this process for a total of three repetitions per trial. Verbal encouragement was offered to each participant during each repetition. The PI encouraged them to skate, "all the way through" the center ice line in order to maximize their efforts. Between each trial the participants were given two minutes of rest. It should be noted that this was different than the 10-minute rest protocol set forth by Power et al. (2012), which was modified to be more specific to the sport, and due to the ice time limitations. Two total trials (six total repetitions) were recorded. Skating times were collected by the on-ice practitioner and recorded by the off-ice practitioner for data analyses. The PI then skated a distance-measuring wheel along the skate marks left by the participants to estimate the average distance skated by the participants.

Anaerobic power (watts) was calculated using the following equation for each repetition: Average Power Output (watts) = (Body mass (kg) x distance (49m) x 9.81 m/sec^2) / skating time(s) (Watson & Sargeant, 1986). PPO was the highest PO out of all six repetitions, and MPO was the average of the six repetitions. Calculations were also performed to give relative PO as well (PPO/BMHE in kg; MPO/BMHE in kg). A %DPO was also calculated using the equation: %DPO = ((Peak PO – Mean PO) / Peak PO) x 100 (McArdle et al., 2010; Oliver, 2009). Average skating times (AST) and fastest skating times (FST) were also used for analyses.

30-15IIT (Buchheit et al., 2011). This was a maximal effort, on-ice test, designed to measure the aerobic capacities of the participants. Prior to testing the participants were instructed on how the test was to be performed and were given a general off-ice warm-up. Once on the ice, the participants were told to take four laps around the ice to warm-up their legs. After their warm-up, four of the participants were fitted with the Oxycon. The other five participants wore just their hockey equipment during testing. The participants that wore the Oxycon were instructed to wear it under their helmets (with no visor) and to have the backpack strapped tightly around their chest during the testing. Additionally, the PI made sure that the mask fit the individual appropriately (i.e. the mask was securely applied to the face, the wind blocker was applied to the mask, and the oxygen tube was attached to both the mask and the computing device on the backpack).

The on-ice practitioner was also responsible for setting up the skating course, and playing the audio file. The off-ice practitioner was responsible for monitoring oxygen uptake throughout the test (Durocher, et al., 2008b). An MP3 file, which played audible “beeps” (that were correspondent with various skating velocities) was played during the test over speakers of the arena.

The participants skated for 30 seconds followed by 15 seconds of rest (per stage). Because of the skating proficiency of the participants, and the time limitations associated with this study, the participants began the test at the seventh stage, in accordance with recommendations set forth by Buchheit (2010). Each subject began skating at 14.58 km/h with a .63 km/h increase in velocity per stage. The participants started the test with their skates facing parallel to the first cone (marking the beginning of the 40m shuttle). They then began to skate at the first audible “beep.” The participants then skated past a cone, which represented the 20m mark, in correspondence to the second audible beep, before proceeding to the final cone (of the 40m) by the third audible beep. The participant would then stop, change directions, and repeat the process. This process continued until each stage was completed (30 seconds). Once the stage was completed the subject was instructed to rest at the next cone (e.g. he skated past the 20m cone, the final beep was a few seconds later, the participant would then glide and stop at the 40m cone to rest, instead of stopping and returning to the 20m cone). Safe zone markers (pucks) were placed 3m in front of each cone (on both sides of the 20m cone). If the player did not reach the 3m zones on three consecutive occasions, the test was terminated and V_{IIT} and/or VO_{2peak} data were recorded (Figure 3 offers a visual depiction of the test course). The subjects were instructed to complete as many stages as possible.

It should also be noted that, due to time constraints, four of the participants completed this test at the same time (i.e. two participants were in two different lanes and completed the test together), whereas the remaining participants (n = 5) completed this test individually. The PI also offered verbal encouragement to each participant when it appeared that they were near exhaustion.

Statistical Analyses

Descriptive statistics were utilized (number of participants, mean, standard deviation, skewness, and kurtosis) for all scale data. Pearson's correlational testing was then used determine the relationship between $VO_{2peak,}$ V_{IIT}, and %DPO, PPO, RPPO, MPO and RMPO. The null hypothesis stated that there would not be a significant relationship between on-ice aerobic capacity (VO_{2peak} and V_{IIT}) %DPO, PPO (absolute and relative), and MPO (absolute and relative). All data were analyzed via IBM's SPSS Statistics software (version 22). Significance levels were set at $\alpha = .05$.

A one-way analysis of variance (ANOVA) was also used to determine if the ice conditions affected the skating times and POs of the participants based on the order that they performed the RIST. The null hypothesis stated that there would not be a significant difference in skating times and testing order between the participants. Significance levels were set at $\alpha = .05$.

Chapter Four: Results

Descriptive Statistics

Eleven professional male ice hockey players were recruited from an AHL club for participation in this research study (n = 11; 7 forwards and 4 defenseman). Two forwards were not able to complete the 30-15_{IIT} testing, due to mid-season recalls by the club's NHL affiliate.

The average age of the participants was 23.10 ± 2.66 years. Their average body mass (BM) 200.73 ± 21.32 pounds, and BMHE 220.75 ± 23.51 lbs. The average %BF was 9.45 ± 1.30 (Yuhasz, 1962). Analysis of descriptive statistics revealed that age was positively skewed (S = 1.291), BM was negatively skewed (S = -1.177), BMHE was platykurtic (K = -1.575), and %BF was negatively skewed (S = -1.649). No outliers existed in this data. Physical characteristic descriptive statistics can be found in Table 1.

Descriptive statistics for the RIST can be found in Table 2. The average distance skated was 64.89 ± .90 meters, and was positively skewed (S = 1.426). There were two outliers in this data, but their data were kept in the analysis as they represented real numbers Figure 4. There was also an outlier present for FST (mean = 8.39 ± .28 seconds). This data was positively skewed, but again, this data were kept for analysis, as they were real numbers (S = 1.42; Figure 5). The average sprint time for all eleven participants was 8.71 ± .30 seconds, and was leptokurtic (K = 1.625); however, no outlier was present. It should also be noted that the average %DPO was 3.77 ± 1.06% (CV = .281).

Similarly, descriptive statistics for the 30-$_{15IIT}$ can be found in Table 3. The average V_{IIT} was 18.71 ± .71 km/h (n = 9), and the average VO_{2peak} was 56.53 ± 10.13

ml/kg/min. All data that were skewed or lepto or platykurtic were kept because they represented real measurements and were not errors.

Pearson's Correlational Testing

Data for correlational results can be found in Table 4. Due to the lack of significant findings, effect sizes (r^2) were calculated for all correlational data. There was a non-significant relationship between VO_{2peak} and V_{IIT} (r =.917; r^2 = .841; p = .083) in the four participants for which this data was collected (Figure 4). While this finding was not significant (likely due to the small sample size; n = 4), 84.1% of the variance in V_{IIT} can be attributed to VO_{2peak}. No significant correlations (p > .05) existed between V_{IIT}, %DPO (r = -.036; Figure 5), PPO (r = -.415; Figure 6), RPPO (r = .477; Figure 7), MPO (r = -.386; Figure 8), and RMPO (r = .565; Figure 9). Additionally, .13% of the variance in %DPO could be attributed to $V_{IIT.}$ No significant correlations (p > .05) existed between VO_{2peak}, %DPO (r = .197; Figure 10), PPO (r = -.783; Figure 11), RPPO (r = .791; Figure 12), MPO (r = -.739; Figure 13), and RMPO (r = .620; Figure 14). Finally, 3% of the variance in %DPO can be attributed to VO_{2peak}.

Affect of Ice Conditions on Skating Ability

One-way ANOVA revealed that there was no significant difference in any measurement of skating ability (F = .421; p > .05) that impaired/enhanced skating performance due to skating order during the RIST (i.e. first, second, third, or fourth participant to skate during testing). Ice conditions did not impair the skating ability of the participants while performing the RIST (Tables 5, 6, & Figure 17; p > .05).

Skating Performance and Variability

RPPO, RMPO, and V_{IIT} were the most reliable measurements of skating ability in the participants (CV = .027, .031, and .038 respectively; Tables 2 & 3). Percent DPO showed a high degree of variability (CV = .281), which was higher than the guidelines set forth by Oliver (2009). RPPO and RMPO also offered a more in-depth view of the participants' skating ability, as it took into consideration the BMHE of each participant; moreover, RMPO took into consideration the data from each repetition during the RIST, whereas RPPO was only the best repetition.

CHAPTER FIVE: DISCUSSION

Purpose/Hypothesis

The purpose of this study was to examine the relationship between on-ice aerobic capacity and RISA in elite level ice hockey players. The PI hypothesized that there would not be a significant relationship between V_{IIT} and/or VO_{2peak} to any measurement of RISA (i.e. %DPO, PPO, RPPO, MPO, and RMPO), which was in agreement with Carey et al. (2007), but contrary to the findings of Peterson et al. (2015). The results of this research study were in agreement with the null hypothesis and the PI's hypothesis. Aerobic capacity was not significantly related to RISA.

Significance

Ice hockey is a sport in which players skate for approximately one minute per shift, and about half of that time players skate at near maximal efforts (Horrigan & Kries, 1994). Because the sport involved high-intensity sprints, intermixed with periods of rest generally around two minutes, players are highly reliant on anaerobic metabolism (69%); however, Montgomery (1988) suggested that aerobic metabolism could contribute to up to 31% of the energy requirements during play.

Many fitness professionals and ice hockey coaches believe that in order to play at an elite level, ice hockey players need to have a high aerobic capacity (Montgomery, 1988; Twist & Rhodes, 1993). While many hockey coaches may not understand the mechanism behind this belief, many fitness professionals believe that it is related to a higher reliance on aerobic metabolism, which may spare anaerobic substrates during play, thus improving their RISA (Peterson et al., 2015; Tomlin & Wegner, 2001; Twist & Rhodes, 1993).

There is conflicting evidence pertaining to the relationship between the relationship between aerobic capacity and RSA. Additionally, there is a dearth of research for ice hockey players; moreover, the available research rarely compared these two variables on the ice, or in a sport specific manner (Bishop et al., 2003; Besson et al., 2013; Buchheit et al., 2011; Carey et al. 2007; Green et al., 2006; Montgomery, 1988; Nagasawa, 2013; Peterson et al., 2015). The results from the current study may help further explain the relationship between these two variables in a group of elite level athletes.

Restatement of Results

The main finding of this study was that on-ice aerobic capacity (V_{IIT}) was not significantly related to RISA (%DPO) in nine professional ice hockey players ($r = -.036$; $p > .05$). Based on these findings, aerobic capacity, as measured by V_{IIT}, can account for only .13% of the variance in RISA. For the participants whose VO_{2peak} data were available (n = 4), the relationship improved ($r = .197$; $p > .05$), but aerobic capacity, as measured by VO_{2peak}, could only account for 3% of the variance in RISA. Participants with a higher aerobic capacity did not have a significant decrease in fatigue during RIST. This could further substantiate the idea that O_2 supply is not the only variable for improving RISA, but one of a multitude of different factors tested during the $30\text{-}15_{IIT}$ (Buchheit, 2010).

Since not all participants were able to use the Oxycon mobile metabolic analyzer, V_{IIT} was the primary variable associated to RISA results; with that being said, there was a non-significant relationship between VO_{2peak} and V_{IIT} in the participants that were able to have gas exchange measured directly (n = 4; $r = .917$; $r^2 = .841$; $p = .083$). While this relationship was non-significant, the effect size was large, indicating a strong relationship between the two variables. Eighty-four percent (84%) of the variation in V_{IIT} could be attributed to VO_{2peak}. This suggests that V_{IIT} was highly related to another standard measurement of aerobic capacity, legitimizing its use as a variable for association with RISA (Buchheit et al., 2010; McArdle, et al., 2007).

Percent DPO had high variability (CV = .281), compared with the recommended use of FIs by Oliver (2009); however, the CV for this data were similar to those of Peterson et al. (2015), and Glaister, Howatson, Pattison, & McInnes (2008). Because of the high CV for %DPO, additional variables were used for association with aerobic capacity (PPO, RPPO, MPO, and RMPO; Table 4) as they had lower levels of variability, similar to those suggested by Oliver (2009).

As seen in Table 4 and Figure 11, RMPO had the highest *r*-value of all of the aforementioned variables, but its relationship to V_{IIT} was still non-significant ($r = .565$; $p = .115$). Thirty-two percent (32%) of the variance in the participants' ability to maintain OPO could be attributed to their aerobic capacity (V_{IIT}). When correlated to VO_{2peak}, the relationship for all measurements of RISA improved, although they were not statistically significant. Most notably, participants with a higher VO_{2peak} had a higher RPPO ($r = .791$; $p < .05$). In this case, 62% of the variance in RPPO could be attributed to the participants' VO_{2peak} (Figure 14). These numbers are similar to the findings of Peterson et al. (2015), although the findings are still not significant. In this case, participants with a higher V_{IIT} and/or VO_{2peak} had a higher RMPO, which could also be used as a measurement of RISA (Oliver, 2009). While not significant, this suggests that aerobic capacity could be related to RISA, although %DPO suggests otherwise (Table 4).

Conversely, participants with a higher aerobic capacity had lower PPOs and MPOs (Table 4). This data suggests that heavier participants (higher absolute POs) had lower aerobic capacities, and participants with faster skating times during the RIST (higher relative POs) had higher aerobic capacities. This data also suggests that individuals with higher aerobic capacities had lower absolute POs, suggesting that aerobic adaptations may hinder absolute power production on the ice.

A concern that arose during testing was the ice conditions for the participants that were tested later in the day for the RIST. Because the participants were skating in the same elliptical pattern, the ice behind the goal line began to roughen, which increased the friction of the skating surface, which may have skewed the results for the participants that skated later during the testing. However, when participant testing order was controlled for (Tables 5, 6, & Figure 17), one-way ANOVA testing revealed that there were no significant differences in AST between and within the participants, further strengthening the findings during the RIST.

Comparison of Literature

This research study was the first (to the author's knowledge) to compare the relationship between on-ice aerobic capacity in a sport specific manner to RISA; moreover, elite level ice hockey players have never been used to compare the aforementioned variables. The majority of previous studies that compared the relationship between aerobic capacity and RSA or RISA have not utilized protocols that were specific to the sport itself; therefore, results from previous studies should be interpreted with caution.

While Peterson et al. (2015) recently found that aerobic capacity was associated with a decrease in fatigue during RIS ($r = -.031$; $p = .04$); however, their aerobic capacity testing protocol lacked the intermittent sprinting nature performed in ice hockey (Besson et al., 2013). It should also be noted that this study had a larger sample size (n = 45), which may have improved the significance of their findings; however, the authors also stated that 28.7% of the variance in RIS fatigue could be attributed to the combined predictive ability of final skating stage completed on the aerobic capacity skating test used, and VO_{2peak}. The authors noted that skating ability (as measured by final stage completed during aerobic capacity testing) was a better predictor of RISA, with 23% of the variance being attributed to final stage completed ($p < .05$). Conversely, VO_{2peak} attributed to only 4.2% of the variance in RISA ($p < .05$). The authors concluded that more efficient skaters could induce less fatigue when compared with less efficient skaters.

The findings of the current research study were contrary to those of Peterson et al. (2015), although similar variables were measured. While this research study may have lacked the statistical power necessary to obtain statistically significant results ($p < .05$) because of the small sample size (n = 9), the effect sizes for V_{IIT} and VO_{2peak} were small when associated with %DPO ($r^2 = .0013$ and .03 respectively; $p > .05$). Even if a larger sample size was used to obtain statistically significant results, the relationship is nearly non-existent; moreover, aerobic capacity can only contribute to .13-3% of the variance in the RISA in this sample.

Conversely, the findings of the current research study were in agreement with those of Carey et al. (2007). In this study, the authors found that off-ice VO_{2max} was not significantly related to RISA ($r = -.422$; $p = > .05$). While the *r*-value of Carey et al. (2007) was similar to those found by Peterson et al. (2015), the lack of significant findings in this study may attributed to a small sample size (n = 14). Even so, off-ice aerobic capacity could only contribute to 17.8% of the variance in RISA.

The lack of significant correlations could be attributed to a variety of different factors, including: skating efficiency, lactate tolerance, anaerobic metabolism, change of direction ability, and inter-effort recovery (Besson et al., 2013; Buchheit, 2010). Saunders, Pyne, Telford, and Hawley (2004) noted that body mass and running economy were better predictors of running performance than VO_{2max} in long distance runners. It could then be deduced that there are other factors that may be more related to improved RISA in elite level hockey players than aerobic capacity alone.

Higher lactate accumulation appears to be a key contributor to improved workload of the lower body musculature during high intensity exercise, as noted by Stone et al. (1987). It appears that trained athletes are able to handle higher levels of lactate at a given workload and are able to sustain work for longer periods of time (Stone et al., 1987). Additionally, it has been found that an increase in muscle H^+ buffering was more related to work decrement during repeated sprints (Bishop, Edge, & Goodman, 2004). In short, athletes that can handle larger spikes in lactate and buffer the H^+ ions more effectively may be more effective during repeat sprint efforts. Lactate shuttling could help assist this buffering (i.e. lactate clearance) by utilization of lactate in slow-twitch muscle fibers instead of entering into the Cori cycle (Brooks, 2009; Twist & Rhodes, 1993). Sporis, Ruzic, and Leko (2008) found that soccer players increased lactate accumulation and improved their 300-m shuttle test times, indicating that players could buffer and utilize lactate more efficiently, which lead to improved performance. This adaptation may be especially important in ice hockey, as these athletes will produce more lactate skating than running, due to the hypoxic nature of the skating stance, which requires hip and knee flexion to be maintained isometrically while skating (Besson et al., 2013). In fact, this adaptation appears to improve throughout the course of a competitive season, as shown by an increased anaerobic capacity, yet an unchanged VO_{2max} (Durocher et al., 2008b; Montgomery, 1988). Moreover, improvements in lactate threshold (LT) have been shown to improve on-ice performance more than VO_{2max} (Bassett & Howley, 2000; Durocher et al., 2008b; Minkoff, 1982). This is important because VO_{2max} is difficult to improve and highly dependent on genetic and lifestyle factors factors (Bouchard, et al., 1999). It is possible that the participants that performed better on both the RIST and $30\text{-}15_{IIT}$ had higher levels of lactate tolerance, but not necessarily a higher aerobic capacity. While Bassett & Howley (2000) noted that O_2 delivery and not muscle O_2 extraction was the limiting factor in VO_{2max}, the authors also concluded that there are a variety of factors that contribute to aerobic capacity, but lactate tolerance appears to be a combination of the aforementioned factors.

The results of the current research study are not implying that aerobic capacity is irrelevant in RISA or reduced fatigue, in fact, some subjects with a higher V_{IIT} had a lower %DPO (Figure 5); however, there are other factors that appear to play more important roles in RISA than aerobic capacity. The mean VO_{2peak} of the participants of this study was 56.53 ml/kg/min, which was considered “superior” relative to the participants’ mean age and sex (ACSM, 2010). As previously stated, based on the literature there appears to be a ceiling for the relationship between aerobic capacity and

RSA (Hoffman et al., 1999; Tomlin & Wegner, 2001). That may have been the case for the participants in this study (Hoffman et al., 1999). Skating ability, body mass, lactate tolerance, neural factors, and biomechanical factors may have all played a role in %DPO and V_{IIT} (Bassett & Howley, 2000; Saunders et al., 2004). While having a higher aerobic capacity may contribute to one's RSA, this may only be true up to a certain point, as evidenced by the findings of the current research study.

Limitations

The sample size (n = 11) was a limitation of this research study. Additionally, due to limitations in ice time availability, some participants had to perform the V_{IIT} at the same time, which may created a competitive mindset within the participants, possibly skewing the aerobic capacity results. Two participants also had to leave the study due to NHL recalls, which further reduced the sample size (n = 9) for correlational analyses. The sample size was reduced even further (n = 4) for data that were used to compare the relationship between VO_{2peak} and %DPO due to malfunctions with the Oxycon portable metabolic analyzer.

It should also be noted that two of the participants of this study were tested (RIST) approximately two months after the other participants, which may have caused a decreased in PO, resultant from aerobic adaptations that occur as the playing season progressed (Durocher et al., 2008b). Additionally, PO was also measured indirectly, which may have caused the RIST results to be not as accurate as a direct measurement, although this method has been shown to be reliable for testing PO in hockey players (ACSM, 2010; Power et al., 2012). The ice conditions were also suspected to have skewed the RIST results, as the ice surface began to roughen with each skater; however, the use of a one-way ANOVA revealed no significant differences between-within the participants that were tested earlier in the testing order (less friction) and those that were tested later in the testing order (more friction). Additionally, the participants skated faster in one direction of the test than the other, which may have skewed the %DPO results, although this is not likely because the mean of the sprints was taken into consideration during the calculation (Oliver, 2009).

Strengths

This research study utilized highly skilled and highly fit participants for the data collection. This is important because it shows the physical capabilities of players that are near the highest levels of professional hockey, and what physical characteristics may have helped them get there.

The tests utilized in this research study were also specific to the nature of the sport itself, and could be easily be implemented in the field. Both tests took approximately five minutes to prepare, and the data were valid and reliable based on the suggestions of Buchheit et al. (2011) and Power et al. (2012).

The RIST took into consideration not only the participants' skating time, but the players' body mass, which offers a deeper understanding of their skating abilities, and a more individualized view of their fatigue (Oliver, 2009).

The 30-15_{IIT} has been shown to be a more specific method for measuring VO_{2peak} and aerobic capacity, as it is performed in an intermittent nature (mirroring that of ice hockey). Furthermore, the 15 second rest period is less than the time necessary to increase O_2 debt, thus central nervous system and muscular fatigue, which occurs in other intermittent aerobic capacity ice tests, meaning the participants' true VO_{2peak} was likely found (Buchhet et al., 2011).

Future Directions

Future research should aim to directly measure skating efficiency, power output, and VO_{2peak} in all participants. It is unclear as to what extent skating efficiency played in the fatigue of the participants, it seems reasonable to assume that more efficient skaters may have used less energy and had a higher V_{IIT} than someone with a higher VO_{2peak} that is a less efficient skater (Saunders et al., 2004). While it was not the goal of this research study to examine how skating efficiency, it may have affected the results, it is likely that it played a key role. Power output and VO_{2peak} should also be measured directly to offer a more in-depth view of the relationship between on-ice aerobic capacity and RISA.

While it was advantageous to examine the relationship between these two variables in-season, as theoretically it would be when the sport specific adaptations would be near their peak, the time limitations and ice-time availability made it difficult to collect the data for all the participants at one time (Durocher et al., 2008b). Future studies should also include a larger sample size to increase the statistical power of their findings.

Practical Applications

While the findings of this research study suggest that a high aerobic capacity is not related to an improved RISA, the reader should keep in mind that this is only in a small sample of elite level athletes that have already established their "aerobic base" (ACSM, 2010; Hoffman et al., 1999). At an elite level, improvements in aerobic capacity do not appear to improve RISA, due to the multitude of factors that are involved in both variables (Bracko, 2004; Saunders et al., 2004). Fitness professionals and ice hockey coaches should use these findings to improve other factors in their athletes, if their goal is to improve RISA, and if a high aerobic base has already been established.

The researcher also utilized sport-specific tests which could be implemented in the field, and offer a more in-depth view of the physical capabilities of an ice hockey player when compared to off-ice testing (Buchheit et al., 2010; Besson et al., 2013; Montgomery, 1988; Power et al., 2012).

Conclusion

It may be concluded that aerobic capacity is not related to RISA in elite level ice hockey players. While these findings were not statistically significant, the small effect size also implies that the relationship between these two variables is not related. Elite level ice hockey players with a high RISA do not necessarily have a higher aerobic capacity.

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Tables /Figures

Table 1

Physical Characteristics of Participants

	N	Mean ± SD	Kurtosis	Skewness
Age	11	23.10 ± 2.66	1.046	1.291
BM (lbs.)	11	200.73 ± 21.32	.479	-1.177
BMHE (lbs.)	11	220.75 ± 23.51	-1.575	0.348
%BF	11	9.45 ± 1.30	-.457	-1.649

Note. N = number, SD = standard deviation, BM = body mass, BMHE = body mass with hockey equipment, %BF = body fat percentage.

Table 2

Descriptive Statistics for RIST

	N	Mean ± SD	Kurtosis	Skewness	CV
Distance (m)	11	64.89 ± .90	1.004	1.426	.014
AST	11	8.71 ± .30	1.625	1.181	.034
FST	11	8.39 ± .28	.722	1.42	.033
%DPO	11	3.77 ± 1.06	-.287	-.609	.281
PPO (watts)	11	7656.56 ± 770.83	.297	-1.697	.101
RPPO (w/kg)	11	76.16 ± 2.33	-.011	-1.457	.031
MPO (watts)	11	7362.49 ± 775.45	.428	-1.250	.103
RMPO (w/kg)	11	73.20 ± 2.00	-.464	-.624	.027

Note. N = number, SD = standard deviation, CV = coefficient of variation, Distance = distance skated in meters, AST = average sprint time for all six trials, FST = fastest sprint time, %DPO = percent decrement of power output, PPO = absolute peak power output, RPPO = relative peak power output, MPO = absolute mean power output, RMPO = relative mean power output.

Table 3

Descriptive Statistics for 30-15$_{IIT}$

	N	Mean ± SD	Kurtosis	Skewness	CV
V_{IIT} (km/h)	9	18.71 ± .71	.492	-1.390	.038
VO_{2peak} (ml/kg/min)	4	56.53 ± 10.13	1.435	1.703	.179

Note. N = number, SD = standard deviation, CV = coefficient of variability, V_{IIT} = velocity for the last completed stage.

Table 4

Pearson's Correlation Coefficients for V_{IIT}, VO_{2peak}, and OPO

		V_{IIT}	VO_{2peak} (ml/kg/min)	%DPO	PPO (watts)	RPPO (w/kg)	MPO (watts)	RMPO (w/kg)
V_{IIT}	*r*	1	.917	-.036	-.415	.477	-.386	.565
	p-value		.083	.927	.266	.194	.305	.113
	N	9	4	9	9	9	9	9
VO_{2peak}	*r*	.917	1	.197	-.783	.791	-.739	.620
	p-value	.083		.803	.217	.209	.261	.380
	N	4	4	4	4	4	4	4

Note. N = number, V_{IIT} = final velocity of 30-15_{IIT}, %DPO = percent decrement of power output, PPO = absolute peak power output, RPPO = relative peak power output, MPO = absolute mean power output, RMPO = relative mean power output.

Table 5

One-way Analysis of Variance of Testing Order and Average Sprint Time

	Sum of Squares	*df*	Mean Square	*F*	*p*
Between Groups	.134	3	.045	.421	.744
Within Groups	.744	7	.106		
Total	.878	10			

Table 6

Tukey's Post hoc Comparison of Testing Order and Average Sprint Time

(I) Testing Order	Mean (s)	(J) Testing Order	Mean Difference (I-J)	Std. Error	*p*
First	8.67	Second	-.21500	.26615	.849
		Third	-.00806	.29757	1.000
		Fourth	.06889	.26615	.993
Second	8.88	First	.21500	.26615	.849
		Third	.20694	.29757	.896
		Fourth	.28389	.26615	.719
Third	8.68	First	.00806	.29757	1.000
		Second	-.20694	.29757	.896
		Fourth	.07694	.29757	.993
Fourth	8.60	First	-.06889	.26615	.993
		Second	-.28389	.26615	.719
		Third	-.07694	.29757	.993

Note. First = first participant tested in RIST, Second = second participant tested in RIST, Third = third participant tested in RIST, Fourth = fourth participant tested in RIST.

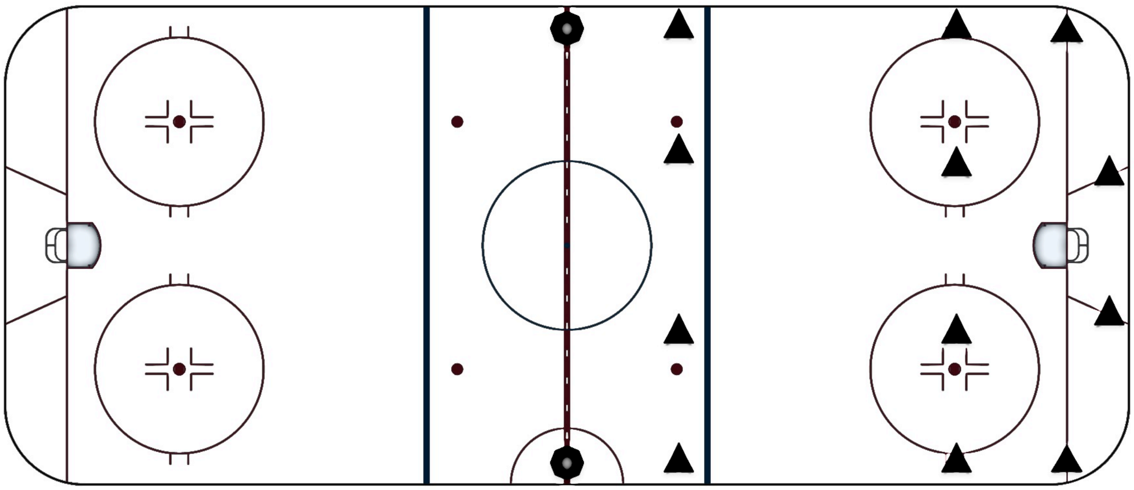


Figure 1. Depiction of the course set-up for the RIST. Triangles = cones; Octagons = Timing systems.

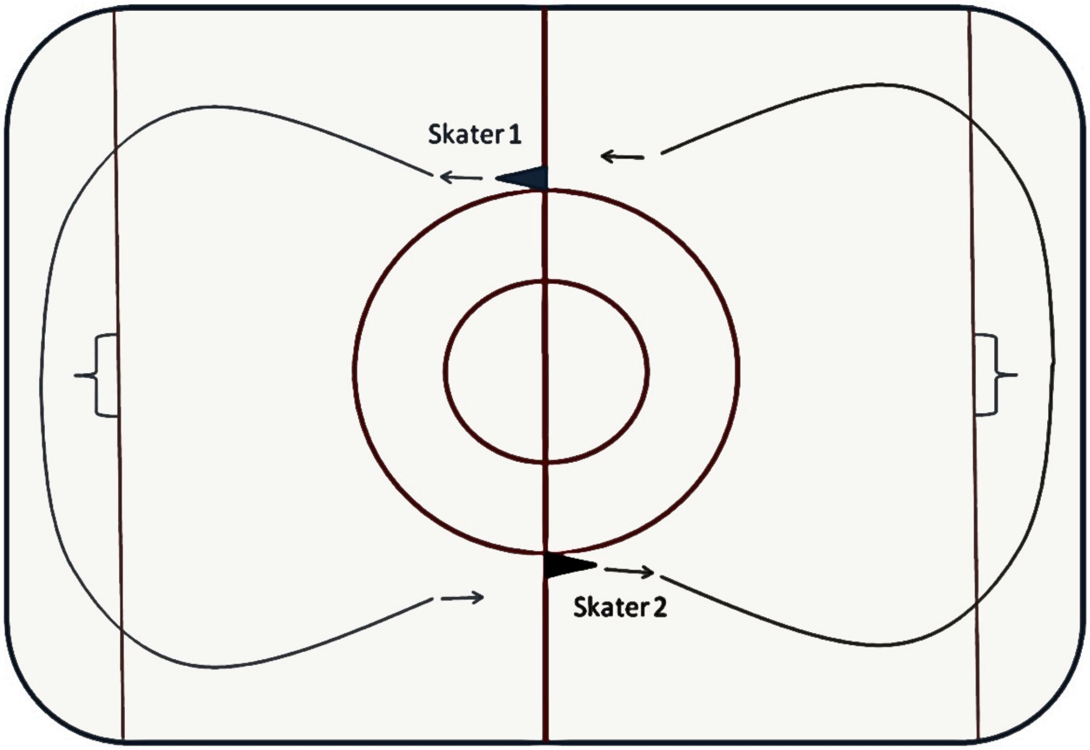


Figure 2. Depiction of the RIST skating path. The timing devices were placed along the center ice line. Cones were also placed ice so that each skater took the same elliptical pattern around the ice. Only one skater Adapted from Power et al. (2012).

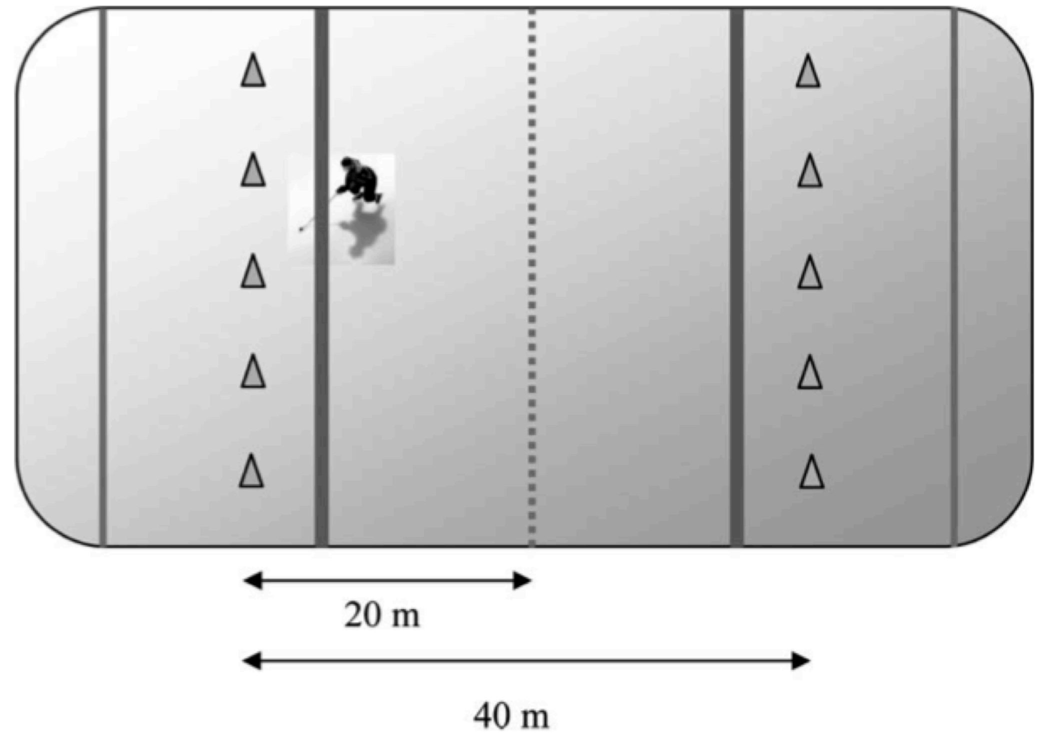


Figure 3. Depiction of the 30-15$_{IIT}$ course. Additional cones placed at the center ice lines, and pucks 3m outside of each cone. Adapted from Buchheit et al. (2011).

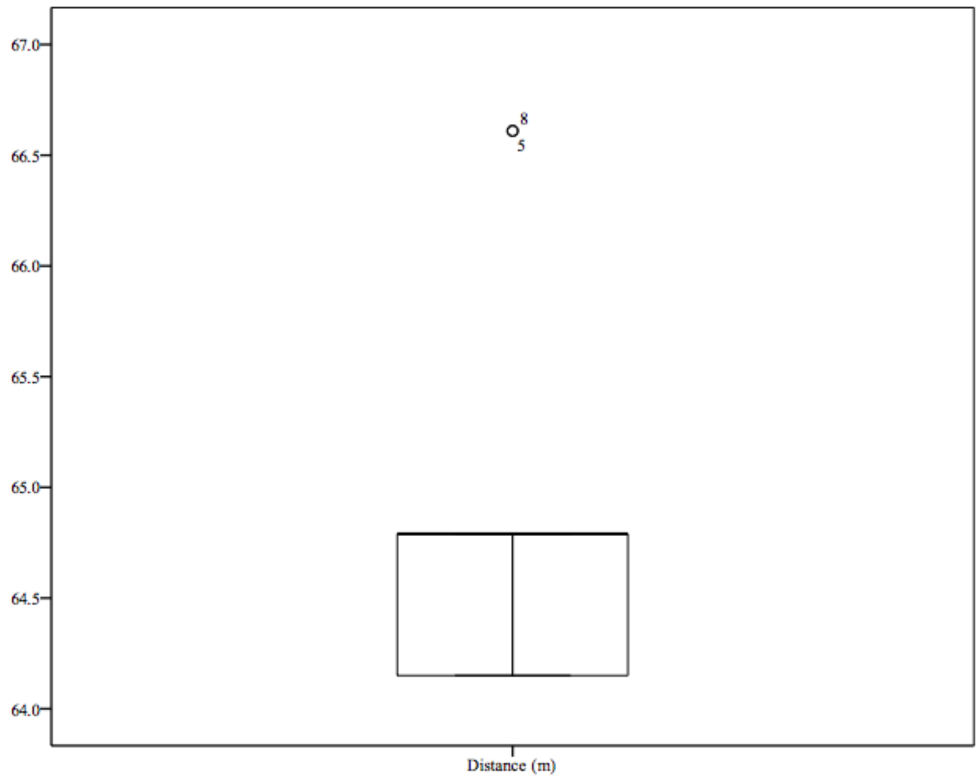


Figure 4. Outliers for distance skated (m) during the RIST.

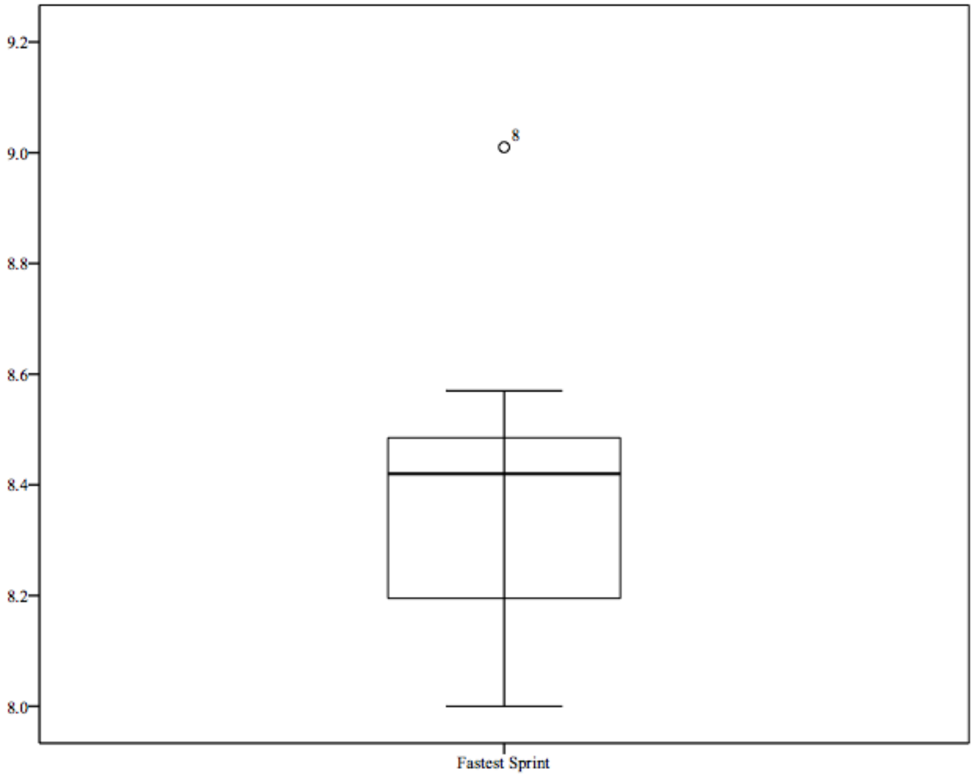
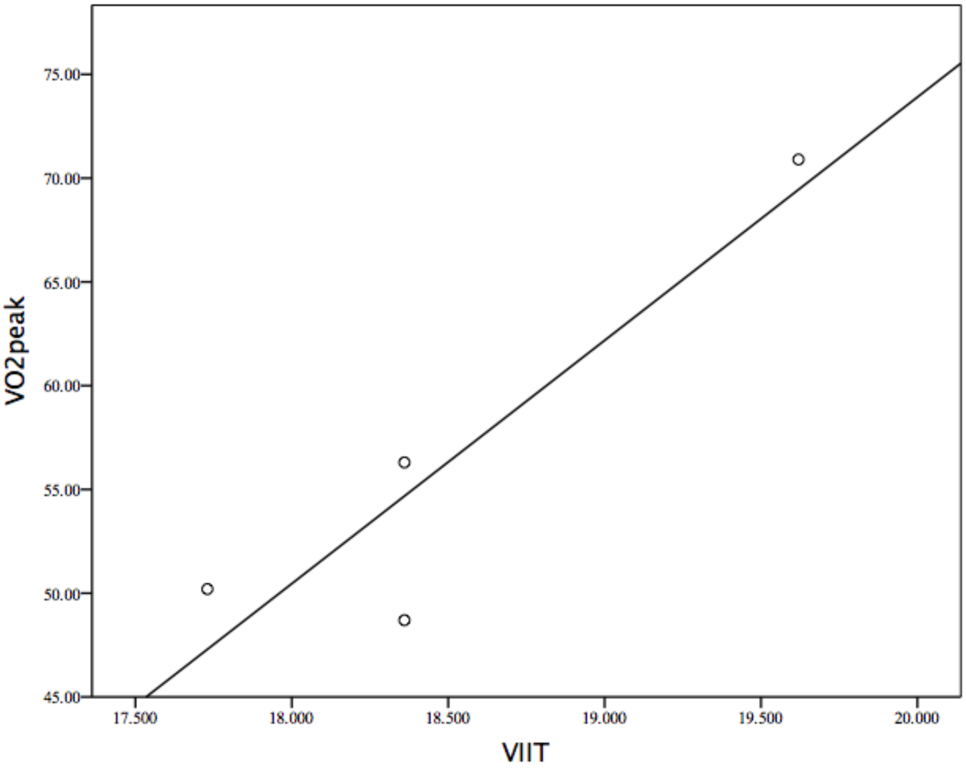
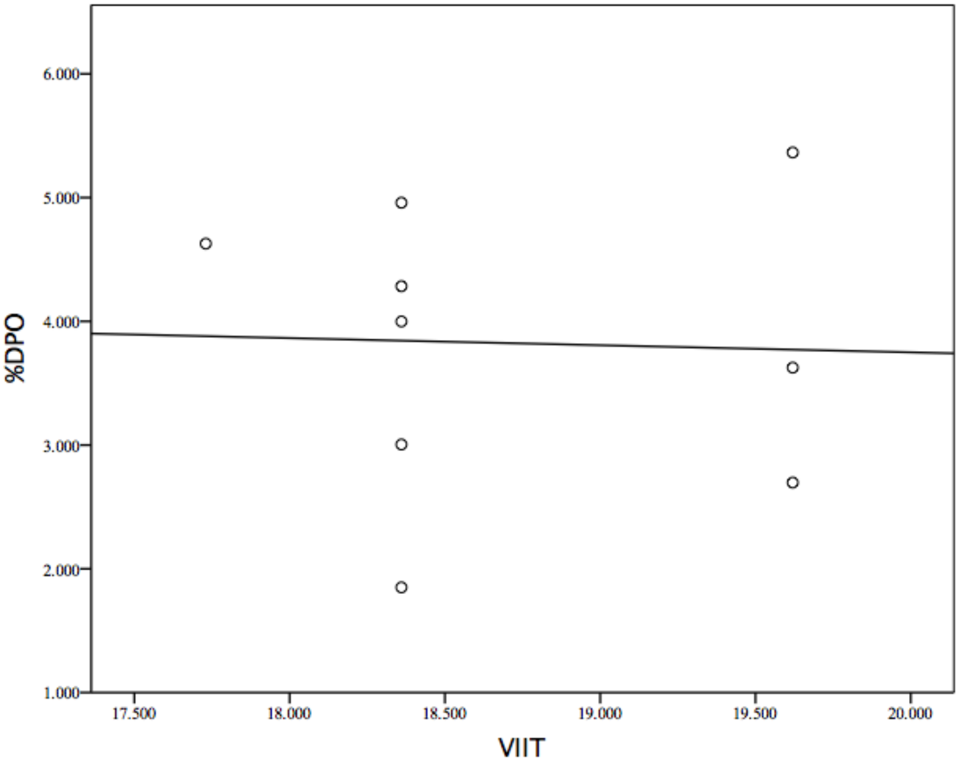


Figure 5. Outlier for FST (s) during the RIST.



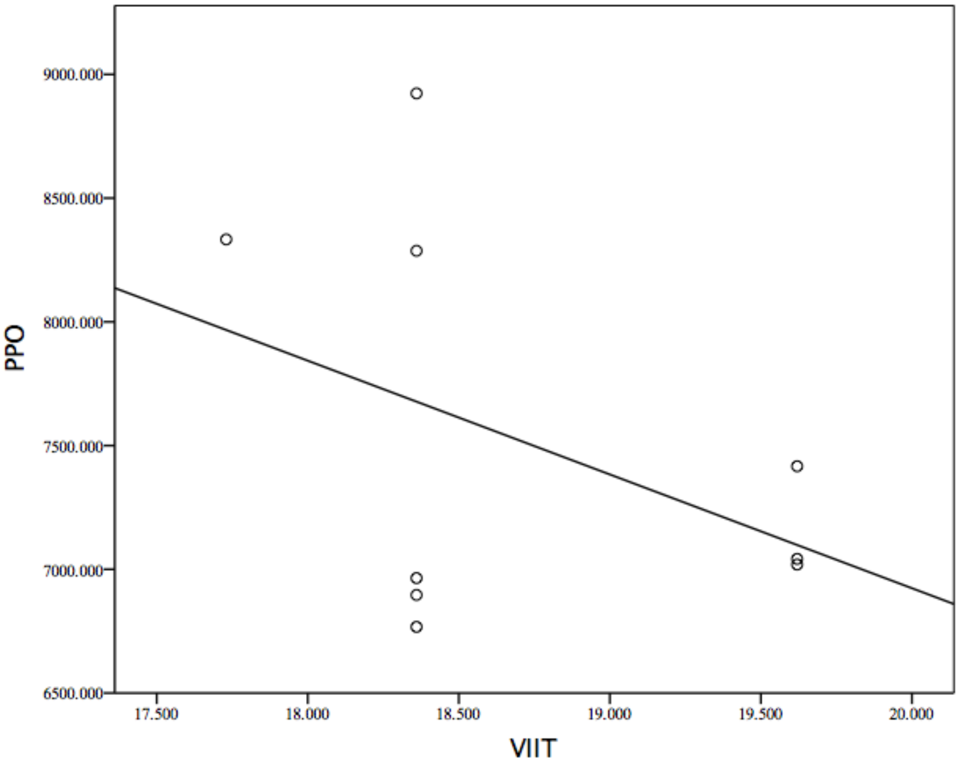
$y = -1.61E2+11.72*x$
$r^2 = .841$
$r = .917$
$p = .083$

Figure 6. Relationship between VO_{2peak} (ml/kg/min) and V_{IIT} (km/h).



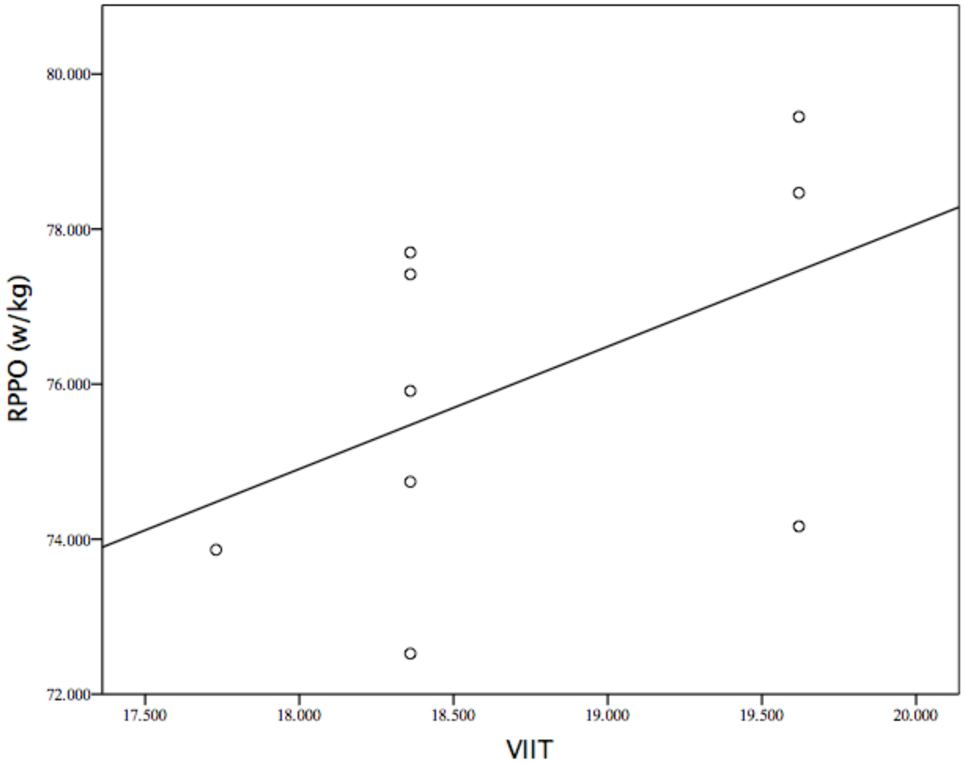
y = 4.9±0.06*x
r^2 = .001
r = - .036
p = .927

Figure 7. Relationship between V_{IIT} (km/h) and %DPO.



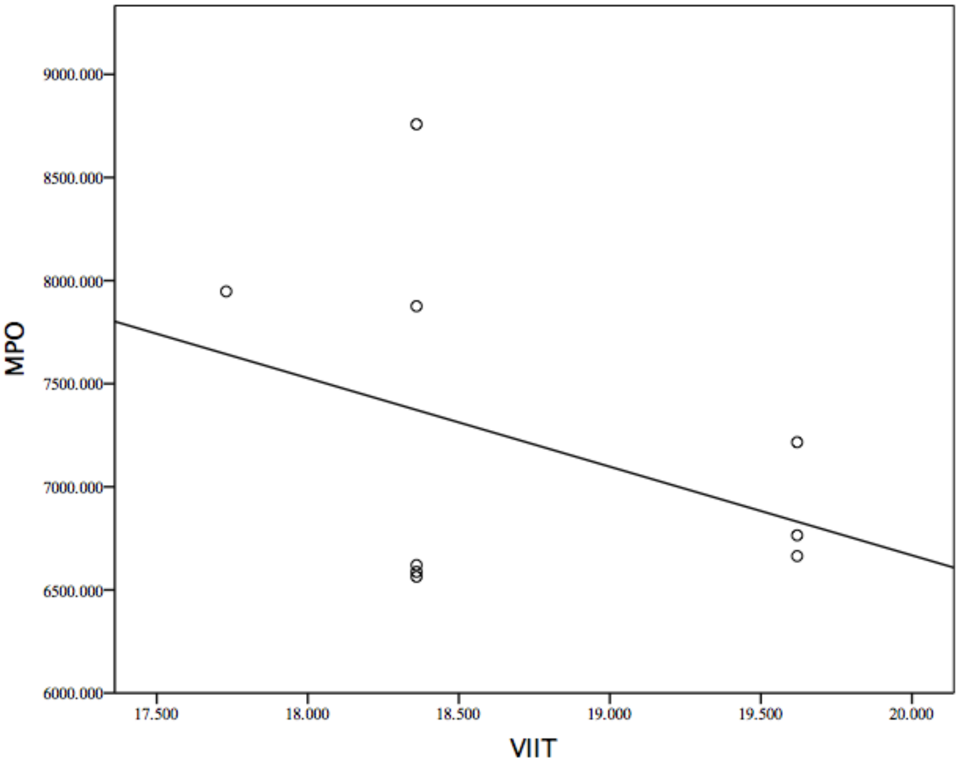
y = 1.61E4±4.6E2*x
$r^2 = .172$
$r = -.415$
$p = .266$

Figure 8. Relationship between V_{IIT} (km/h) and PPO (watts).



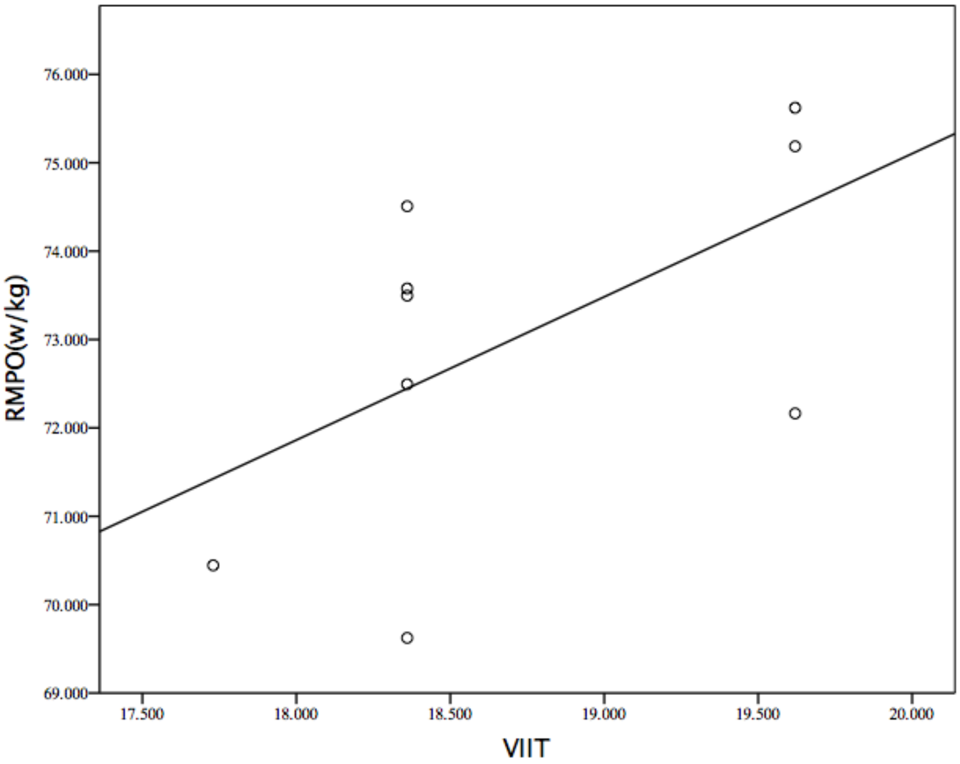
$y = 46.48+1.58*x$
$r^2 = .227$
$r = .477$
$p = .194$

Figure 9. Relationship between V_{IIT} (km/h) and RPPO (w/kg).



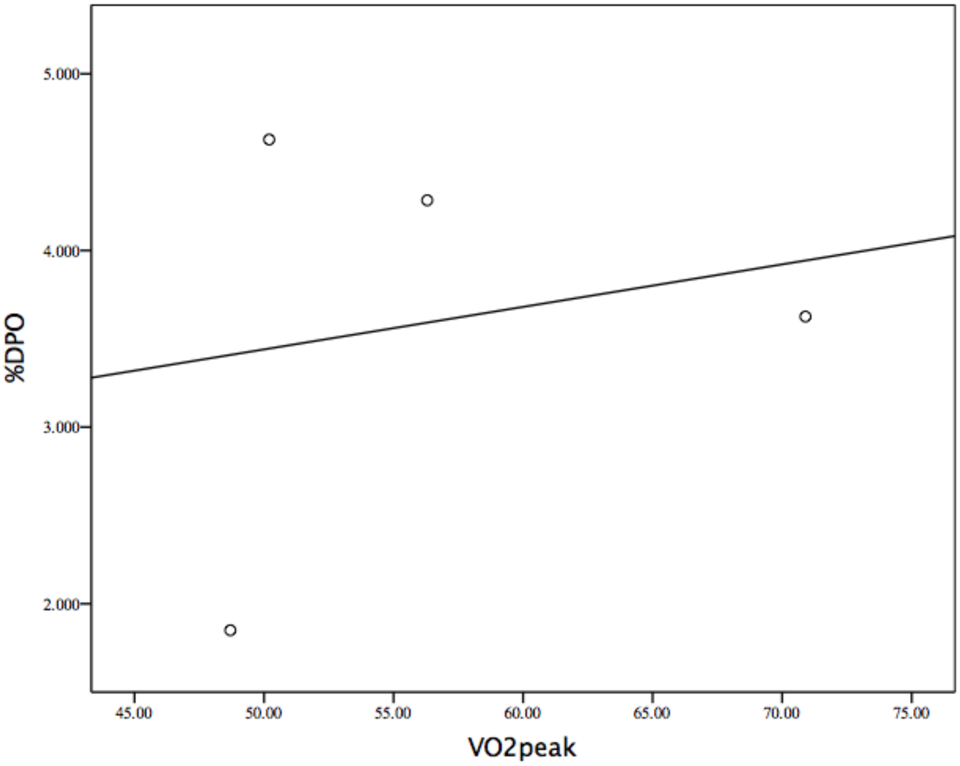
y = 1.53E4±4.3E2*x
$r^2 = .149$
$r = -.386$
$p = .305$

Figure 10. Relationship between V_{IIT} (km/h) and MPO (watts).



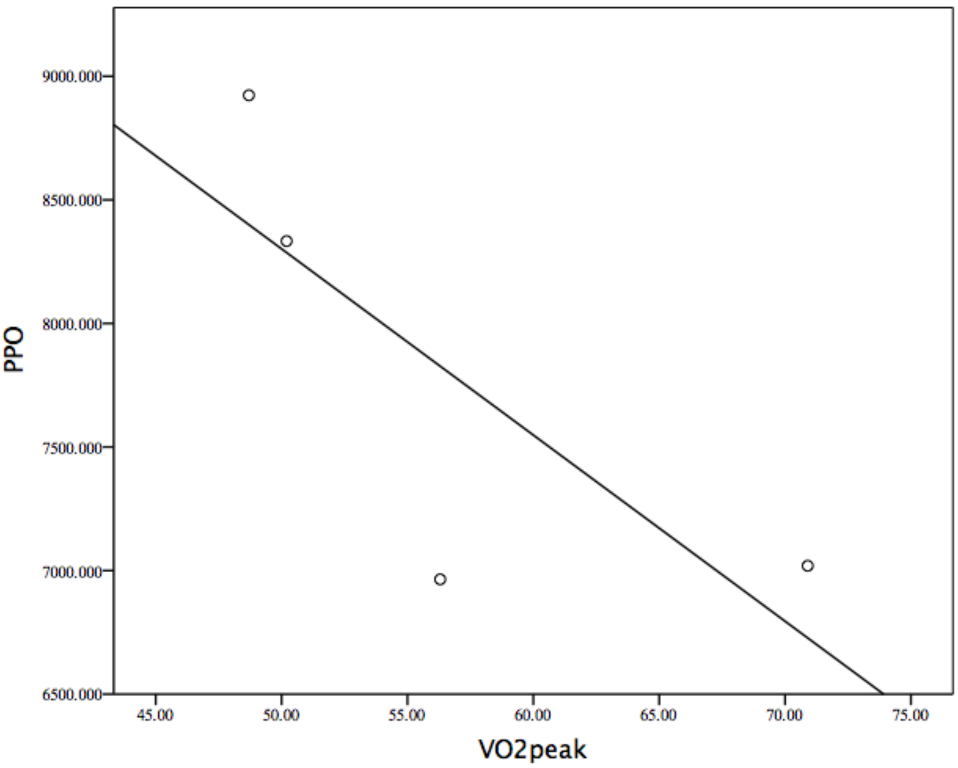
$y = 42.7+1.62*x$
$r^2 = .319$
$r = .565$
$p = .113$

Figure 11. Relationship between V_{IIT} (km/h) and RMPO (w/kg).



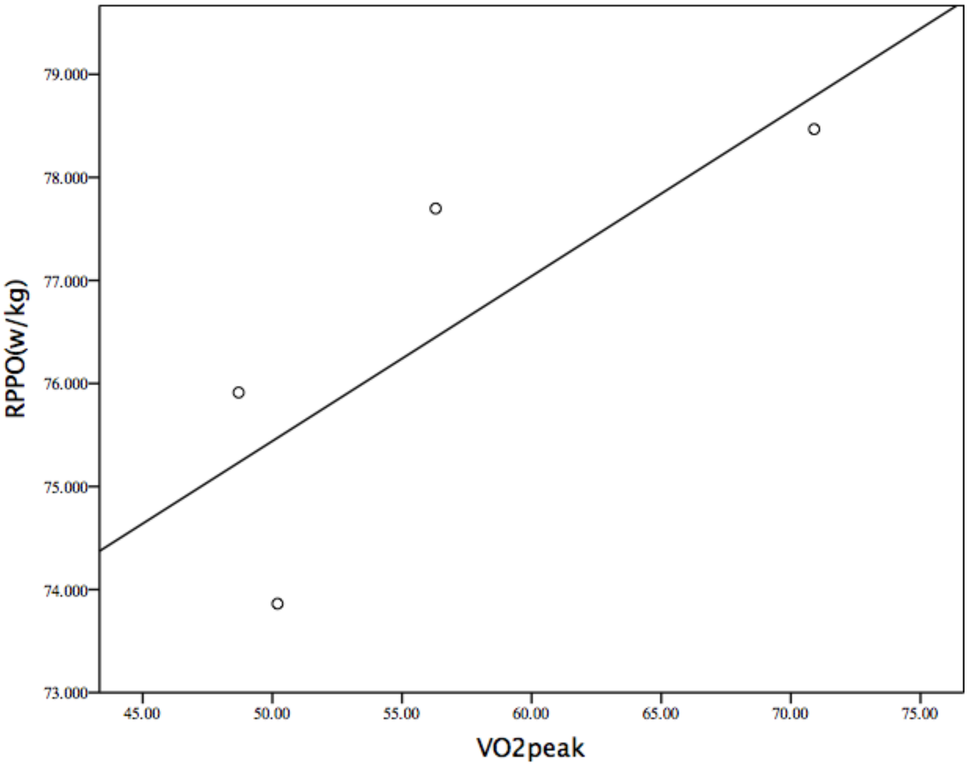
$y = 2.24+0.02*x$
$r^2 = .039$
$r = .197$
$p = .803$

Figure 12. Relationship between VO_{2peak} (ml/kg/min) and %DPO.



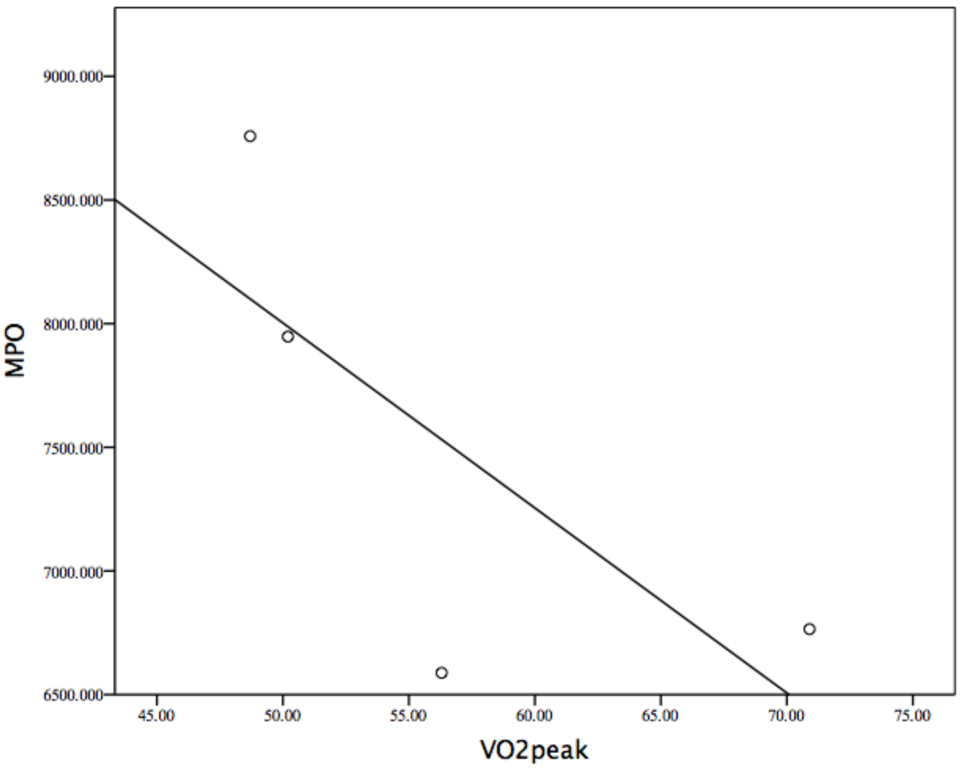
y = 1.21E4±75.32*x
r^2 = .612
r = -.783
p = .217

Figure 13. Relationship between VO_{2peak} (ml/kg/min) and PPO (watts).



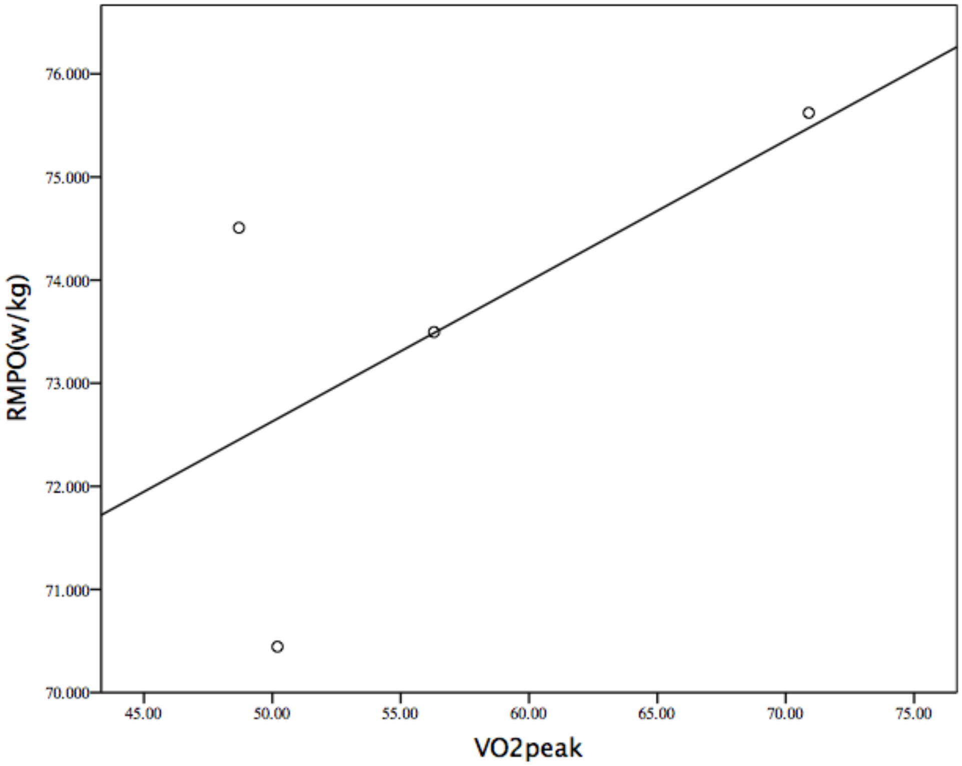
$y = 67.44+0.16*x$
$r^2 = .626$
$r = .791$
$p = .209$

Figure 14. Relationship between VO_{2peak} (ml/kg/min) and RPPO (w/kg).



y = 1.17E4±74.82*x
$r^2 = .546$
$r = -.739$
$p = .261$

Figure 15. Relationship between VO_{2peak} (ml/kg/min) and MPO (watts).



y = 65.82+0.14*x
r^2 = .385
r = .620
p = .380

Figure 16. Relationship between VO_{2peak} (ml/kg/min) and RMPO (w/kg).

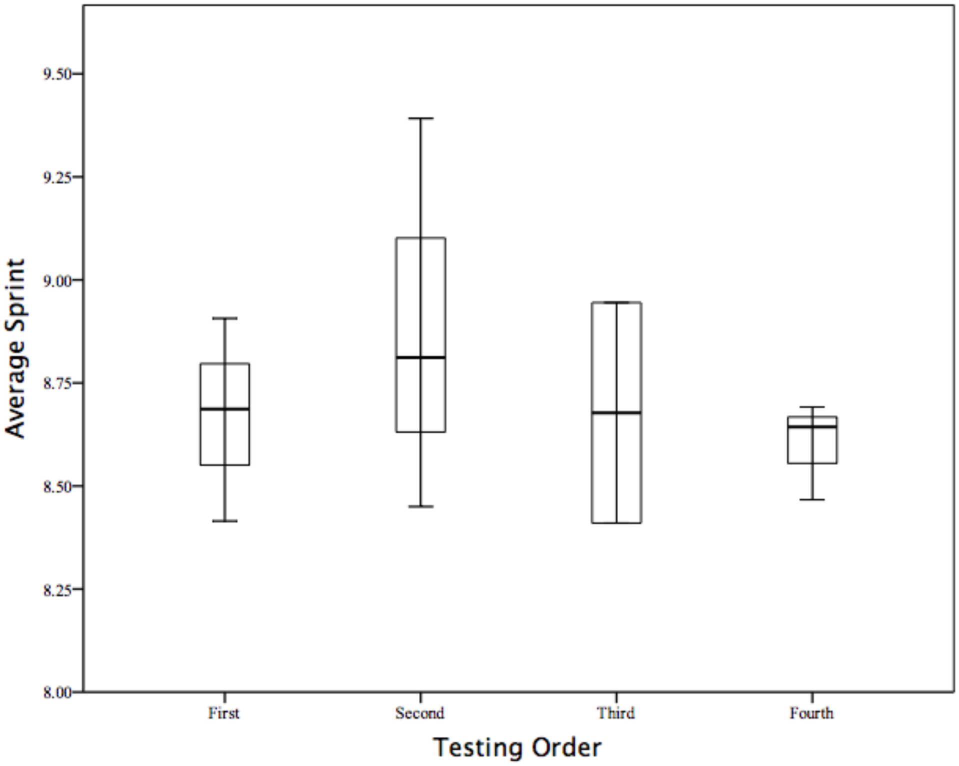


Figure 17. Effect of ice surface on average sprint time.

Appendix A

IRB Approval

January 14, 2015 IRB
Application #: 14185

Proposal Title: The Relationship Between On-Ice Aerobic Capacity And On-Ice Power Output During Repeated Sprints In Elite Ice Hockey Players

Type of Review: Initial-Expedited

Investigator(s):
Mr. Patrick Love
Dr. Jerel Cowan
Department of Kinesiology & Health Studies
College of Education & Professional Studies
Campus Box 189
University of Central Oklahoma
Edmond, OK 73034

Dear Mr. Love and Dr. Cowan:

Re: Application for IRB Review of Research Involving Human Subjects

We have received your materials for your application. The UCO IRB has determined that the above named application is APPROVED BY EXPEDITED REVIEW. The Board has provided expedited review under 45 CFR 46.110, for research involving no more that minimal risk and research category 7.

Date of Approval: 1/14/2015
Date of Approval Expiration: 1/13/2016

If applicable, informed consent (and HIPAA authorization) must be obtained from subjects or their legally authorized representatives and documented prior to research involvement. A stamped, approved copy of the informed consent form will be sent to you via campus mail. The IRB-approved consent form and process must be used. While this project is approved for the period noted above, any modification to the procedures and/or consent form must be approved prior to incorporation into the study. A written request is needed to initiate the amendment process. You will be contacted in writing prior to the approval expiration to determine if a continuing review is needed, which must be obtained before the anniversary date. Notification of the completion of the project must be sent to the IRB office in writing and all records must be retained and available for audit for at least 3 years after the research has ended.

It is the responsibility of the investigators to promptly report to the IRB any serious or unexpected adverse events or unanticipated problems that may be a risk to the subjects.

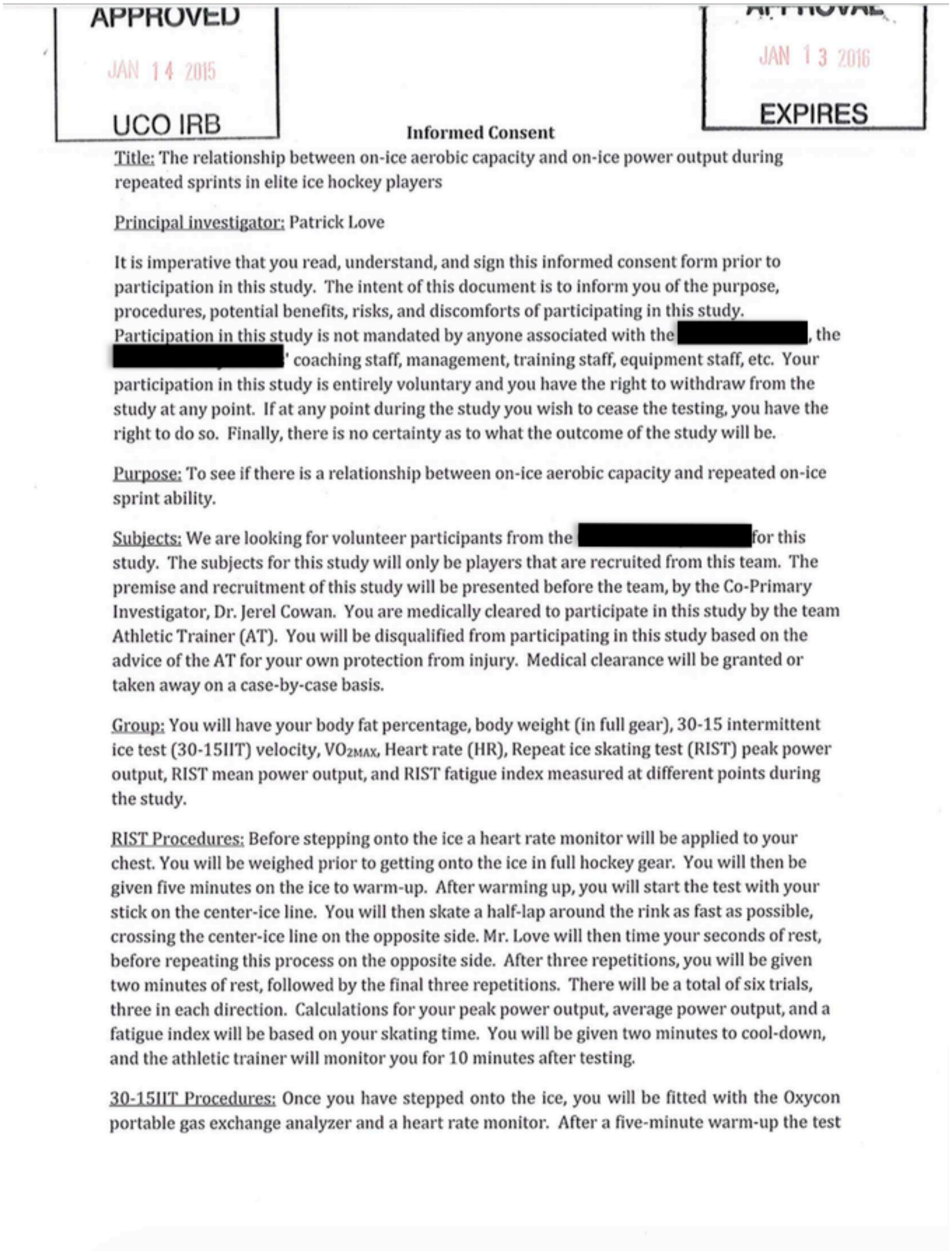
On behalf of the UCO IRB, I wish you the best of luck with your research project. If our office can be of any further assistance, please do not hesitate to contact us.

Sincerely,

Robert D. Mather, Ph.D.
Chair, Institutional Review Board
NUC 341, Campus Box 132
University of Central Oklahoma
Edmond, OK 73034
405-974-5479
irb@uco.edu

Appendix B

IRB Approved Informed Consent



APPROVED
JAN 14 2015
UCO IRB

JAN 13 2016
EXPIRES

Informed Consent

Title: The relationship between on-ice aerobic capacity and on-ice power output during repeated sprints in elite ice hockey players

Principal investigator: Patrick Love

It is imperative that you read, understand, and sign this informed consent form prior to participation in this study. The intent of this document is to inform you of the purpose, procedures, potential benefits, risks, and discomforts of participating in this study. Participation in this study is not mandated by anyone associated with the [redacted], the [redacted]' coaching staff, management, training staff, equipment staff, etc. Your participation in this study is entirely voluntary and you have the right to withdraw from the study at any point. If at any point during the study you wish to cease the testing, you have the right to do so. Finally, there is no certainty as to what the outcome of the study will be.

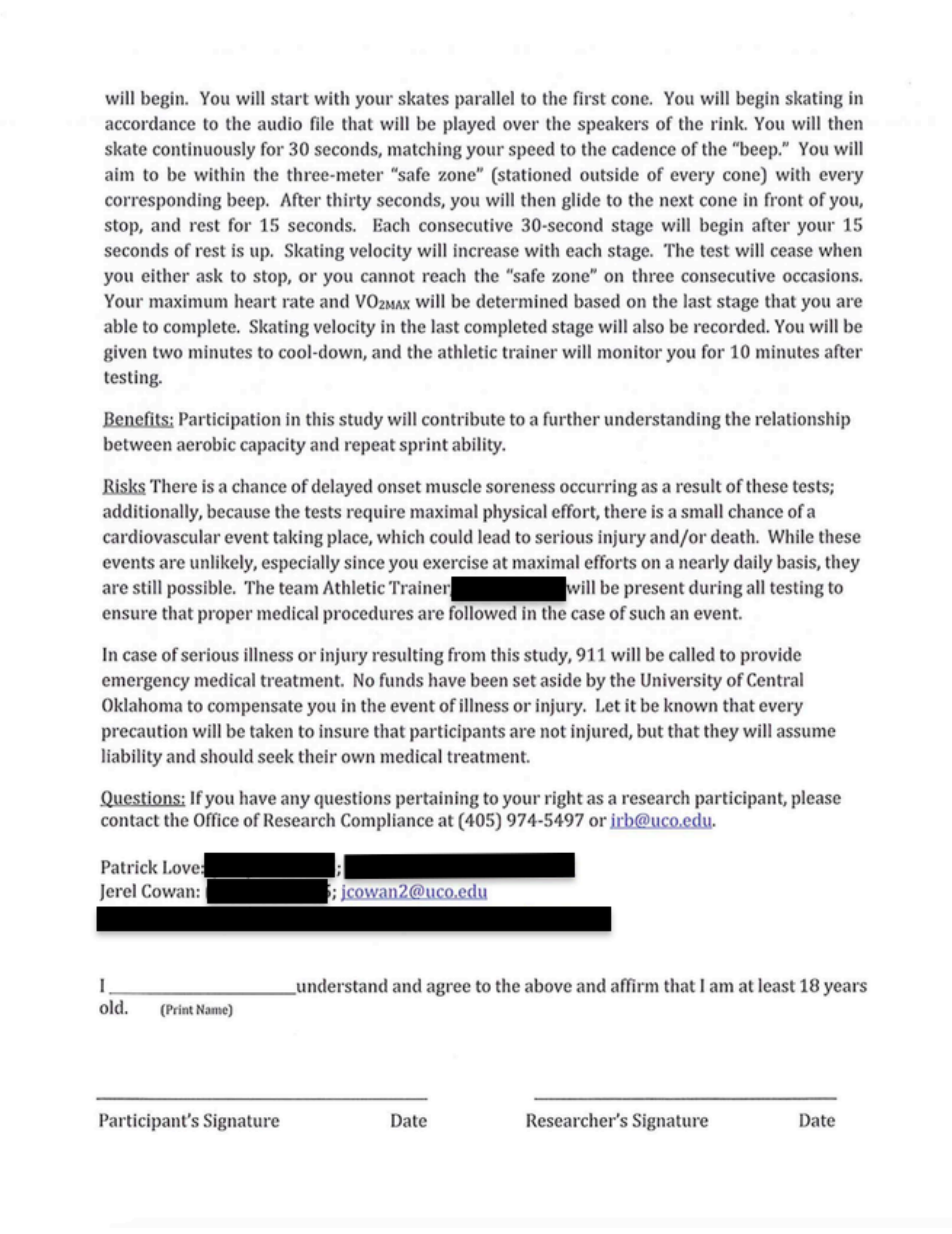
Purpose: To see if there is a relationship between on-ice aerobic capacity and repeated on-ice sprint ability.

Subjects: We are looking for volunteer participants from the [redacted] for this study. The subjects for this study will only be players that are recruited from this team. The premise and recruitment of this study will be presented before the team, by the Co-Primary Investigator, Dr. Jerel Cowan. You are medically cleared to participate in this study by the team Athletic Trainer (AT). You will be disqualified from participating in this study based on the advice of the AT for your own protection from injury. Medical clearance will be granted or taken away on a case-by-case basis.

Group: You will have your body fat percentage, body weight (in full gear), 30-15 intermittent ice test (30-15IIT) velocity, VO_{2MAX}, Heart rate (HR), Repeat ice skating test (RIST) peak power output, RIST mean power output, and RIST fatigue index measured at different points during the study.

RIST Procedures: Before stepping onto the ice a heart rate monitor will be applied to your chest. You will be weighed prior to getting onto the ice in full hockey gear. You will then be given five minutes on the ice to warm-up. After warming up, you will start the test with your stick on the center-ice line. You will then skate a half-lap around the rink as fast as possible, crossing the center-ice line on the opposite side. Mr. Love will then time your seconds of rest, before repeating this process on the opposite side. After three repetitions, you will be given two minutes of rest, followed by the final three repetitions. There will be a total of six trials, three in each direction. Calculations for your peak power output, average power output, and a fatigue index will be based on your skating time. You will be given two minutes to cool-down, and the athletic trainer will monitor you for 10 minutes after testing.

30-15IIT Procedures: Once you have stepped onto the ice, you will be fitted with the Oxycon portable gas exchange analyzer and a heart rate monitor. After a five-minute warm-up the test



will begin. You will start with your skates parallel to the first cone. You will begin skating in accordance to the audio file that will be played over the speakers of the rink. You will then skate continuously for 30 seconds, matching your speed to the cadence of the "beep." You will aim to be within the three-meter "safe zone" (stationed outside of every cone) with every corresponding beep. After thirty seconds, you will then glide to the next cone in front of you, stop, and rest for 15 seconds. Each consecutive 30-second stage will begin after your 15 seconds of rest is up. Skating velocity will increase with each stage. The test will cease when you either ask to stop, or you cannot reach the "safe zone" on three consecutive occasions. Your maximum heart rate and VO_{2MAX} will be determined based on the last stage that you are able to complete. Skating velocity in the last completed stage will also be recorded. You will be given two minutes to cool-down, and the athletic trainer will monitor you for 10 minutes after testing.

Benefits: Participation in this study will contribute to a further understanding the relationship between aerobic capacity and repeat sprint ability.

Risks There is a chance of delayed onset muscle soreness occurring as a result of these tests; additionally, because the tests require maximal physical effort, there is a small chance of a cardiovascular event taking place, which could lead to serious injury and/or death. While these events are unlikely, especially since you exercise at maximal efforts on a nearly daily basis, they are still possible. The team Athletic Trainer [redacted] will be present during all testing to ensure that proper medical procedures are followed in the case of such an event.

In case of serious illness or injury resulting from this study, 911 will be called to provide emergency medical treatment. No funds have been set aside by the University of Central Oklahoma to compensate you in the event of illness or injury. Let it be known that every precaution will be taken to insure that participants are not injured, but that they will assume liability and should seek their own medical treatment.

Questions: If you have any questions pertaining to your right as a research participant, please contact the Office of Research Compliance at (405) 974-5497 or irb@uco.edu.

Patrick Love: [redacted]; [redacted]
Jerel Cowan: [redacted]; jcowan2@uco.edu
[redacted]

I ____________________ understand and agree to the above and affirm that I am at least 18 years old. (Print Name)

____________________________ ____________________________

Participant's Signature Date Researcher's Signature Date

Appendix C

Manuscript for Participant Recruitment

Dr. Jerel Cowan: Written Manuscript for Presentation of Patrick Love's Masters Thesis proposal to the AHL Club

Preface:

"Participation in this study is not mandated by Patrick Love. Your participation, or lack thereof is completely voluntary, and will have no bearing on your working relationship with Mr. Love."

Purpose:

"To see if there is a relationship between on-ice aerobic capacity (VO_{2max}) and on-ice power output during repeated sprints. A fatigue index (%FI), mean power output (MPO) and peak power output (PPO) will be correlated to VO_{2max}."

Procedures:

"First, it should be noted that some players may be excluded from participating in this study based on the advice of the Athletic Trainer, if said player has an acute or chronic injury/medical condition. Height, weight, and body fat percentage will be measured one day before on-ice testing begins. On-ice power output will be tested (in full hockey gear) via the Repeat Ice Skating Test. The participant will be weighed in full-hockey gear prior to testing. The participant will then be asked to skate a half lap around the rink as fast as possible, rest for ten seconds, and repeat a half lap around the rink in the opposite direction. After three repetitions the participant will rest for two minutes before completing the protocol for three more repetitions. There will be a total of six repetitions for this test. Heart rate will be monitored during testing. PO will then be determined based on the participant's time and body weight (in full gear). A %FI will then be calculated based on the participant's power output (PO). Maximal sprinting effort is expected by the participants.

A second test designed to tax the participant's aerobic system will be administered the following week. There will be two weeks available for aerobic testing to ensure that all participants have ample time to complete the test. Scheduling for this test will be randomized. The participants will wear a portable gas exchange analyzer and complete the 30-15 intermittent ice test. This is an on-ice graded test designed to test the participant's aerobic capacity in a sport specific manner. This is a maximal test, and the researchers ask that the participants put forth maximal physical effort. The participant will skate to cones marked on the ice corresponding to the cadence of an audible beep, which will be played over the speakers in the rink. The player will skate for 30 seconds (stopping at the end cones and changing directions), matching the speed of the beep, and rest for 15 seconds at the cone in front of them after the final beep of the stage. Skating velocity will increase with every stage. The test will end when the participant cannot reach the three-meter 'safe zone' in front of every cone, which will be marked with pucks, corresponding to the beep, on three consecutive occasions, or when he wants to voluntarily stop the test. Oxygen consumption will be collected data will be collected via an Oxycon portable oxygen consumption analyzer; heart rate will also be monitored throughout the test.

A video will then be presented to the team to give the prospective participants a visual representation of the 30-15 intermittent ice test. Dr. Cowan will request that questions are saved until the end of his presentation.

http://www.youtube.com/watch?v=RiErH0xTFXo

Benefits

"The participants will help contribute to the scientific community's understanding of the relationship between aerobic capacity and repeat sprint ability in elite level ice hockey players. There is currently a lack of evidence on this subject."

Expected Length of Participation

"Testing for this study will last three weeks, with three testing days in February, 2015. RIST will occur prior to aerobic capacity testing. All participants will be testing on the same day for this test. This test is expected to last approximately five minutes per participant. $30\text{-}15_{IIT}$ will occur on two separate days to ensure ample time for each participant to complete the testing. This test will take a maximum of 16 minutes per participant."

Potential Risks or Discomforts

"There is a chance of delayed onset muscle soreness occurring as a result of these tests; additionally, because the tests require maximal physical effort, there is the chance of a cardiovascular event taking place, which could lead to serious injury and/or death. While these events are unlikely, they are possible. The team Athletic Trainer will be present during all testing to ensure that proper medical procedures are followed in the case of such an event."

"ALL testing will be monitored by the team athletic trainer. His contact information is attached to the informed consent, which the participants will be signing. The researchers' contact information and contact information for the university of Central Oklahoma is also available."

"***To reiterate, participation in this study is completely voluntary. The NHL affiliate, AHL club, and all of its affiliate employees are not requiring that anyone participate in this study; moreover, all information collected is completely confidential and will not be shared with ANYONE, including ownership, management, coaching staff, etc., of the NHL affiliate's organization, nor any of its affiliates or said affiliates' employees. If you elect to participate in this study, you also have the right to withdraw from the study for any reason."***

Appendix D

Participant Inclusion/Exclusion Criteria

To Whom It May Concern:

The athletes participating in the study will be clear of injury or illnesses, including but not limited to the following list:

- Musculoskeletal Injuries
    - Sprains
    - Strains
    - Fractures
- Acute Illness
- Chronic Illness
- Neurological Deficits
- Psychological Deficits
- Sociological Deficits

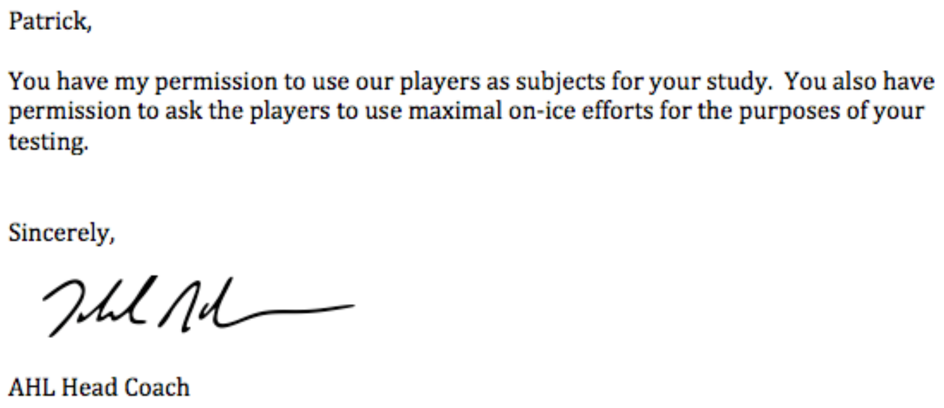
If you have any questions regarding any of these injuries or illness, or any participants in the study, please feel free to contact me.

Sincerely,

AHL Athletic Trainer, MS, ATC, LAT

Appendix E

Head Coach Assent for Recruitment



Patrick,

You have my permission to use our players as subjects for your study. You also have permission to ask the players to use maximal on-ice efforts for the purposes of your testing.

Sincerely,

AHL Head Coach

Appendix F

Pre-Testing Instructions

Pre-Testing Instructions

1. Don’t drink coffee
2. Foam roll for 5 minutes
3. Steady state bike ride for 5 minutes
4. 30 second hip flexor stretch on each side
5. 30 second pigeon glute stretch on each side
6. 2x10 Glute bridge
7. 2x :10 Full tension plank (RKC Plank)
8. Get fully dressed in your gear
9. Weigh in with your hockey gear on and your stick in your hand on the scale in the dressing room
10. Details of the test will be discussed on the ice