High-Intensity Inspiratory Muscle Training Improves Skating Performance and Maximal Oxygen Consumption in Division 1 College Ice Hockey Players

Dylan M. Wiwchar, Ken Chatham,
Daniel S. Boothby, Stephen B. Clark, Lawrence P. Cahalin

Northeastern University
Department of Physical Therapy and Athletics Department
Boston, Massachusetts, USA

Author E-mail addresses
Dylan M. Wiwchar: dwiwchar@gmail.com
Ken Chatham: kwchatham@btinternet.com
Daniel S. Boothby: d.boothby@neu.edu
Stephen B. Clark: clark.s@neu.edu
Lawrence P. Cahalin: l.cahalin@neu.edu

Address for Correspondence:
Lawrence P. Cahalin PhD, PT, CCS
Northeastern University
360 Huntington Avenue
Department of Physical Therapy
6 Robinson Hall
Boston, Massachusetts 02115
Phone: 617-373-3783
Fax: 617-373-3161
E-mail: L.Cahalin@neu.edu

Funding to perform this study was provided by a Northeastern University Undergraduate Research Grant.

Abstract

High-intensity inspiratory muscle training (IMT) has been observed to improve exercise performance and many physiologic parameters in a variety of athletes. Because IMT has not been previously studied in ice hockey players we sought to examine the effects of a short-term, high-intensity IMT program in Division 1 college ice hockey players. A stratified random assignment of 6 players to a control group (CG) and 6 players to an experimental group (EG) was performed at the beginning of the 2009-2010 hockey season with 5 players in each group completing the study. The EG performed 6 weeks of high-intensity (80% of maximal inspiratory performance) IMT 2x/week via the Test of Incremental Respiratory Endurance (TIRE) for 30 minutes per session. The CG performed no IMT. Baseline maximal inspiratory pressure (MIP), sustained maximal inspiratory pressure (SMIP), accumulated SMIP, inspiratory work, inspiratory muscle time of contraction (IMTOC), and inspiratory vital capacity (IVC) were similar between groups ($p>0.05$), but all were significantly greater ($p<0.05$) in the EG after IMT (43%, 28%, 101%, 42%, 11%, and 15%, respectively). Baseline lengths skated and estimated maximal oxygen consumption (VO_{2max}) were similar between groups ($p>0.05$), but both were significantly greater ($p<0.05$) in the EG after IMT (11% and 7.4%, respectively). Post-study VO_{2max} was significantly correlated to post-study IMTOC and to post-study IVC ($r=0.67$ and 0.64, respectively; $p<0.05$) identifying the mechanisms by which IMT likely improved skating performance. High-intensity IMT produced significant improvements in inspiratory muscle performance, skating performance, and estimated VO_{2max}.

Keywords: Ice skating, ice hockey, Division 1 college ice hockey, respiratory muscles, inspiration, inspiratory muscle training, maximal oxygen consumption.

Introduction

Ice hockey is a sport requiring both aerobic and anaerobic exercise (Green et al. 1976; Paterson 1979; Green 1987; Montgomery 1988, 2000; Twist and Rhodes 1993). An optimal aerobic foundation is likely to result in superior anaerobic exercise performance. Also, improved aerobic fitness will result in more rapid recovery from anaerobic exercise and enable ice hockey players to return to the ice sooner (Green et al. 1976; Paterson 1979; Green 1987; Montgomery 1988, 2000; Twist and Rhodes 1993). Furthermore, greater levels of aerobic fitness have been found to be associated with improved on-ice performance (Green et al. 2006). Green et al (2006) found that maximal oxygen consumption (VO_{2max}) was the only significant predictor of net scoring chances in Division 1 college ice hockey players. Aerobic exercise training is a major component of pre-season ice hockey training, but appears to receive less attention as the ice hockey season progresses (Green et al. 1976; Paterson 1979; Green 1987; Montgomery 1988, 2000; Twist and Rhodes 1993). Methods used to improve aerobic and anaerobic exercise performance include a variety of training methods and ergogenic aids (Twist 1997; MacAdam and Reynolds 2001). One training method to improve exercise performance in ice hockey that does not appear to have been addressed is inspiratory muscle training (IMT).

IMT is a form of exercise aimed to specifically improve the performance of the inspiratory muscles (Sapienza 2008). Various methods of IMT can be used with some methods more robust than others. The goal of IMT is to increase the strength and endurance of the diaphragm and accessory muscles of inspiration (e.g. scalene, sternocleidomastoid, and intercostal muscles) with subsequent improvement in pulmonary function, breathing efficiency, and cardiorespiratory fitness (Sapienza 2008; Chatham 2000; Chatham et al. 2004; Gething et al. 2004; Enright et al. 2006; Mickleborough et al. 2008, 2009). Inspiratory muscle strength and endurance cannot be measured directly and are inferred from the generation of pressures that are most commonly obtained at the mouth. The standard measure of inspiratory strength is maximal inspiratory pressure (MIP) which reflects the peak negative pressure at residual volume or functional residual capacity over the first second of an inspiratory effort (Sapienza 2008). The ability to sustain this pressure isokinetically until total lung capacity is reached, through a full range of muscle contraction, is unique to the IMT system used in the present study and reflects both power through range and single breath work capacity. This is termed the sustained maximum inspiratory pressure (SMIP). A variety of methods to examine inspiratory muscle endurance identified by task failure have been previously described and the method used in the present study was assessed using the Test of Incremental Respiratory Endurance (TIRE) and was defined as the accumulated SMIP (Chatham 2000; Chatham et al. 2004; Gething et al. 2004; Enright et al. 2006; Mickleborough et al. 2008, 2009).

High-intensity IMT has been observed to improve exercise performance and many physiologic parameters in a variety of athletes. Runners, swimmers, rugby players, and cyclists have been observed to improve one or more of the following variables including exercise tolerance, VO_{2max}, heart rate, lactate response, and symptoms after 6 to 10 weeks of high-intensity IMT using the progressive increasing work to rest ratio of the TIRE incorporated within the RT2 system (Chatham 2000; Chatham et al. 2004; Gething et al. 2004; Enright et al. 2006; Mickleborough et al. 2008, 2009). The IMT performed with the TIRE RT2 in these studies was performed at 80% of maximal inspiratory performance throughout the full range of inspiration (from residual volume to total lung capacity) with targeted visual biofeedback utilizing specific computer software all of which to our knowledge are not characteristics with other forms of IMT (Chatham 2000; Chatham et al. 2004; Gething et al. 2004; Enright et al. 2006; Mickleborough et al. 2008, 2009).

Because of the beneficial effects of high-intensity IMT in other sports and because IMT has not been previously studied in ice hockey players we sought to examine the effects of a short-term, high-intensity IMT program on inspiratory capacity, skating performance, and estimated VO_{2max} in Division 1 college ice hockey players. We hypothesized that high-intensity IMT would significantly improve inspiratory capacity as well as skating performance and estimated VO_{2max}.

Materials and methods

Subject Characteristics

The participants for this research study were recruited from the Northeastern University (NU) men’s ice hockey team after the study had been approved by the NU Office of Human Subject Research Protection and after the subjects provided informed consent to participate in the study. The inclusion criteria for the study were NU ice hockey players who were: 1) 18 years of age or older and healthy and 2) willing and able to participate in resisted breathing exercises and understand the instructions and methods to perform the breathing exercises. The exclusion criteria for the study were NU ice hockey players who were: 1) less than 18 years of age, 2) injured, 3) unable to participate in resisted breathing exercises for any reason, and 4) unable to understand the instructions and methods to perform the breathing exercises.

A stratified random assignment to the experimental or control group was performed with player position (forward versus defenseman) used as the stratification method. Three forwards and three defensemen were randomly assigned (via luck of the draw) to each of the groups. One forward in each of the groups was injured during the study period and the data from these subjects were not included in the study results. Due to the loss of these research subjects, author DMW who was also a subject in the experimental group was retained in the study and data from this subject was included in the study results. However, separate analyses with and without this subject were performed and revealed no difference in the study results. The characteristics of the subjects in the experimental and control groups are shown in Table 1. There was no significant difference in the mean age, height, and weight between the experimental and control groups.

Measurements

Test of Incremental Respiratory Endurance (TIRE): The TIRE is incorporated within the RT2 device (DeVilbiss Healthcare Ltd) that is connected in series with a laptop or desktop computer (Chatham 2000; Chatham et al. 2004; Gething et al. 2004; Enright et al. 2006; Mickleborough et al. 2008, 2009). Inspiratory muscle strength was measured as MIP at residual volume (RV). Single breath inspiratory work capacity was measured as SMIP and was measured from RV to total lung capacity (TLC). Total inspiratory muscle work achieved during a testing or training session was measured as accumulated SMIP (ΣSMIP) at 80% of SMIP and was the primary measurement of inspiratory muscle endurance. The conversion of pressure generation through the 2 mm leak of the manometer mouthpiece to SI units of inspiratory power and work and the safe use of the

TIRE RT2 in a variety of athletes has been previously reported (Chatham et al. 2004; Enright et al. 2006; Mickleborough et al. 2008, 2009).

Previous work has established a calibration curve for the electronic manometer via the 2 mm leak of the mouthpiece which provides the volume of air entering the manometer for a given pressure to be determined and enables the conversion of pressure to energy and power via: Power (P) = p x Q where p=pressure expressed as N/m^2 and Q=flow rate expressed in m^3/second utilizing a calibration constant for the 2 mm leak of $Q=3.226 \times 10^{-6} \times \sqrt{p}$ (Chatham et al. 2004; Enright et al. 2006; Mickleborough et al. 2008, 2009). Thus, the measurement of inspiratory power was expressed in Watts and inspiratory muscle work was expressed in Joules. The measurement of inspiratory work per breath was obtained from the power curve and was expressed in Joules/breath of inspiratory work. Inspiratory power at 25%, 50% and 75% of the inspiratory power curve was identified at ¼, ½, and ¾ of the inspiratory power curve, respectively, and was expressed in Watts after which the relative and absolute values at baseline and post-study were compared. Relative post-study inspiratory power was compared to baseline inspiratory power using 25%, 50%, and 75% of the baseline power curve as the reference values. Absolute baseline and post-study inspiratory power was compared at 25%, 50%, and 75% of each power curve. An endurance ratio was also calculated via inspiratory power at 75% of the inspiratory power curve/inspiratory power at 25% of the inspiratory power curve which was multiplied by 100. The inspiratory muscle time of contraction (IMTOC) was extracted from the SMIP recording and was defined as the time of inspiratory muscle contraction from RV to TLC. The inspiratory vital capacity (IVC) was measured from RV to TLC and was calculated as accumulated inspiratory flow in liters (ΣQ x 1000) (Chatham et al. 2004; Enright et al. 2006; Mickleborough et al. 2008, 2009).

The TIRE is characterized by the serial presentation of submaximal isokinetic profiles based upon maximum voluntary contraction (MVC) of the respiratory muscles. These efforts are presented at an on-screen target of 80% of MVC or SMIP within a progressive increasing work to rest ratio, with rest periods decreasing from 60 seconds at level A to 45, 30, 15, 10 and 5 seconds at levels B through F, respectively (Figure 1) (Chatham et al. 2004; Enright et al. 2006; Mickleborough et al. 2008, 2009). Each of the six levels has 6 resisted breaths through the manometers 2mm leak but is fixed at 80% of SMIP at each examination or training session. The TIRE IMT is characterized by through-range IMT with the need for the subject to match or exceed 90% of the 80% on-screen target throughout the entire inspiratory effort (from RV to TLC). Thus, an examination or training session continues until task failure indicated by an inability to match 90% of the on screen target, or until a maximum of 36 resisted breaths have been performed (Chatham et al. 2004; Enright et al. 2006; Mickleborough et al. 2008, 2009).

The TIRE RT2 was used during the first 2 weeks of IMT using the exact methods described above for 30-45 minutes, 2x/week. The last 4 weeks of IMT via the TIRE was performed for approximately 30 minutes, 2x/week due to a shorter rest period between the six breaths of the first two TIRE levels which was changed to enable a full IMT session (36 resisted breaths) to be completed within approximately 30 minutes. Therefore, the rest period was reduced from 60 and 45 seconds at levels A and B, respectively, to 30 seconds. Thus, the work to rest ratio used during the last 4 weeks of TIRE IMT during levels A through C was 30 seconds followed by 15, 10, and 5 seconds at levels D through F, respectively. The TIRE RT2 IMT performed by the subjects in the experimental group was done after on-ice practice sessions due to schedule availability and to impose a greater task/workload upon the inspiratory muscles. Six weeks after IMT was terminated TIRE RT2 testing was performed in the subjects of the experimental group to examine the effects of de-training on inspiratory muscle performance.

The Faught Aerobic Skating Test (FAST): The FAST is an incremental aerobic on-ice skating test that is used in the examination of ice hockey players (Petrella et al. 2007). The test consisted of the subjects skating continuously on a course measuring 160 feet using a CD with audio cues to pace the skater with a beep signal to cross the starting line at each end of the course. The FAST skating speed begins at 11.7 km/hour with a cadence of 15 seconds between lengths and progressively increases skating speed to a maximum of 26.9 km/hour with a cadence of 5.5 seconds between lengths. Two proctors at each end of the course examined the ice hockey players for consistency in crossing the starting line with each beep. Violations during the FAST were given to ice hockey players failing to (1) remain behind the starting line before the beep was announced and (2) reach the starting line at the other end of the course before the beep was announced. Subjects were allowed to continue skating until they had accumulated 2 consecutive violations or voluntarily stopped the test due to fatigue. The ice hockey player’s final successfully completed length of the course was recorded as the maximum FAST distance (Petrella et al. 2007). The proctors at each end of the course examining and recording the FAST results were familiar with the methods to implement the FAST, were not the primary study investigators, and did not know which players were in the experimental and control groups.

Previous studies have found the FAST to have good test-retest reliability with intra-class correlation coefficients ranging from 0.76 – 0.81 (Faught et al. 2003; Petrella et al. 2005). A regression equation using FAST results and demographic characteristics provides an estimate of VO_{2max} with R^2 values ranging from 0.387 – 0.601 and standard error estimates of 5.48 – 7.25 ml/kg/min (Faught et al. 2003; Petrella et al. 2005). The regression equation used to estimate VO_{2max} from the FAST was: VO_{2max} = {34.119 x height (m)} – {0.244 x weight (kg)} + {0.757 x FAST lengths (#)} – {0.975 x age (yrs)} – 3.285 (Petrella et al. 2007). The ice hockey players were informed and instructed in the manner by which the FAST would be implemented each time before the FAST was performed. The FAST was performed before and after the 6 week study period.

Experimental Group Inspiratory Muscle Training Study Questionnaire and Rating of Perceived Exertion during and after IMT: A questionnaire was developed using previous IMT literature (Chatham et al. 2004; Enright et al. 2006; Mickleborough et al. 2008, 2009) and focus group discussions with ice hockey coaches and ice hockey players. The questions were constructed using a 5-point Likert scale ranging from strongly disagree (score of 0) to strongly agree (score of 4) except for one question (question # 4) which reversed the subjective scoring to provide an overall “favourable” total score for the questionnaire of 18. Conversely, an overall “unfavourable” total score for the questionnaire was 0. The questionnaire was administered to the subjects in the experimental group after 6 weeks of IMT.

The rating of perceived exertion (RPE) of the TIRE sessions was examined during and after the IMT period using the Borg RPE scale of 6 to 20 (Borg 1982). The average RPE of the IMT sessions during the 6 week IMT period was compared to the RPE during TIRE testing performed 6 weeks after IMT was terminated.

Study Design

The stratified randomized controlled design of this study allowed us to address the study hypotheses by examining the effects of high-intensity, through-range IMT (the independent variable) performed by the experimental group on the dependent variables of this study which included MIP, SMIP, accumulated SMIP, inspiratory power and work, IMTOC, IVC, FAST lengths, and estimated VO_{2max}. All subjects in both the experimental and control groups participated in routine team training and practice sessions. The addition of IMT to the subjects in the experimental group was the only difference between the experimental and control groups of this study. Therefore, any differences in the dependent variables were attributable to the high-intensity, through-range IMT with biofeedback. The above dependent variables represent common outcome measure in previous studies examining the effects of IMT on exercise performance and the effects of exercise/fitness in ice hockey (Chatham et al. 2004; Enright et al. 2006; Mickleborough et al. 2008, 2009; Faught et al. 2003; Petrella et al. 2005, 2007).

The study procedures involved baseline testing, implementation of the IMT program, follow-up testing, and de-training testing. Baseline and follow-up testing included: (1) measurement of inspiratory muscle performance via the TIRE and (2) measurement of skating performance and estimated VO_{2max} using the FAST. De-training testing consisted of the measurement of inspiratory muscle performance in the experimental group 6 weeks after IMT was terminated. The FAST was not performed 6 weeks after IMT was terminated because of a lack of time between scheduled competition and practices. A one-week IMT familiarization period was provided to subjects in both groups before baseline measurements were obtained. Baseline measurements were obtained after the familiarization period and only the experimental group performed IMT for the following 6 weeks. Testing was performed at the NU Matthews Arena which included on-ice testing and use of a separate training room for testing and training of the inspiratory muscles.

Statistical Analyses

Data were analyzed using SPSS version 17.0 statistical softwear (SPSS, Inc. Chicago, IL, USA). All data were assessed for normality using the Kolmogorov-Smirnov test and Levene's test was used to test for homogeneity of variance between groups. Between group differences were examined using the Mann Whitney U Test. Differences between the study time periods were examined using the Wilcoxon Signed Ranks Test. Bivariate non-parametric correlation analyses were performed between study variables using Spearman's Rho Tests. The level of significance for all analyses was set at $p<0.05$. The statistical power of this study for a sample size of 5 was sufficient in view of previous studies using the TIRE RT2 demonstrating effect sizes of 2.94 for MIP, 2.01 for SMIP, 1.47 for accumulated SMIP, and 2.0 for inspiratory work after high-intensity IMT (Chatham et al. 2004; Enright et al. 2006; Mickleborough et al. 2008, 2009). In fact, the post-hoc power of this study using the study results, a one-tailed test, alpha of 0.05, and sample size of 5 in each group was calculated to be 0.85, 0.32, 0.99, and 0.39 for MIP, SMIP, accumulated SMIP, and inspiratory work, respectively (Faul et al. 2007). An a-priori power analysis of FAST performance was not performed due to the absence of previous literature examining interventions on FAST performance, but the post-hoc power of this study using the FAST results, a one-tailed test, alpha of 0.05, and sample size of 5 in each group was calculated to be 0.91 and 0.79 for lengths skated and estimated VO_{2max}, respectively (Faul et al. 2007).

RESULTS

Adherence to Inspiratory Muscle Training

The adherence to IMT was 88% with two subjects performing all 12 sessions of IMT, two subjects performing 10 sessions of IMT, and one subject performing 9 sessions of IMT.

Inspiratory Muscle Performance

The measures of inspiratory muscle performance in the experimental and control groups are shown in Figures 2 through 5. There was no significant difference in baseline MIP, SMIP, accumulated SMIP, inspiratory work, peak inspiratory power, inspiratory power at 25%, 50%, or 75% of inspiratory work, endurance ratio, IMTOC, and IVC between groups ($p>0.05$). After the 6-week study period, the mean MIP, SMIP, accumulated SMIP, inspiratory work, IMTOC, and IVC of the experimental group were significantly greater than the control group ($p<0.05$) and the peak inspiratory power of the experimental group was greater than the control group, but was not statistically significant ($p=0.05$). In the experimental group the mean MIP increased 43%, the mean SMIP increased 28%, the mean accumulated SMIP increased 101%, the mean inspiratory work increased 42%, the mean IMTOC increased 11%, the mean IVC increased 15%, and the mean peak inspiratory power increased 45%. In the control group the mean MIP decreased 4%, the mean SMIP increased 15%, the mean accumulated SMIP increased 10%, the mean inspiratory work increased 13%, the mean IMTOC increased 3%, the mean IVC increased 11%, and the mean peak inspiratory power decreased 12.5%.

There was no significant difference ($p>0.05$) in the absolute or relative inspiratory power at 25%, 50%, or 75% of inspiratory work between groups after the 6-week study period and there was no significant difference in the endurance ratio between groups after the 6-week study period.

The measurements of inspiratory muscle performance 6 weeks after terminating IMT are shown in Table 2. A significant ($p<0.05$) decrease in MIP, accumulated SMIP, and inspiratory work was observed 6 weeks after terminating IMT. Although SMIP, peak inspiratory power, IMTOC, IVC, and absolute as well as relative inspiratory power at 50% and 75% of inspiratory work were lower 6 weeks after terminating IMT, the differences were statistically insignificant ($p>0.05$). Absolute and relative inspiratory power at 25% of inspiratory work was slightly greater 6 weeks after terminating IMT, but the differences were statistically insignificant ($p>0.05$). Subjective reports during TIRE testing in the experimental subjects indicated that the TIRE test session was significantly more difficult to complete (with an RPE rating of 16/20 compared to an average RPE of 11/20 during the 6 week IMT period; $p<0.05$) 6 weeks after terminating IMT.

Skating Performance and Estimated Oxygen Consumption

The skating performance and estimated VO_{2max} of the experimental and control groups are shown in Figures 6 and 7. There was no significant difference in the baseline FAST lengths skated and estimated VO_{2max} between groups ($p>0.05$). After the 6-week study period, both the mean number of FAST lengths skated and the estimated VO_{2max} of the experimental group were significantly greater than the control group ($p<0.05$). The mean number of FAST lengths skated by the experimental group increased by almost 5 lengths (11% increase) and the mean VO_{2max} increased 7.4%. The mean number of FAST lengths skated by the control group increased by almost ½ lengths (0.9% increase) and the mean VO_{2max} increased 0.6%.

Correlation Analyses

No significant correlations were found between baseline FAST lengths skated and baseline measures of inspiratory muscle performance and between baseline VO_{2max} and baseline measures of inspiratory muscle performance. However, several significant post-study relationships were observed and are shown in Figure 8.

Figure 8a shows the near significant relationship between post-study period MIP and post-study period FAST lengths skated (r=0.62; p=0.05). Figure 8b shows the significant relationship between post-study period SMIP and post-study period FAST lengths skated (r=0.76; p=0.01). Figure 8c shows the significant relationship between post-study period accumulated SMIP and post-study period FAST lengths skated (r=0.70; p=0.02). The relationship between post-study period SMIP and VO_{2max} was near significance (r=0.58; p=0.08). The relationship between post-study period accumulated SMIP and VO_{2max} was significant (r=0.71; p=0.02). Figure 8d shows the significant relationship between post-study period IVC and post-study period VO_{2max} (r=0.64; p=0.02). A significant relationship between post-study period IVC and post-study period FAST lengths skated was also observed (r=0.74; p=0.01). Significant relationships between post-study IMTOC and post-study VO_{2max} as well as post-study IMTOC and post-study FAST lengths skated were observed (r=0.67 and 0.67, respectively; p<0.05). Significant relationships were observed between the baseline IMTOC and baseline IVC (r=0.96; p=0.0001) and post-study IMTOC and post-study IVC (r=0.94; p=0.0001).

Correlation analyses examining the relationship between baseline measures of inspiratory muscle performance and (1) the percent change in inspiratory muscle performance during the study period and during the de-training period, (2) the percent change in FAST lengths skated and (3) the percent change in VO_{2max} found no significant relationships. No significant relationships were observed between the dependent variables and the results of the IMT questionnaire (both the individual questions and the total questionnaire score) administered to the experimental group after the study period.

Questionnaire Results

The results of the questionnaire administered to the experimental group after the study period is shown in the Appendix. The median and mode for each question were the same and are bolded and underlined. Also, all subjects answered questions 5 and 6 affirmatively. The consensus among the ice hockey players in the experimental group was that high-intensity IMT was beneficial and did not impair their ability to play hockey the day after IMT. The total score from the IMT study questionnaire ranged from 14-18.

DISCUSSION

To the best of our knowledge, this is the first study to examine the effects of IMT in ice hockey players. The key findings from this study include significant improvements in FAST lengths skated and estimated VO_{2max} after 6 weeks of high-intensity, through-range IMT. Accompanying the improvements in FAST lengths and VO_{2max} were significant increases in MIP, SMIP, accumulated SMIP, inspiratory work, IMTOC, and IVC in the ice hockey players performing high-intensity IMT. In fact, a significant correlation between FAST lengths skated and inspiratory muscle performance after IMT was observed and significant correlations between VO_{2max} and IMTOC as well as VO_{2max} and IVC after IMT were also observed. These findings provide insight into the mechanisms responsible for improved skating performance and VO_{2max} after IMT. This study also appears to be the first to examine the effects of de-training of the inspiratory muscles after IMT. A significant decrease in strength (MIP), endurance (accumulated SMIP), and inspiratory work which were accompanied by a significantly greater RPE was observed 6 weeks after IMT was terminated.

Effects of Inspiratory Muscle Training on Aerobic and Anaerobic Exercise

The improvements from high-intensity IMT appeared to improve both anaerobic and aerobic performance in view of the significant increase in FAST lengths skated and estimated VO_{2max}, respectively. The incremental manner by which the FAST was conducted required players to progressively skate faster with decreasing cadence and highlights the need for optimal anaerobic skating performance during the latter stages of the FAST (Green et al. 1976; Paterson 1979; Green 1987; Montgomery 1988, 2000; Twist and Rhodes 1993; Faught et al. 2003; Petrella et al. 2005, 2007). Additionally, the progressive skating speed of the FAST from approximately 11.7 km/hour to approximately 26.9 km/hour highlights the need for optimal aerobic skating performance (Green et al. 1976; Paterson 1979; Green 1987; Montgomery 1988, 2000; Twist and Rhodes 1993; Faught et al. 2003; Petrella et al. 2005, 2007). High-intensity IMT appeared to improve both anaerobic and aerobic skating performance by increasing the number of FAST laps skated and VO_{2max}, respectively.

An improvement in aerobic and anaerobic skating performance from IMT is supported by the significant correlations between post-study FAST lengths skated and post-study SMIP as well as post-study FAST lengths skated and post-study accumulated SMIP. The greater number of laps skated during the FAST were related to increased inspiratory muscle performance that increased IMTOC and IVC. The significant correlations between post-study IMTOC and post-study VO_{2max} as well as post-study IMTOC and post-study FAST lengths skated explain partially the mechanism of improved skating performance. The significant correlations between post-study IVC and post-study FAST lengths skated as well as post-study IVC and post-study VO_{2max} further explain the mechanism of improved skating and the role that IVC had in anaerobic and aerobic skating performance after the study period. Skating faster and longer could only be accomplished with an improvement in both anaerobic and aerobic skating capacity. Thus, high-intensity IMT improved inspiratory muscle performance, IMTOC, and IVC that lead to improvements in both aerobic and anaerobic exercise. An increase in IMTOC and IVC are likely to facilitate gas exchange and subsequently improve aerobic as well as anaerobic exercise performance (West 1985).

We speculate the improvements from IMT on skating performance and estimated VO_{2max} are due to several related mechanisms including: (1) improved inspiratory muscle strength, endurance, and efficiency as well as increased venous return with subsequent increase in peripheral blood flow, (2) improved ventilation and gas exchange, (3) attenuation of the inspiratory muscle metaboreflex with subsequent preservation of limb locomotor blood flow during exercise, (4) improved intrinsic contraction, recruitment pattern, and velocity of shortening of the inspiratory muscles, (5) alteration of inspiratory muscle fiber size and fiber type composition, and (6) decreased sensation of breathlessness or reduced afferent feedback of respiratory effort (Chatham et al. 2004; Enright et al. 2006; Mickleborough et al. 2008, 2009; El-Manshawi et al. 1986; Scott et al. 2001; Miller et al. 2005; Witt et al. 2007). Furthermore, the increase in diaphragmatic thickness observed in previous TIRE RT2 studies may have provided more efficient skating due to an improvement in the interplay/association between the postural muscles, diaphragm, and other accessory muscles of inspiration (Gething et al. 2004; Enright et al.

2006). The above speculations are likely responsible for the lower oxygen consumption, minute ventilation, respiratory exchange ratio, respiratory rate, heart rate, and blood lactate levels that were recently observed during constant workload exercise after high-intensity IMT in runners (Mickleborough et al. 2009). However, future investigation of the above speculations is needed.

An additional finding that is worthy of discussion is the substantial increase in FAST performance of two of the subjects in the experimental group shown in Figure 6b. The two players with the lowest baseline FAST laps increased the number of laps skated by 27% and 37%. Both subjects were defenseman. In view of this limited data, defenseman may receive greater benefit from high-intensity IMT. Alternatively, athletes with poorer aerobic and anaerobic capacity may benefit most from high-intensity IMT regardless of position. However, future investigation of the effects of high-intensity IMT on skating performance and VO_{2max} in a larger number of defensemen and forwards is needed.

Frequency of Inspiratory Muscle Training and Sample Size

It is somewhat surprising that the high-intensity IMT prescription which was limited to twice per week produced the observed results. However, the high-intensity and through-range IMT with a progressive increase in the work to rest ratio used in this study produced significant improvements despite the exercise prescription frequency being less than that considered necessary to elicit training adaptations (ACSM 2009). The 2x/week frequency of IMT used in this study was due to NCAA student-athlete time restrictions and because other training commitments prevented more frequent IMT. Also, the targeted visual biofeedback provided by the TIRE is likely to have produced optimal IMT and greater adherence to IMT as shown in motor learning and biofeedback literature (Zaichkowsky and Fuchs 1988; Schmidt and Wrisberg 2000; Schmidt and Lee 2005).

Thus, the 80% intensity of IMT from RV to TLC with visual biofeedback and progressively increasing work to rest periods (from 60 to 5 seconds) achieved with the TIRE RT2 elicited significant improvements in inspiratory capacity and skating performance.

Despite the sample size being relatively small, several studies of IMT have used similar sample sizes, but more frequent IMT (Gething et al. 2004; Mickleborough et al. 2008, 2009). Gething (2004) examined the effects of IMT performed 3x/week for 10 weeks via the TIRE RT2 on inspiratory and cycling performance in 15 healthy persons (3 groups with 5 subjects in each group) and found significant improvements in MIP (34%), SMIP (32%), constant workload cycling at 75% of VO_{2max} (36%), cardiorespiratory response during constant workload cycling (approximately 10% lower heart rate, ventilation, and rating of perceived exertion), and an unspecified increase in diaphragm thickness in the high-intensity IMT group.

Furthermore, several other studies of high-intensity IMT via the TIRE RT2, but using more frequent IMT sessions have found significant improvements in inspiratory muscle performance that were almost identical to our results. For example, Mickleborough et al (2009) performed 6 weeks of high-intensity IMT with the TIRE RT2 in 24 recreational runners (3 groups with 8 subjects in each group) after which the MIP and SMIP increased 43.9% and 26.6%, respectively, in the high-intensity IMT group. We observed an increase in MIP and SMIP of 43% and 28%, respectively, in the high-intensity IMT group. Additionally, compared to our results, Mickleborough et al (2009) observed a slightly greater percent increase in endurance exercise (16% versus 11%) after IMT, but the FAST lengths skated were done during a progressive incremental skating test and not during constant workload exercise as done by Mickleborough et al (2009). It is likely that the percent increase in endurance exercise would be greater in our study if a constant workload skating test were employed. Also, although Mickleborough et al (2009) observed a slightly greater percent increase in IMTOC after IMT (18.8% versus 11%) the Division 1 ice hockey players in the current study had a mean baseline IMTOC that was 26% greater than that of the recreational runners studied by Mickleborough et al (2009).

Nonetheless, it is reasonable to assume that our findings are more valid and generalizable since they are similar to those of other studies using high-intensity IMT via the TIRE RT2. Also, the post-hoc power analysis results of our study are impressive given the sample size of our study. Finally, it appears that IMT using the methods we employed need only be performed twice per week to produce meaningful results. However, the detraining results of our study identify the need to continue IMT to maintain inspiratory muscle performance. Future investigation of maintenance of skating performance after IMT is needed.

Inspiratory Muscle Training and Pulmonary Dysfunction in Ice Hockey

The results of the current study are important given the recent findings of Durocher et al (2008) as well as Game and Bell (2006). Durocher et al (2008) found a significantly lower level of aerobic performance after a competitive season of Division 1 ice hockey and Game and Bell (2006) also found a slight, but non-significant decrease in VO_{2max} after a season of varsity college ice hockey. The hypotheses for decreased levels of VO_{2max} during a hockey season have been suggested to be due to pulmonary dysfunction, fatigue, and over-training (Game and Bell 2006; Durocher et al. 2008). In fact, Game and Bell (2006) compared resting and post-exercise test pulmonary function before and after a competitive hockey season and found a significant decrease in pulmonary function immediately after maximal exercise during post-season testing. Game and Bell (2006) also found significant decreases in arterial oxygen saturation (SaO2) levels at VO_{2max} during pre-season and post-season maximal exercise testing with the decrease in SaO2 at VO_{2max} during post-season testing to be significantly lower than that at pre-season. The authors concluded that some hockey players appear to experience pulmonary limitations over the course of a competitive ice hockey season (Game and Bell 2006). Thus, based on our results and other studies, high-intensity IMT may minimize and possibly prevent pulmonary limitations to exercise and increase or at least maintain aerobic capacity during an ice hockey season (Weiner et al. 1992; Weiner et al. 2000; Lotters et al. 2002; Geddes et al. 2008). Improvements in pulmonary function and exercise tolerance from IMT have been observed in people with pulmonary limitations such as asthma or obstructive lung disease (Weiner et al. 1992; Weiner et al. 2000; Lotters et al. 2002; Geddes et al. 2008).

Subjective Reports of Inspiratory Muscle Training and Conclusion

The results from the IMT study questionnaire revealed that the IMT program used in this study was beneficial and did not impair the athlete’s ability to play hockey the day after IMT. These are important issues faced by coaches when developing and implementing a training program during the ice hockey season. Although it is possible that a Hawthorne effect (improved behavior because of research study participation) may have produced the positive survey responses of the subjects in the experimental group, the responses varied little and were consistent among all of the subjects in the experimental group. Furthermore, several of the subjects in the experimental group requested to resume IMT approximately one month after IMT was terminated due to greater dyspnea and fatigue and longer recovery times since IMT had been terminated.

In conclusion, a short-term program of high-intensity and through-range IMT performed twice per week significantly improved inspiratory muscle performance, IVC, lengths skated, and estimated VO_{2max}. Post-study VO_{2max} was significantly correlated to post-study IMTOC and to post-study IVC ($r=0.67$ and 0.64, respectively; $p<0.05$) identifying the mechanisms by which IMT likely improved skating performance. The IMT study questionnaire results as well as the improvements in inspiratory capacity, skating performance, and VO_{2max} observed in this study highlight the potential role of IMT in ice hockey. The detraining results reveal the need to continue IMT to maintain improved inspiratory muscle performance.

Acknowledgements

Sincere appreciation is extended to Paul K. Canavan for his assistance with the study. This study was supported by a Northeastern University Undergraduate Research Grant.

References

ACSMs guidelines for exercise testing and prescription. 2009. 8th ed. Lippincott Williams & Wilkens.

Borg GA. 1982. Psychophysical bases of perceived exertion. Med Sci Sports Exerc 14: 377-381.

Chatham, K. 2000. Individualized fixed load inspiratory muscle training responses in a patient with severe restrictive lung disease and an elite sportsman. Physiotherapy 86(1): 28-31.

Chatham K, Ionescu AA, Nixon LS, Shale DJ. 2004. A short-term comparison of two methods of sputum expectoration in cystic firbrosis. Eur Respir J 23: 435-439.

Durocher, JJ, Leetun, DT, and Carter, JR. 2008. Sport-specific assessment of lactate threshold and aerobic capacity throughout a collegiate hockey season. Appl Physiol Nutr Metab 33(6): 1165-1171.

El-Manshawi, A, Killian, KJ, Summers, E, Jones, NL. 1986. Breathlessness during exercise with and without resistive loading. J Appl Physiol 61(3): 896-905.

Enright, SJ, Unnithan, VB, Heward, C, Withnall, L, and Davies, DH. 2006. Effect of high-intensity inspiratory muscle training on lung volumes, diaphragm thickness, and exercise capacity in subjects who are healthy. Phys Ther 86: 345-54.

Enright S, Unnithan VB, Davies D. 2006. Reproducibility of measurements of inspiratory work capacity in cystic fibrosis patients. Respir Physiol Neurobiol 150: 35-43.

Faught, BE, Nystrom, M, and Montelpare, WJ. 2003. Precision and accuracy of an on-ice skating test to predict maximal oxygen capacity. Can J Appl Physiol 28: S52.

Faul, F, Erdfelder, E, Lang, A-G, and Buchner, A. 2007. G*Power 3: A flexible statistical power analysis program for the social, behavioral, and biomedical sciences. Behavior Research Methods 39: 175-191.

Game, AB and Bell, GJ. 2006. The effect of a competitive season and environmental factors on pulmonary function and aerobic power in varsity hockey players. Appl Physiol Nutr Metab 31: 95-100.

Geddes, EL, O'Brien, K, Reid, WD, Brooks, D, Crowe, J. 2008. Inspiratory muscle training in adults with chronic obstructive pulmonary disease: An update of a systematic review. Respiratory Medicine 102(12): 1715-1729.

Gething, AD, Williams M, and Davies, B. 2004. Inspiratory resistive loading improves cycling capacity: a placebo controlled trial. Br J Sports Med 38: 730-736.

Green, HJ. 1987. Bioenergetics of ice hockey: considerations for fatigue. J Sports Sci 5: 305-317.

Green, HJ, Bishop, P, Houston, ME, McKillop, R, Norman, R, and Strothart, P. 1976. Time-motion and physiological assessments of ice hockey performance. J Appl Physiol 40: 159-163.

Green, MR, Pivarnik, JM, Carrier, DP, and Womack, CJ. 2006. Relationship between physiological profiles and on-ice performance of a national collegiate athletic association division I hockey team. J Strength Cond Res 20: 43-46.

Lotters, F, van Tol, B, Kwakkel, G, Gosselink, R. 2002. Effects of controlled inspiratory muscle training in patients with COPD: a meta-analysis. Eur Respir J 20: 570-576.

MacAdam, D, and Reynolds, G. 2001. 52-week hockey training: a proven plan for strength, power, speed, agility, and performance. Human Kinetics, Champaign, IL.

Mickleborough, TD, Stager, JM, Chatham, K, Lindley, MR, and Ionescu, AA. 2008. Pulmonary adaptations to swim and inspiratory muscle training. Eur J Appl Physiol 103: 635-646.

Mickleborough, TD, Nichols, T, Lindley, MR, Chatham, K, and Ionescu, AA. 2009. Inspiratory flow resistive loading improves respiratory muscle function and endurance capacity in recreational runners. Scand J Med Sci Sports June 16, published ahead of print at: http://www.ncbi.nlm.nih.gov/pubmed/19558387?itool=EntrezSystem2.PEntrez.Pubmed.Pubmed_ResultsPanel.Pubmed_RVDocSum&ordinalpos=6.

Miller, JD, Pegelow DF, Jacques AJ, Dempsey JA. 2005. Skeletal muscle pump versus respiratory muscle pump: modulation of venous return from the locomotor limb in humans. J Physiol 563.3: 925-943.

Montgomery, DL. 1988. Physiology of ice hockey. Sports Med 5: 99-126.

Montgomery, DL. 2000. Physiology of ice hockey. In: Exercise and sport science. Garrett, WE and Kirkendall, DT, eds. Williams and Wilkens, Philadelphia, PA. pp. 815-828.

Paterson, DH. 1979. Respiratory and cardiovascular aspects of intermittent exercise with regards to ice hockey. Can J Appl Sport Sci 4: 22-28.

Petrella, NJ, Montelpare, WJ, Nystrom, M, Plyley, M, and Faught, BE. 2005. Assessment of the reliability of the FAST using a test-retest design and the intra-class correlation coefficient. Can J Appl Physiol 30: S24.

Petrella, NJ, Montelpare, WJ, Nystrom, M, Plyley, M, and Faught, BE. 2007. Validation of the FAST skating protocol to predict aerobic power in ice hockey players. Appl Physiol Nutr Metab 32: 693-700.

Sapienza, CM. 2008. Respiratory muscle strength training applications. Curr Opin Otolaryng Head Neck Surg 16(3): 216-220.

Scott W, Stevens J, Binder-Macleod SA. 2001. Human skeletal muscle fiber type classifications. Phys Ther 81: 1810-1816.

Twist, P. 1997. Complete conditioning for ice hockey. Human Kinetics, Champaign, IL.

Twist, P, and Rhodes, T. 1993. The bio-energetic and physiological demands of ice hockey. J Strength Cond Res 15: 68-70.

Schmidt, RA and Lee, TD. 2005. Augmented feedback. Chapter 12, In: Motor Control and Learning – A behavioral emphasis. 4th Edition. Human Kinetics, Champaign, IL. pp. 364-400.

Schmidt, RA and Wrisberg, CA. 2000. Providing feedback during the learning experience. Chapter 10, In: Motor Learning and Performance – A problem-based learning approach. 2nd Edition. Human Kinetics, Champaign, IL. pp. 255-285.

Weiner, P, Azgad, Y, Ganam, R, Weiner M. 1992. Inspiratory muscle training in patients with bronchial asthma. Chest 102(5): 1357-1361.

Weiner, P, Berar-Yanay, N, Davidovich, A, Magadle, R, Weiner, M. 2000. Specific inspiratory muscle training in patients with mild asthma with high consumption of inhaled β_2-agonists. Chest 117: 722-727.

West, JB. 1985. Ventilation. Chapter 2, In: Respiratory Physiology – the essentials. 3rd Edition. Williams & Wilkins, Baltimore, MD. pp. 11-20.

Witt JD, Guenette JA, Rupert JL, McKenzie DC, Sheel AW. 2007. Inspiratory muscle training attenuates the human respiratory muscle metaboreflex. J Physiol 584: 1019-1028.

Zaichkowsky, LD and Fuchs, Z. 1988. Biofeedback applications in exercise and athletic performance. In: Exercise and Sport Science Reviews. Pandolf KB, ed. MacMillan, New York. pp. 381-421.

Figure Legends

Figure 1. A subject performing IMT via the TIRE RT2.

Figure 2. Baseline and post-study period maximal inspiratory pressure (MIP) of the control and experimental groups. Baseline and post-study period MIP of the control group (2a) and experimental group (2b).
(⊥ = mean±SD).

Figure 3. Baseline and post-study period sustained maximal inspiratory pressure (SMIP) and accumulated SMIP of the control and experimental groups. Baseline and post-study period SMIP of the control group (3a) and experimental group (3b). Baseline and post-study period accumulated SMIP of the control group (3c) and experimental group (3d).
(⊥ = mean±SD).

Figure 4. Baseline and post-study period inspiratory work of the control and experimental groups. Baseline and post-study period inspiratory work of the control group (4a) and experimental group (4b).
(⊥ = mean±SD).

Figure 5. Baseline and post-study period inspiratory vital capacity of the control and experimental groups. Baseline and post-study period inspiratory vital capacity of the control group (5a) and experimental group (5b).
(⊥ = mean±SD).

Figure 6. Baseline and post-study period FAST results of the control group and experimental groups. Baseline and post-study period FAST results of the control group (6a) and experimental group (6b).
(⊥ = mean±SD).

Figure 7. Baseline and post-study period maximal oxygen consumption results of the control group and experimental groups. Baseline and post-study period maximal oxygen consumption results of the control group (7a) and experimental group (7b).
(⊥ = mean±SD).

Figure 8. Scatter plots and statistics identifying the relationship between post-study period FAST lengths and inspiratory performance (8a-8c) as well as the relationship between post-study period maximal oxygen consumption and post-study period inspiratory vital capacity (8d). 8a. Scatter plot between post-study period FAST lengths (PostFAST) and post-study period maximal inspiratory pressure (PostMIP). 8b. Scatter plot between post-study period FAST lengths (PostFAST) and post-study period sustained maximal inspiratory pressure (PostSMIP). 8c. Scatter plot between post-study period FAST lengths (PostFAST) and post-study period accumulated sustained maximal inspiratory pressure (PostAccumSMIP). 8d. Scatter plot between the post-study period maximal oxygen consumption (PostVO2) and post-study period inspiratory vital capacity (PostIVC).

Figure 1.

[redacted]

Figure 2a.

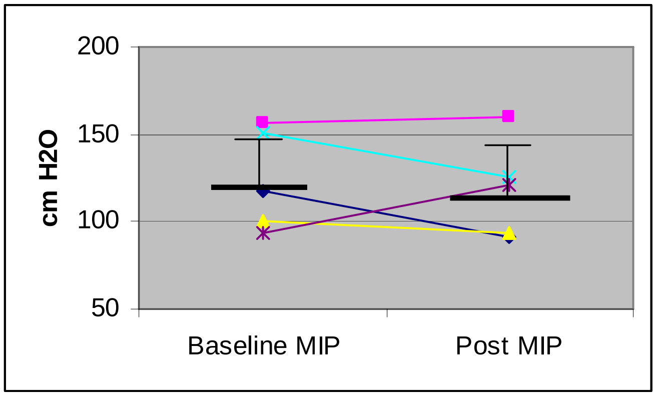


Figure 2b.

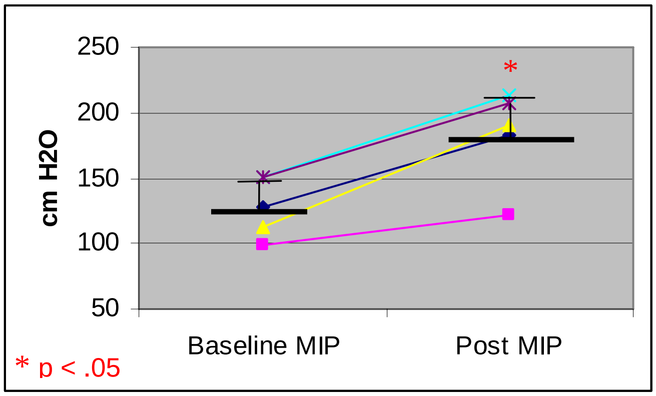


Figure 3a.

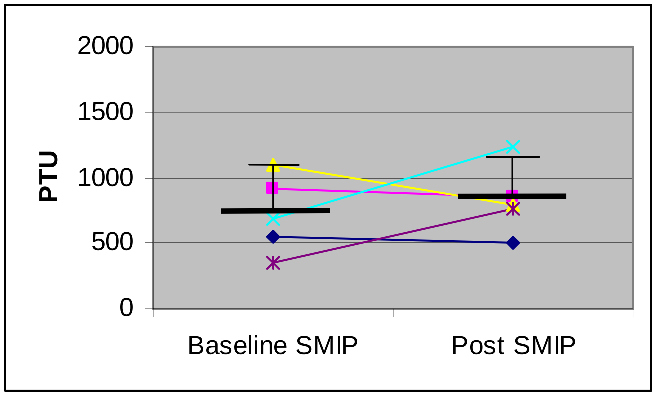


Figure 3b.

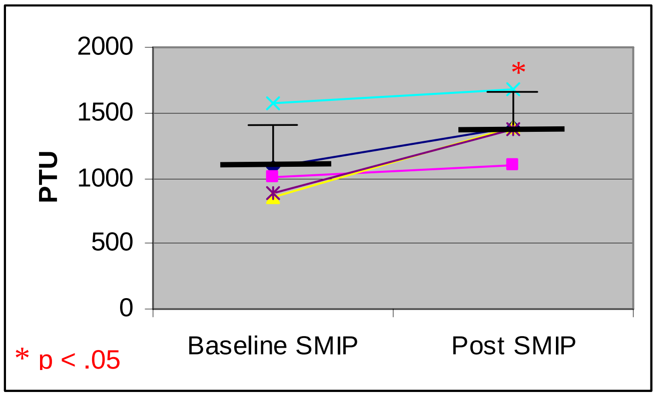


Figure 3c.

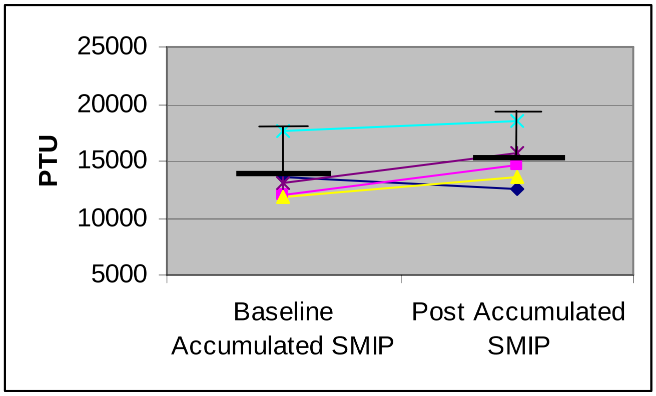


Figure 3d.

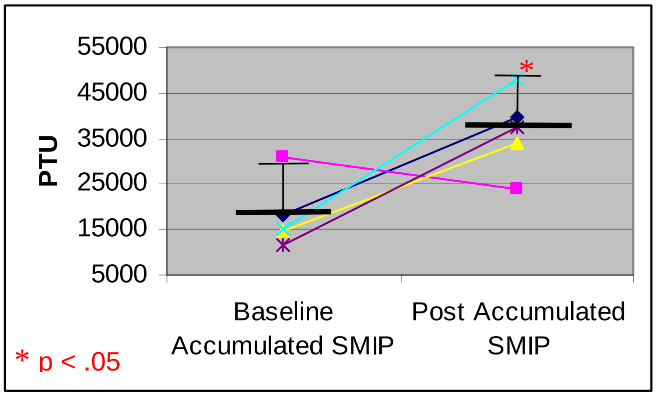


Figure 4a.

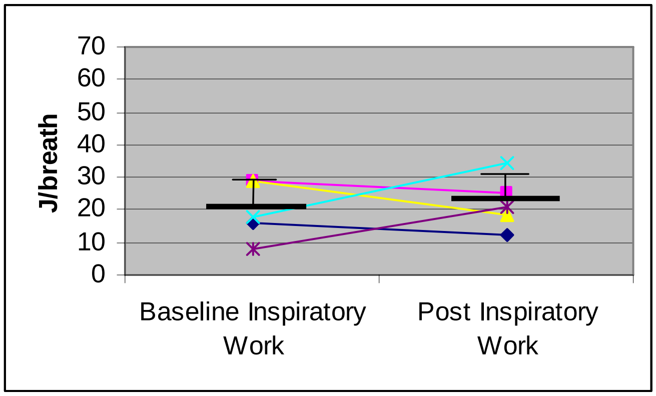


Figure 4b.

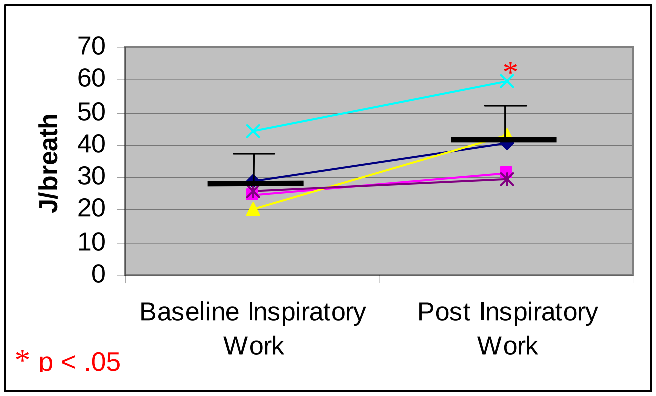


Figure 5a.

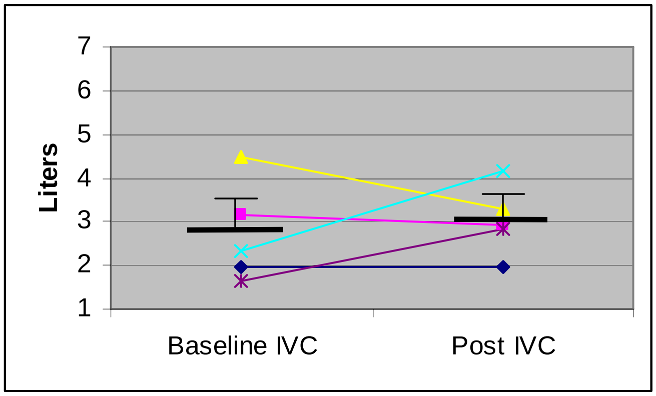


Figure 5b.

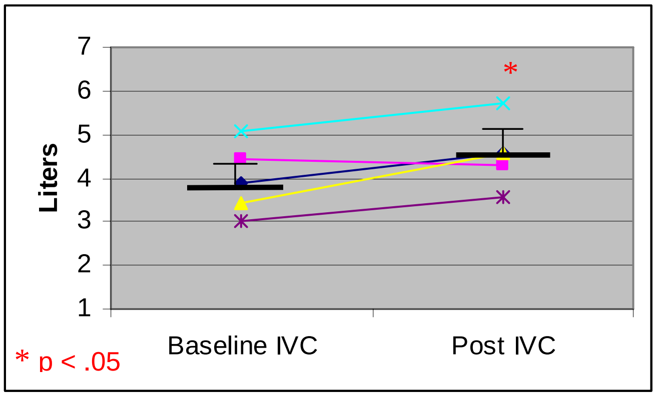


Figure 6a.

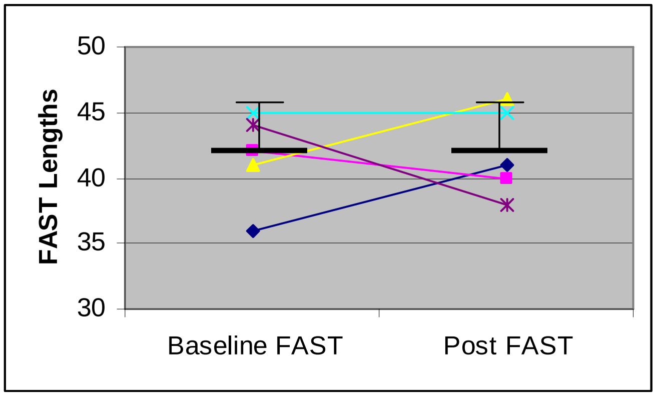


Figure 6b.

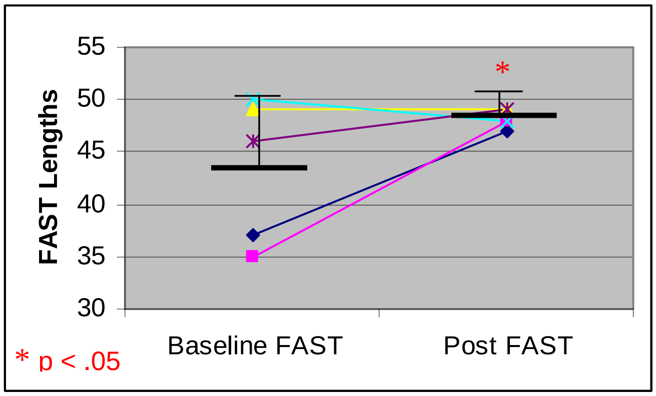


Figure 7a.

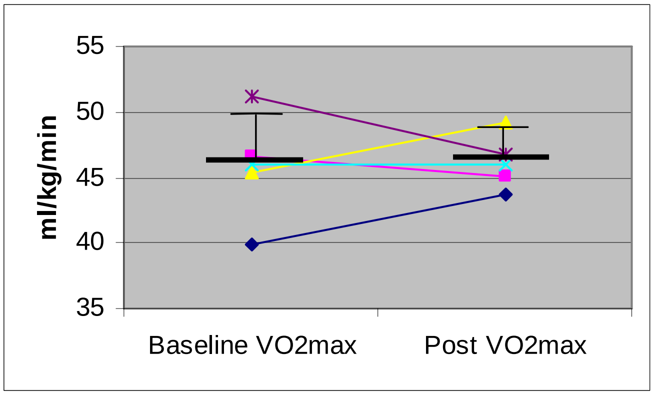


Figure 7b.

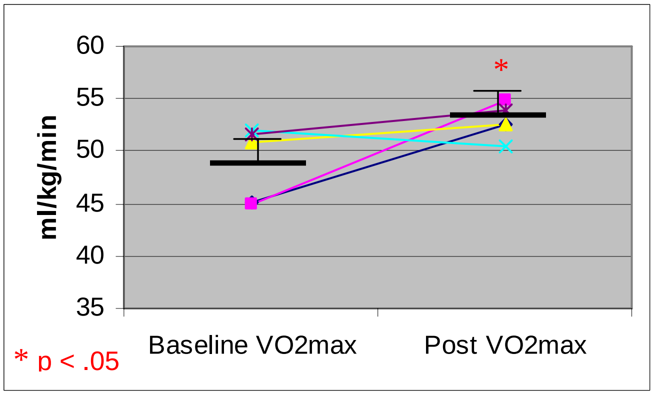


Figure 8a.

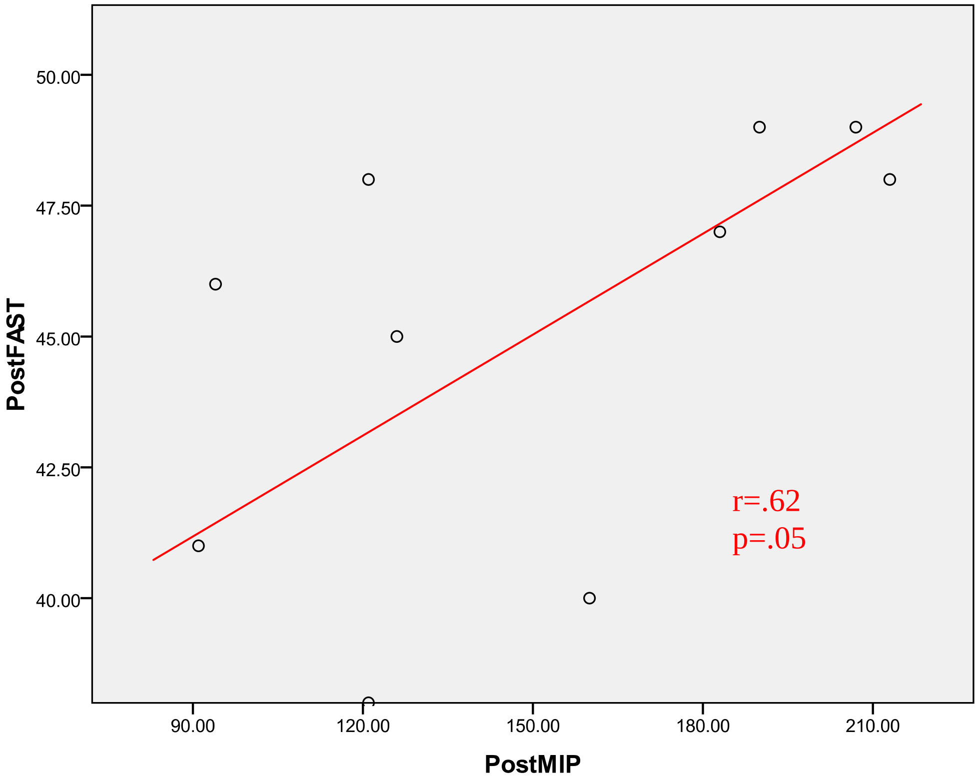

50.00
47.50
45.00
42.50
40.00
PostFAST
90.00
120.00
150.00
180.00
210.00
PostMIP
r=.62
p=.05

Figure 8b.

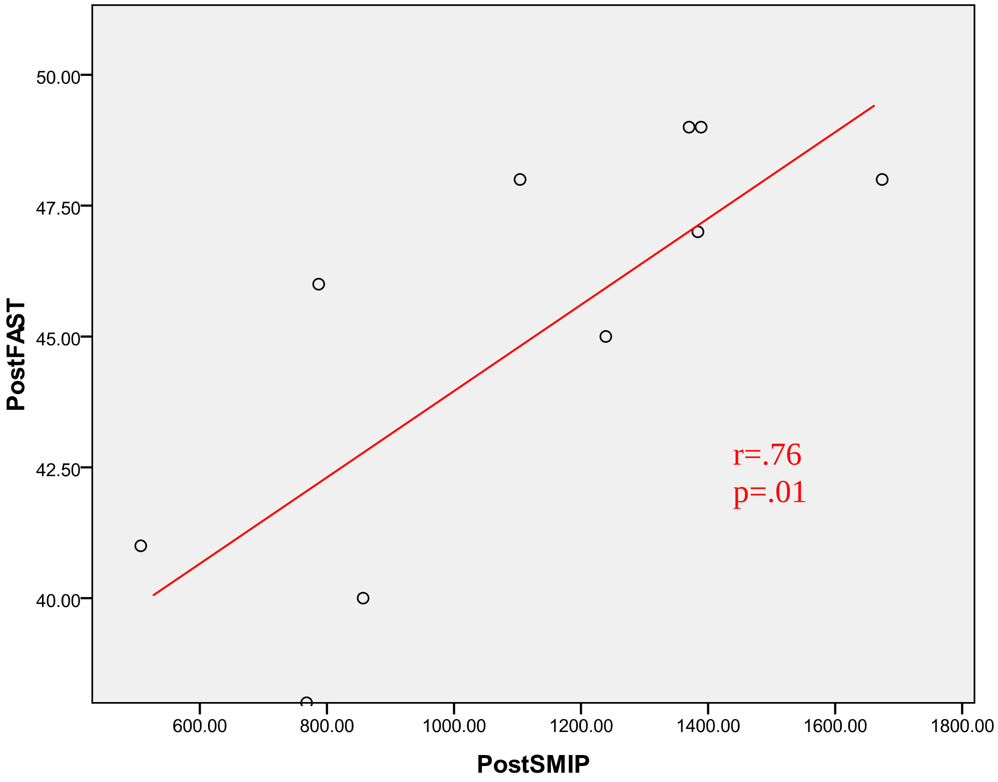

50.00
47.50
45.00
42.50
40.00
PostFAST
600.00
800.00
1000.00
1200.00
1400.00
1600.00
1800.00
PostSMIP
r=.76
p=.01

Figure 8c.

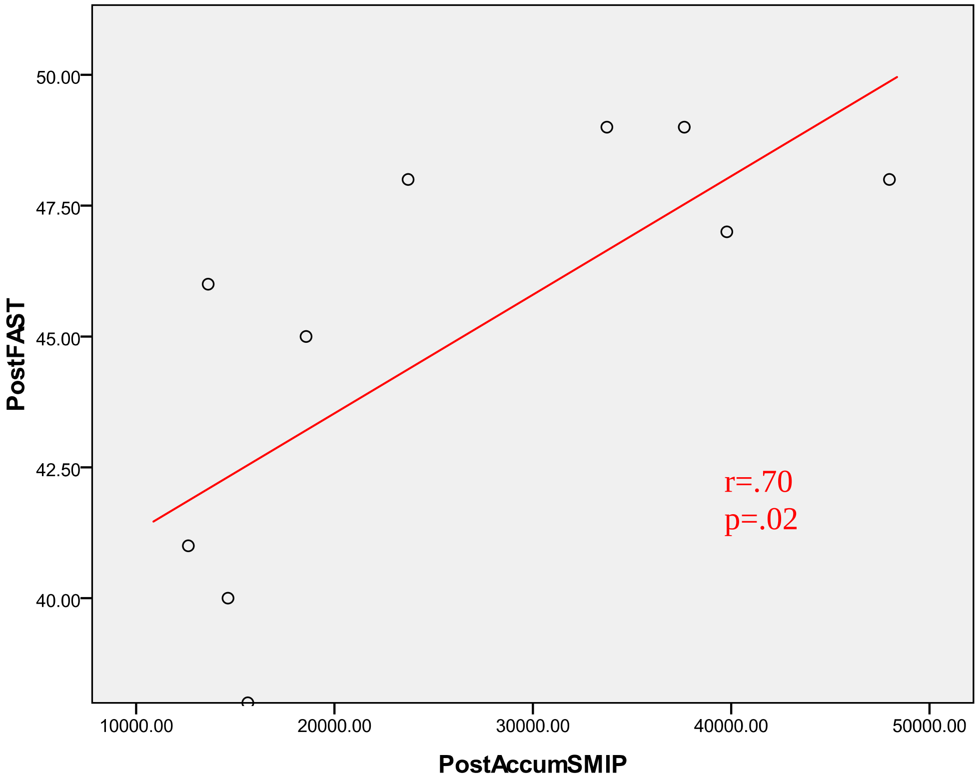
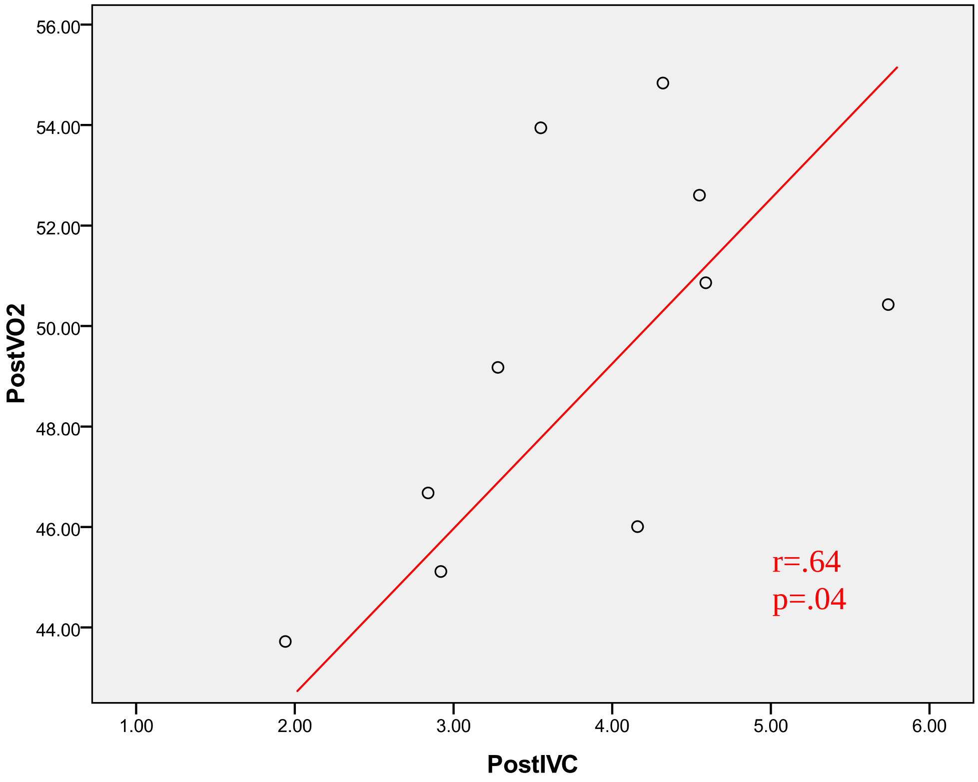

50.00
47.50
45.00
42.50
40.00
PostFAST
10000.00
20000.00
30000.00
40000.00
50000.00
PostAccumSMIP
r=.70
p=.02

Figure 8d.



56.00
54.00
52.00
50.00
48.00
46.00
44.00
PostVO2
1.00
2.00
3.00
4.00
5.00
6.00
PostIVC
r=.64
p=.04

Table 1. Demographic Characteristics of the Study Subjects.

Variable	**Control Group** (N=5)	**Experimental Group** (N=5)
Age (yrs)	23±1	22±1
Height (cm)	179±8	182±4
Weight (kg)	86.7±7	87.1±4
Position (F/D)	2/3	2/3

F=Forward
D=Defenseman

Table 2. Inspiratory Muscle Performance After 6 Weeks of IMT and 6 Weeks After Terminating IMT.

Variable	**After 6 Weeks of IMT** (N=5)	**6 Weeks After IMT** (N=5)
MIP (cm H2O)	183±37	165±39*
SMIP (PTU)	1,384±202	1,219±282
Accumulated SMIP (PTU)	36,569±8,874	30,561±4,863*
Peak Inspiratory Power (Watts)	6.4±2.3	5.7±2.1
Inspiratory Work (J/breath)	40.75±12	33.64±11*
Power at 25% of Inspiratory Work (Watts)	3.6±0.4	3.9±.9
Power at 50% of Inspiratory Work (Watts)	2.3±0.4	2.1+0.1
Power at 75% of Inspiratory Work (Watts)	0.94±0.25	0.93±0.17
Endurance Ratio^	26.5±9.3	25.7±11.9
IMTOC (seconds)	18±2.8	16±3.2
IVC (liters)	4.6±0.8	4.1±0.9
RPE (6-20)	11+1	16+0.5*

*p<0.05

MIP=maximal inspiratory pressure; SMIP=sustained maximal inspiratory pressure; J=Joules; IMTOC= inspiratory muscle time of contraction; IVC=inspiratory vital capacity; RPE=rating of perceived exertion.

^Endurance ratio=power at 75% of inspiratory work / power at 25% of inspiratory work. Absolute power at 25%, 50%, and 75% is reported.

Appendix. Experimental Group Inspiratory Muscle Training (IMT) Study Questionnaire*

1. Do you feel that the IMT has positively affected you?

0	1	2	***3***	4
Strongly Disagree	Disagree	Undecided	***Agree***	Strongly Agree

2. Do you feel like you breathe more efficiently on the ice as a result of the IMT?

0	1	2	3	***4***
Strongly Disagree	Disagree	Undecided	Agree	***Strongly Agree***

3. Do you feel like you are better able to recover as a result of the IMT?

0	1	2	3	***4***
Strongly Disagree	Disagree	Undecided	Agree	***Strongly Agree***

4. Do you feel like the IMT negatively affects your ability to play hockey the day after IMT (**please notice the change in response with the below numbers compared to above**)?

0	1	2	***3***	4
Strongly Agree	Agree	Undecided	***Disagree***	Strongly Disagree

5. Would you suggest IMT to the other players on your team?

No 0 [✓ Yes 1]

6. If offered would you continue IMT after the study period?

No 0 [✓ Yes 1]

*The median and mode for each question were the same and are bolded and underlined. All subjects answered questions 5 and 6 affirmatively.