The Effects of an Upper Body Plyometrics Program on Male University Hockey Players

by

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ABSTRACT

Given the value of scoring at the competitive levels of hockey, training methods to improve weaknesses in scoring ability would be of great benefit to hockey players. One method to score goals involves the use of a high velocity shooting method known as the slap shot. To become successful at the slap shot, a player must be able to generate great upper body power to impart a large impulse to the puck. A relatively new method to improve power is through the use of upper body plyometrics training.

The purpose of this study was to investigate the effects of a short-term plyometrics training program on slap shot velocity of male university hockey players. Twenty-one male university hockey players, volunteered to take part in this study. Seven players were allocated to the experimental group and fourteen players were allocated to the control group. The experimental group participated in a mean of 6 $\pm$ 2 sessions of plyometrics training. Subjects in both the control and experimental group were pre- and post-tested for isometric strength of the chest, shoulders, biceps and triceps, as well as slap shot puck velocity. In addition, the experimental group was pre- and post-tested in the laboratory for stick velocity.

This study was a 2 * 2 factorial design with repeated measures on pre- and post-testing. The independent variables were the group factor with two levels (control and experimental) and the time factor with two levels (pre- and post-testing). The dependent variables were puck velocity, stick velocity and isometric strength of the chest, shoulders, biceps and triceps. A 1-Way ANOVA was also used to measure differences between groups on dependent variables. A Paired T-test was used to analyze improvements in

stick velocity and Pearson (2-tailed) correlations were used to examine the relationship between strength and puck and stick velocities. All statistical analyses were evaluated at the $p<0.05$ level.

Results of the 2-Way ANOVA revealed an improvement in biceps and triceps strength from pre- to post-testing. Isometric biceps strength increased by 6.9 % and 8.8 % for the experimental and control groups respectively. Further, isometric triceps strength increased by 8.8 % and 19 % for the experimental and control groups respectively. However, an interaction effect was not found between groups for gains in biceps and triceps strength. No significant changes for either isometric chest or shoulder strength were found. Other findings showed that the slap shot puck velocity improved by 4.2 % for the experimental group and 2.5 % for the control. These gains were statistically significant, although no interaction effect between groups was found. A Paired T-test showed that in the laboratory, the stick velocity improved 13 % for the experimental group; however, these gains did not translate into on-ice slap shot improvements. A 1-Way ANOVA revealed no differences between groups at the start or end of the study in terms of any strength or velocity measures

The conclusions based this data suggest that the short-term, upper body plyometrics protocol used in this study may be able to improve ballistic coordination of the upper and lower body in the laboratory setting to improve stick velocity, although more than 6 ± 2 sessions of training and more than a 13% improvement in stick velocity may be required to translate into improvements in slap shot puck velocity.

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CHAPTER 1

INTRODUCTION

To become successful in many competitive sports, a high-performance athlete must not only possess great strength, but also enormous speed to exert large forces in a minimal amount of time. The challenge is to find a sport specific training method to link strength and speed. In the sport of hockey, an athlete must possess great upper body strength and speed to be successful both offensively and defensively (Twist, 1997)

At competitive levels of hockey, there exists a strong emphasis on offensive play such as goal scoring. In fact, The National Hockey League (NHL) is continually struggling to implement rule changes to increase the amount of scoring by decreasing the obstruction of offensive players (Hickey, 2000). The emphasis on a player's ability to score goals is also reflected in player salaries. The players with the most goals scored, are typically the highest paid players in the National Hockey League (NHL). As of the year 2000, the top eight highest paid players in the NHL were all in offensive positions. For example, the highest paid player in the league, Peter Forsberg (forward position), received $10,000,000.00 US per year, compared to the eighth highest paid player, Joe Sakic, who received $7,900,000.00 US per year for the same position (National Hockey League Player's Association, 2000).

Given this emphasis on scoring, players use a variety of techniques to score goals. One common method for hockey players is to try to score goals using a slap shot. This shooting method allows the athlete to move the puck towards the net at a higher velocity than any other shooting method in hockey. The advantage of this shot is that the puck moves with such a high velocity that the goalie is unable to react in time to prevent a goal. To perform an effective slap shot, however, the shooter must possess great upper body strength and speed. Using the proper technique, a player must be strong and quick enough to rapidly cock the stick, than change the direction of the stick to impart a large force on the puck in a minimal amount of time. The rapid cocking of the stick, followed by a quick change in direction, causes the muscles to stretch or lengthen. Plyometrics is a training method that develops the nervous system to react to muscle lengthening with maximal speed, consequently developing the muscle's ability to shorten rapidly with maximal force (Chu, 1986).

Most competitive hockey players are involved in some form of off-ice conditioning program, whether it be weight training, running, or rollerblading. Typically, weight training is used to improve upper body strength. However, weight training does not train the muscles to respond quicker to a muscle pre-stretch. Consequently, alternative training methods such as plyometrics, need to be investigated so that players can train the muscle to respond with maximal speed and force.

STATEMENT OF THE PROBLEM

The purpose of this investigation was to study the effects of a short-term, plyometrics training program on slap shot velocity for male university hockey players, during the course of a normal hockey season.

Sub-problems

1. To investigate isometric strength changes for the chest, shoulders, biceps and triceps, as a result of plyometrics training and normal hockey training.
2. To investigate on-ice slap shot (puck) velocity changes as a result of plyometrics training and normal hockey training.
3. To investigate the stick velocity changes, as a result of in-laboratory plyometrics training.
4. To determine the relationship between isometric strength and slap shot velocity.
5. To determine the relationship between isometric strength and stick velocity.
6. To determine the relationship between changes in stick velocity and changes in on-ice slap shot (puck) velocity.

DEFINITIONS

Plyometrics Exercises – Exercises characterized by an eccentric muscle contraction rapidly coupled to concentric muscle contraction.

Short-term Plyometrics Training – A plyometrics training program characterized by less than four weeks of plyometrics training.

Long-term plyometrics training – A plyometrics training program characterized by more than four weeks of plyometrics training.

Consistent Plyometrics Training - A plyometrics training protocol whereby subjects train an equal number of times per week over the duration of the study (ie. three training sessions per week).

Staggered plyometrics training – A plyometrics training protocol whereby subjects do not train consistently from week to week over the duration of the study (ie. 2 training sessions for week 1; no training sessions for week 2; 1 training session on week 3).

Countermovement Jump - A jump in which the subject rapidly lowers the center of gravity (eccentric contraction) and then rapidly follows this action with a concentric contraction.

Squat Jump – A jump that involves no eccentric action whereby the jumper starts from a squatting position and performs a rapid concentric contraction using leg muscles, to raise the centre of gravity.

Depth Jump - A form of jump training from a fixed height, which emphasises an explosive takeoff after landing from the fixed height. Depth jumping is designed to train the neuromuscular system and to make use of temporarily stored elastic energy.

Power – Is equal to Force * Velocity

Impulse – Is equal to Force * Time

Plyometric Power System - A training machine, which can record force, speed and power produced during plyometrics training.

SIGNIFICANCE OF THE STUDY

The information collected for this study is valuable to both athletes and coaches involved in competitive hockey. At the present time, there have been a limited number of studies involving upper body plyometrics and no controlled, published studies on the effects of plyometrics on hockey players. A tested training program would provide valuable results for the design of future training programs so that training time is not wasted on ineffective plyometrics exercises. The relationship between strength and shooting velocity, experienced by competitive hockey players throughout the season, would also provide useful normative data for future study in the area of hockey strength and conditioning.

LIMITATIONS

1. The investigator had no control over the subjects' activities outside the training sessions.
2. The subjects for this study skated a similar number of hours per week, but did not have identical hockey skills nor did they participate in the same volume of off-ice strength training.
3. Motivation to produce maximum effort could not be measured in this study.
4. Due to injuries, classes or other circumstances, data collection for some tests involved a small number of subjects. Since all subjects were not able to attend all testing sessions, conclusions for this study are based on a small sample size.
5. No control group was evaluated for stick velocity since all players who were available for extra testing and training were allocated to the experimental group at the start of the study.

CHAPTER 2

REVIEW OF LITERATURE

At the present time, limited information is available on the effects of upper body plyometrics. The use of the medicine ball or light weighted objects is a relatively new form for training, designed to increase contraction velocity of the muscles. There have been no previous training studies concerning the effects of upper body plyometrics on the shooting velocity for hockey players.

Studies on the Slap Shot

A limited number of studies have investigated the hockey slap shot. In general, it is known that the strength of the chest, shoulder, back, arm, and torso muscles contribute to shooting ability and puck control (Roy and Dore, 1976; Twist, 1997). During shooting, a player must rotate at the hips and apply a force outside the body's center of gravity. This places enormous demand on the low back and abdominals. Inadequate torso strength is argued to limit shooting ability and increase the chance of injury from excessive twisting in this repetitive motion (Agre et al., 1988; Twist, 1997). Although no studies have investigated the exact muscle groups involved in the slap shot, Hayes (1965) provides a biomechanical description of the general mechanics involved in a slap shot. Hayes (1965) emphasizes that all movements are rotations, which place great importance on weight transfer, balance and coordination. During the shooting action the body moves from slight flexion and the trunk is rotated along the axis of the body, which places the upper arm in adduction at the shoulder joint. The lower-arm action for the slap shot involves adduction of the upper arm, followed by hyperextension. The wrists then follow from supination to extension. Further, the lower forearm is initially extended, while the arm is flexed at the shoulder joint. The lower wrist is then moved from pronation to flexion.

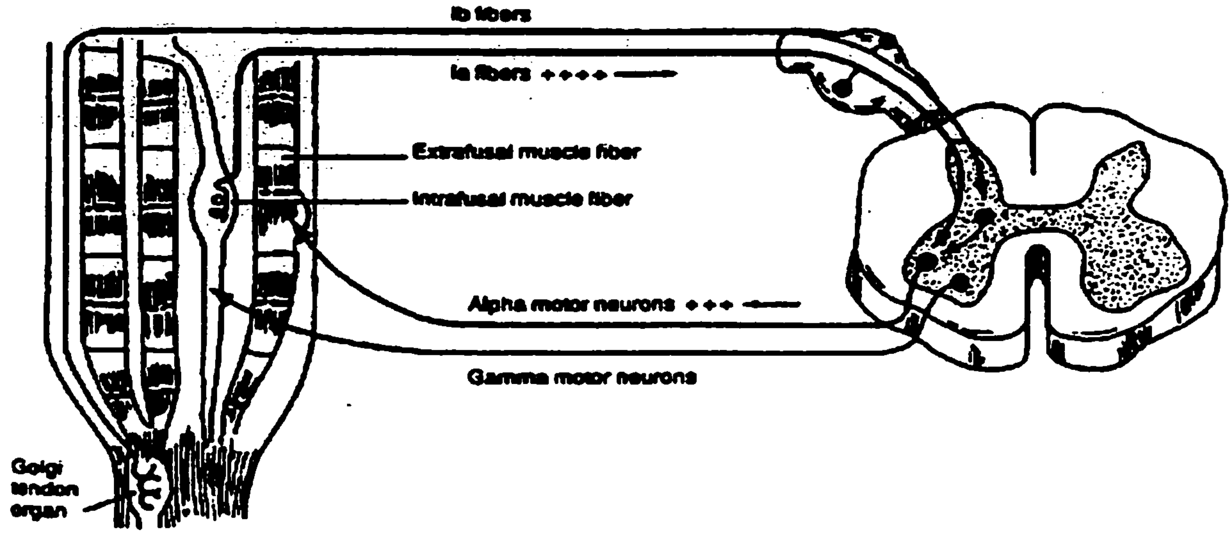
Based on the research by Agre et al., (1988), Hayes (1965), and Twist (1997) it is apparent that sport-specific training must involve rotations of the torso, to train the low back and abdominal muscles. Exercises must also be targeted at the major muscle groups controlling the range of motion of the upper limbs, mainly the chest, shoulders, and arm muscles involved in the stick swinging motion of the upper body.

Principals of Plyometics Training

Plyometrics is a form of training, which emphasizes fast explosive actions. The emphasis is on changing the direction of a moving limb as quickly as possible. For example, if a subject is to throw a medicine ball, he or she should focus on moving from the cocking phase to the release phase, changing direction of the ball rapidly.

The rapid coupling of an eccentric to a concentric contraction, known as the stretch-shortening cycle, stimulates the body's proprioceptors to facilitate an increase in maximal force production (Chu, 1983; Thomas, 1988). The proprioceptors of the body include the muscle spindle and the golgi tendon organ. The organization of the muscle can be seen in Figure 1.

Figure 1. The Organization of Skeletal Muscle (Wilk et al., 1993)



The muscle spindle is a complex receptor consisting of intrafusal (non-contractile) muscle fibers, which are sensitive to changes in the stretch velocity of the muscle. The intrafusal muscle fibers are innervated by a Type 1a phasic nerve fiber. If the muscle fiber is quickly stretched the muscle spindle will reflexively produce a rapid contraction of agonist and synergistic extrafusal (contractile) muscle fibers via the alpha motor neuron. The rate of stretch determines the magnitude of the reaction from the muscle spindle: the greater the rate of pre-stretch, the larger the effect produced on the extrafusal (contractile) fibers. This cycle occurs in 0.3 to 0.5 milliseconds and is mediated at the level of the spinal cord in the form of a monosynaptic reflex, such as the myotatic stretch reflex. In general, for a concentric contraction (no pre-stretch), the muscle spindle activity is reduced since the muscle fibers are either shortening or attempting to shorten.

Conversely, for an eccentric contraction, muscle spindle activity is increased which facilitates the stretch reflex (Bielik et al., 1986; Chu, 1983; DeSpain and Chevrette, 1987; LaChance, 1995; Lees and Graham-Smith, 1996; Lundin, 1985; Thomas, 1988).

Other studies involving low-limb stretch-shorten tasks, support the explanation that improved muscle performance is due to neural adaptations, particularly involving neural reflex potentiation, as a result of a pre-stretch (Viitasalo and Bosco, 1982). During a pre-stretch the neural reflex is potentiated, causing an increase in muscle stiffness. The stiffened muscle thereby increases the return of elastic energy during the concentric contraction to improve performance (Aura and Komi, 1986; Bosco and Komi, 1979; Bosco et al., 1981; Bosco et al., 1982a; Bosco et al., 1982b). Thus, plyometric training may train the neural reflex to increase muscle stiffness when stretched or it may improve the neural reaction time of the reflex. It should be emphasized, that the neural interactions are more complex than described here. For example, some muscles such as flexors, adductors, and internal rotators show greater potentation to the stretch reflex than extensor, external rotator and abductor muscles (Wilk et al., 1993).

The golgi tendon organ, located at the origin and insertion areas of the tendon and extrafusal muscle fibers, is sensitive to the magnitude of muscle tension. This organ is arranged in series with the muscle fibers and like the muscle spindle, becomes activated when the muscle is stretched. Unlike the muscle spindle, however, the function of the golgi tendon organ is to inhibit muscle contraction. Excessive muscle tension activates the golgi tendon organ to send impulses to the spinal cord, which cause an inhibition of the alpha motor neurons of the contracting (agonist) and synergist muscles (Figure 1). This reaction limits force generation by the muscle and has been hypothesized to function as a protective mechanism against over-contraction or excessive stretch. Nevertheless, the golgi tendon organ uses at least one interneuron in its synaptic cycle, which increases transmission time when compared to Type 1a monosynaptic interneuron excitation. Thus, appropriate plyometrics training can stimulate the reflex arc of the stretch reflex and facilitate contraction before the golgi tendon organ can inhibit the forceful stimulus for muscle contraction (Chu, 1983; LaChance, 1995; Lees and Graham-Smith, 1996; Lundin, 1985; Thomas, 1988). Therefore, the concept is that an athlete can train the muscle harder via bypassing the inhibitory effects of the golgi tendon organ.

In addition to neurological influences, the elastic properties of muscle also contribute to increased force generation ability. When a muscle is rapidly stretched, the increased load can be stored in the elastic components of the contractile filaments (strained actin-myosin crossbridges) and subsequently recovered during the concentric contraction. The ability of the muscles to utilize elastic energy is affected by the duration, the magnitude and the velocity of the stretch. For example, if an athlete is slow to transfer from the eccentric to the concentric phase of muscle contraction, due to insufficient muscle strength, the duration of the pre-stretch will be too long, and the stored elastic energy will be lost as heat. It is still unknown whether plyometrics training causes the muscle to become more elastic or if the muscle just becomes more efficient at utilizing a greater percentage of its elastic energy (Bielik et al., 1986; Grimsley, 1987; Koutedakis, 1989; LaChance, 1995; Lees and Graham-Smith, 1996; Lundin, 1985; Thomas, 1988). In summary, improved muscle performance that may occur as a result of plyometrics training is mainly due to the combined effects of improved elastic properties and enhancements within the nervous system.

The ability to rapidly contract the muscle would improve the power output for the athlete, even if strength did not improve, since muscle power = muscle force * muscle contraction velocity. Consequently, an athlete should be able to impart a larger force on the puck in a minimal amount of time. Also, a larger impulse would we imparted on the puck (Impulse = Force * Time). In essence, neural adaptations, as a result of plyometrics training, should result in faster slap shot speeds for hockey players.

Studies on Upper Body Plyometrics

Since upper body plyometrics is relatively new, the topic has seen limited research. Despite this lack of research, plyometrics been recently been advocated by clinicians and researchers in the rehabilitation setting to re-train the lower limbs (Chu, 1999; Davies, 1995; Fees, 1996; Lees and Graham-Smith, 1996; Pfeiffer, 1999; Radcliffe and Osternig, 1995; Snyder-Mackler, 1996; Stone, 1998; Swanik and Swanik, 1999) and upper limbs following injury (Cordasco et al., 1996; Courson et al., 1999; O'Connor, 1999; Richards and Kibler, 1997; Wilk and Arrigo, 1993; Wilk et al., 1993; Wilk et al., 1996).

Despite the growing popularity of plyometrics, only a limited number of studies have investigated the effects of an upper-body, plyometrics training program. A study by McEvoy and Newton (1998) investigated an upper body protocol involving throwing velocity. Eighteen National League baseball players from two teams were divided into one of two groups, a control group (n=18) who participated in their normal preseason baseball training and an experimental group (n=18) that participated in normal preseason baseball training as well as plyometrics. The plyometrics training included bench throws using a load of 30-50 % of 1-Repetition Maximum, 3-sessions per week every 2-weeks, for 15 training sessions total. For the experimental group, 3 sets of 6-8 repetitions were executed on the Plyometric Power System for 10-weeks. Results of throwing velocity showed that the experimental group statistically improved 2.0 ± 1.5 % from pre to post testing ($p<0.05$) while the control group experienced a non-significant decrease ($p<0.05$) of 0.4 ± 3.2 %.

Another study by Hetu et al. (1998) examined the effects of an 8-week conditioning program on 12 male and 5 female golfers (mean age = 52.4 ± 6.7 years). The subjects performed strength training, foam ball and medicine ball tosses (2.3 kg ball) using 1-2 sets of 10-15 repetitions, twice weekly. Results showed significant increases ($p<0.05$) in strength (chest; grip; and leg extension), flexibility, and club head speed, although no control group was used. Similarly, Wilson et al., (1996) examined the effects of an 8-week (2 sessions/week) training program on 41 weight-trained male science students, who were divided into one of three groups: a weight training group (n=14), a plyometrics group (n=14), and a control group (n=13). The plyometrics group performed 1- 4 sets of 8 repetitions of medicine ball throws in a bench-press style. Statistically significant improvements were recorded for the plyometrics group in regards to average force generated for a countermovement (upper body push-up) jump only. However, the weight training showed significant increases in 1-repetition maximum, average force, peak force, and rate of force development generated from a countermovement (push-up) jump. No statistical differences were noted between increases for both groups.

Another 8-week investigation was reported by Heiderscheit et al., (1996) who studied 81 college sedentary females participating in either plyometrics (1.36 kg weighted ball throws; n=27), or isokinetics (n=27), or no training (control group; n=27) The plyometrics group trained twice weekly using 3-4 sets of 10 repetitions. Results showed no increase in isokinetic power and no more distance on a softball throw for the plyometrics group. Only the isokinetic group showed a statistical increase in isokinetic power but not for softball throw distance.

In general, upper-body plyometrics programs have led to variable results. Based on the limited number of upper body studies by Heiderscheit et al., (1996), Hetu et al. (1998), McEvoy and Newton, (1998) and Wilson et al., (1996) it is difficult to predict the success of any given plyometrics program. Nonetheless, it appears that anywhere between 1-4 sets of 6-15 repetitions may prove effective for upper body plyometrics training.

Candidates for Plyometrics

Given that plyometrics was developed for high-performance athletes, it is not surprising that competitive athletes have typically shown the greatest benefits from plyometric training (Brown et al., 1986; Clutch et al., 1983; Duke and BenEliyahu, 1992; Fry et al., 1991; Gettman et al., 1987; Hewett et al., 1996; Hewett et al., 1999; Hutchinson et al., 1998; Kramer et al., 1983; Lyttle et al., 1996; McEvoy and Newton, 1998; Paavolainen et al., 1990; Polhemus and Burkhardt, 1980; Polhemus, et al., 1980; Rimmer and Sleivert, 1996; Verkhoshansky and Chernousov, 1974; Verkhoshansky and Tatyan, 1973; Wagner and Kocak, 1997; Whittle, 1998; Wilson et al., 1993). However, studies have shown that plyometrics can also produce benefits for non-athlete populations (Bassey et al., 1998; Benn et al., 1998; Blattner and Nobel, 1979; Blakey and Southard, 1987; Dean et al., 1998; Delecluse et al., 1995; Ford et al., 1983; Fowler et al., 1995; Gehri et al., 1998; Hakkinen and Komi, 1986; Heinonen et al., 1996; Hetu et al., 1998; Morris et al., 1997; Newton et al., 1999; Pen, 1987; Steben and Steben, 1981; Wagner and Kocak, 1997; Wilson and Murphy, 1996; Wilson et al., 1993; Wilson, et al, 1996; Witzke and Snow, 2000). Based on this research, it appears to be clear that a competitive university hockey team would be well suited to train and benefit from plyometrics.

General Conditioning Before Commencing a Plyometrics Program

It is commonly advocated, that a strength-training program be instituted prior to plyometrics, to ensure safety and to maximize training results (Ebben and Watts, 1998). Nevertheless, only a few studies actually have followed this "pre-training" protocol. Fry et al., (1991) and Clutch, et al., (1983) have shown 2-weeks to be an effective pre-training period for athletes, although 2-weeks has not proven effective for non-athletes (Bauer et al., 1990). Nevertheless, there are many studies that have demonstrated beneficial effects from plyometrics without a prior weight-training period (Blakey and Southard, 1987; Cossor at al., 1999; Duke and BenEliyahu, 1992; Fowler et al., 1995; McEvoy and Newton, 1998). The men's university hockey team would have already participated in an off-season strength-training program, since team members are instructed to weight train during the off-season. Moreover, at least one month of on-ice conditioning would have passed before players became available to participate in a plyometrics training program.

Number of Weeks of Training

Many studies report six weeks to yield effective results (Duke and BenEliyahu, 1992; Hewett et al., 1996; Hewett et al., 1999; Paavolainen et al., 1990; Polhemus et al., 1980; Wagner and Kocak, 1997). Many other studies have also investigated 7-weeks (Steben and Steben, 1981) and 8-weeks of training (Blakey and Southard, 1987; Heiderscheit et al., 1996; Hetu et al., 1998; Lyttle et al., 1996; Newton et al., 1999;

Rimmer, 1996; Wilson et al., 1996). The effects of short-term studies that have also proven effective include 3-week (Fowler et al., 1995) and 4-week studies Dean et al. (1998) and Hutchinson et al. (1998).

Given the limited amount of time available to participate in extra training, a short-term study would be most practical for a university hockey team. Short-term studies in the past have proven effective and the results from a men's university hockey team would add valuable data to the limited literature on short-term plyometrics. A short-term study would also minimize the interruption of normal hockey training by extensive additional training.

Number of Sessions per Week

Many researchers have shown three days of training per week to be beneficial (Adams et al., 1987; Bauer et al., 1990; Blakey and Southard, 1987; Blattner and Nobel, 1979; Cossor et al., 1999; Duke and BenEliyahu, 1992; Ford et al., 1983; Gehri et al., 1998; Hakkinen and Komi, 1986; Heinonen et al., 1996; Hewett et al., 1996; Hewett et al., 1999; Kramer et al., 1983; McEvoy and Newton, 1998; Morris et al., 1997; Polhemus, 1980; Whittle, 1998; Witzke and Snow, 2000). Another common regime has subjects perform training two days per week (Clutch et al., 1983; Dean et al., 1998; Delecluse et al., 1995; Fry et al., 1991; Heiderscheit et al., 1996; Hutchinson et al., 1998; Lyttle et al., 1996; Newton et al., 1999; Pen, 1987; Wilson et al., 1993; Wilson et al., 1996).

Given the busy hockey schedule for the men's university hockey team, two training sessions per week would be most practical. Since plyometrics is high intensity exercise, training sessions should never be performed on consecutive days, to allow for adequate recovery.

Duration of Training Sessions

Few studies limit the duration of training within a training session. Sometimes a time limit is useful, for example, to examine whether plyometrics can be used as a substitute for other sport-specific training such as pool time (Cossor et al., 1999). Of the few studies that have reported training time per session, effective results have been shown for relatively short training sessions. Effective short training sessions include: 8-9 minutes (Polhemus and Burkhardt, 1980; Polhemus et al., 1980), 10 minutes (Bassey et al., 1998), 15 minutes (Cossor et al., 1999), and 20 minutes (Kramer et al., 1983). Longer training sessions that have been reported include 30 minutes (Morris et al., 1997), 30-45 minutes (Witzke and Snow, 2000), approximately 45 minutes (Cook et al., 1993; Nicopoulou et al., 1998), 60 minutes (Hutchinson et al., 1998), 1.5 hours (Dean et al., 1998), and 2 hours (Hewett et al., 1996, Hewett et al., 1999).

Since training time is limited for competitive student-athletes a short training session would be favourable. Therefore, a strategically designed training protocol could involve a light warm-up of plyometrics exercises (1-2 sets of sub-maximal efforts with stretching in between sets), so subjects would be able to perform maximally for 15-20 minutes of total training time.

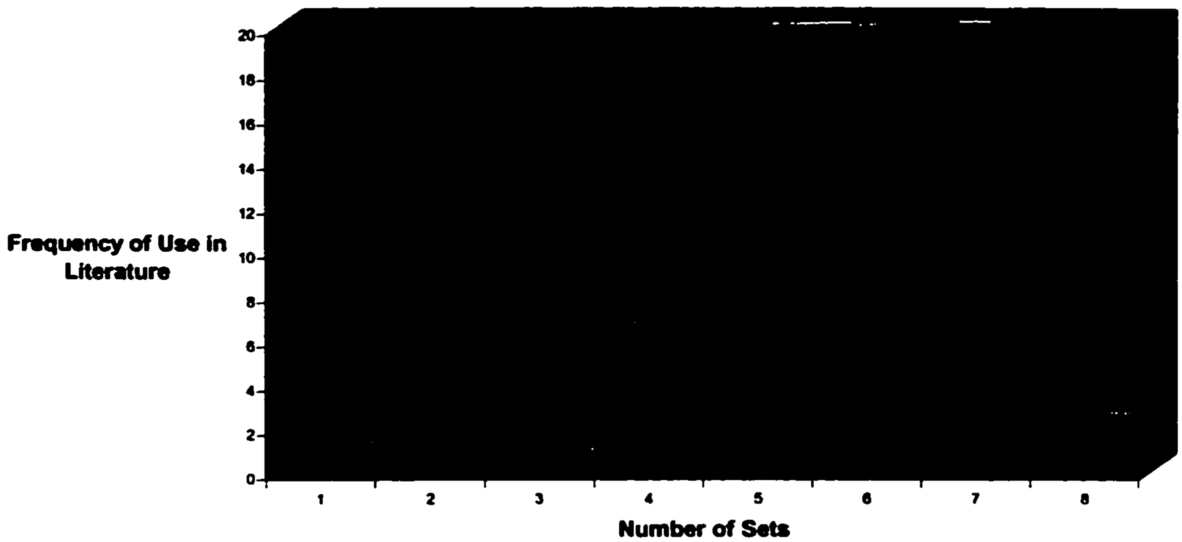
Sets and Repetitions

There is great variability in terms of sets and repetitions used by various investigators. Many programs progressively increase the sets and repetitions on a per session or per week basis, based on the discretion of the researchers involved (Bauer et al., 1990; Benn et al., 1998; Blakey and Southard, 1987; Fowler et al., 1995; Fry et al., 1991; Gehri et al., 1998; Heiderscheit et al., 1996; Hetu et al., 1998; Hewett et al., 1996;

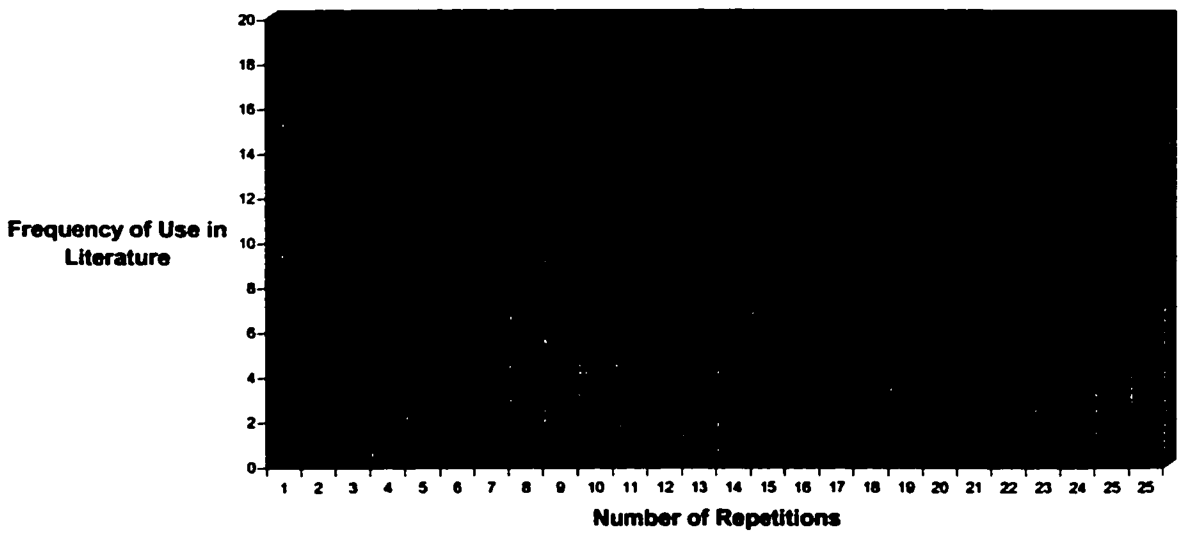
Hewett et al., 1999; Kramer et al., 1983; Lyttle et al., 1996; Popov et al., 1974; Wagner and Kocak, 1997; Whittle, 1998; Wilson and Murphy, 1996; Wilson et al., 1993; Wilson et al., 1996; Witzke and Snow, 2000).

Based on past studies, a progressive program would be most effective. To determine the appropriate number of sets, a literature review was performed on training protocols and the most commonly used sets are summarized in Graph 1. A literature review was also performed to determine the appropriate number of repetitions. The most frequently used repetitions in the literature are summarized in Graph 2. The literature review was based on the following studies that examined plyometrics training over a number of weeks: Adams et al. (1987), Bassey et al. (1998), Bauer et al. (1990), Benn et al. (1998), Blakey and Southard (1987), Blattner and Noble (1979), Brown et al. (1986), Clutch et al. (1983), Cook et al. (1993), Cossor et al. (1999), Dean et al. (1998), Delecluse et al. (1995), Duke and BenEliyahu (1992), Ford et al. (1983), Fowler et al. (1995), Fry et al. (1991), Gehri et al. (1998), Gettman et al. (1987), Hakkinen and Komi (1986), Heiderscheit et al. (1996), Heinonen et al. (1996), Hetu et al. (1998), Hewett et al. (1996), Hewett et al. (1999), Hutchinson et al. (1998), Kramer et al. (1993), Lyttle et al. (1996), McEvoy and Newton (1998), Morris et al. (1997), Newton et al. (1999), Nicopoulou et al. (1998), Paavolainen et al. (1991), Pen (1987), Polhemus and Burkhardt (1980), Polhemus et al. (1980), Popov et al. (1974), Rimmer and Sleivert (1996), Steben and Steben (1981) Verkhoshansky and Chernousov (1974), Verkhoshansky and Tatyan (1973), Wagner and Kocak (1997), Whittle (1998), Wilson and Murphy (1996), Wilson et al. (1993), Wilson et al. (1996), Witzke and Snow (2000).

Graph 1: Most Commonly Used Sets



Graph 2: Most Commonly Used Repetitions



Rest Between Sets

Most authors do not report rest intervals between sets during training. In addition, exactly how the rest intervals were monitored or controlled is unknown for the majority of studies. Appropriate recovery time is important to allow greater recovery for muscles to rebuild ATP-CP stores (Heiderscheit et al., 1996). Short rest intervals of 30 to 60 seconds have been reported by Ford et al. (1983), Fowler et al. (1995), Gehri et al. (1998), Polhemus and Burkhardt (1980), Polhemus et al. (1980), Hewett et al. (1996); Hewett et al. (1999) and Whittle (1998). Longer intervals, between 1.5 to 3 minutes, have also been used (Blattner and Nobel, 1979; Clutch et al., 1983; Dean et al., 1998; Heiderscheit et al., 1996; McEvoy and Newton, 1998; Wilson and Murphy, 1996; Wilson et al., 1993; Wilson et al., 1996). Many authors prefer short rest times to decrease training time and to keep subjects from boredom in large group settings. Although no research has investigated the impact of rest intervals on adaptations to plyometrics, a rest interval of 1-3 minutes seems appropriate for muscle recovery.

Sport Specificity

Numerous studies support the importance of sport-specific training (principle of specificity) including velocity-specific training (Aagaard et al., 1996; Amiridis et al., 1997; Behm and Sale, 1993; Bell et al., 1989; Doherty and Campagna, 1993; Hakkinen and Komi, 1986; Housh and Housh, 1993; Morrissey et al., 1995; Petersen et al., 1989; Seger et al., 1998; Sharp, 1986) and movement-specific training (Behm, 1995; Sharp, 1986; Stewart and Page, 1997). The principal of specificity is generally advocated for plyometrics training (McEvoy and Newton, 1998). Since shooting requires a torque of the upper body, exercises that require a similar motion should be most effective. This is a challenge, since there is a lack of research on upper body plyometrics (Holcomb et al., 1998). Consequently, few authors have investigated the effects of various exercises involving trunk twisting, although some reports involving medicine ball training can be found (Courson et al., 1999; Hetu et al., 1998). Since limited research exists on upper body plyometrics, the most popular plyometric exercises that mimic torso twisting movement patterns in hockey shooting, should have the greatest chance to stimulate neural training adaptations. These exercises are discussed below.

Number of Exercises and Types of Exercises

Numerous studies have selected the number of exercises based on the discretion of the research team. Other reports are vague and others do not report quantity of exercises. Studies which have reported the number of exercises used for plyometrics training include: 1 exercise (Adams et al., 1987; Bassey et al., 1998; Benn et al., 1998; Blakey and Southard, 1987; Blattner and Nobel, 1979; Brown et al., 1986; Clutch et al., 1983; Heiderscheit, et al., 1996; Hetu et al., 1998; Newton et al., 1999; Pen, 1987; Popov et al., 1974; Wilson et al., 1993; Wilson et al., 1996); 2 exercises (Ford, 1983; Fowler et al., 1995; Gehri et al., 1998; Lyttle et al., 1996; McEvoy and Newton, 1998; Polhemus et al., 1980); 3-4 exercises (Bauer et al., 1990; Fry et al., 1991; Kramer et al., 1983; Morris et al., 1997; O'Connor, 1999; Polhemus and Burkhardt, 1980; Rimmer and Sleivert, 1996; Steben and Steben, 1981; Verkhoshansky and Chornovsov, 1974; Wagner and Kocak, 1997; Whittle, 1998); 5-11 exercises (Dean et al., 1998; Delecluse et al., 1995; Hakkinen and Komi, 1986; Verkhoshansky and Tatyan; 1973) and 12-26 exercises (Duke and BenEliyahu, 1992; Hewett et al., 1996; Hewett et al., 1999; Hutchinson et al., 1998 Witzke and Snow, 2000)

Since upper body plyometrics are a relatively new concept, more than one exercise should be selected to ensure success. Three common and sport-specific exercises are described since it has been suggested that they would likely develop trunk torque ability and upper body strength relevant to hockey shooting performance (Chu, 1986; Bompa, 1993). A forth exercise, a weighted hockey stick, would also provide sport-specific training using plyometrics. Scientific support for selected exercises is listed below:

(1) Wheelbarrow Hops

Performing push-up hopping, and variations of it, is currently employed in the rehabilitation setting and sports training environments to train the chest, shoulders and triceps (Courson et al., 1999; O'Connor, 1999; Chu, 1999). A wheelbarrow hop is a rapid push-up action whereby the hands of each subject leave the matted surface between push-up efforts. An illustration of a wheelbarrow hop movement pattern is shown in Figure 2. It can be used to develop the chest, shoulder muscles (Bompa, 1993), and the serratus anterior muscles (O'Connor, 1999). Plate-hops have been developed from low body plyometrics involving hopping. There is still a debate, however, as to the ideal training heights for hops to promote superior training results. Some researchers report certain drop heights to be more effective than others (Adams, 1987; Dursenev and Raevsky, 1979; Katschajov et al., 1976; Lees and Fahmi, 1994; Radcliffe and Osternig, 1995). However, there is large disagreement as to the ideal drop height. Drop heights that have been tested range from 0.12 cm to 2.6m.

The dispute concerning the effects of drop heights may be due to the different jumping techniques used by subjects in various experiments. Jumping technique has been demonstrated to affect the accuracy of reported data (Bobbert et al., 1987a; Bobbert et al., 1987b; Kibele, 1999). For example, it has been found that as drop height increases, athletes naturally lower their center of gravity to decrease the landing impact, which can change the actual drop height from trial-to-trial and subject-to-subject (Bedi et al., 1987; Bobbert et al., 1987a). Moreover, many studies do not mention how drop height was controlled, including: Asmussen and Bonde-Pertersen, 1974a; Asmussen and Bonde-Pertersen, 1974b; Bosco et al., 1982a; Lees and Fahmi, 1994)

Other studies report that a variety of drop heights can lead to the same amount of improvement. For example, it has been reported that subjects improve similarly for drop heights reported between 25 to 85 cm, thus, no difference existed between drop heights (Bedi et al., 1987; Bobbert et al., 1987b). In addition, Courson et al., 1999 argue that drop height may not be as important as once thought and that various drops heights have been effectively used to train the upper-body during rehabilitation.

Since drop height may not be critical and safety is critical, a wheelbarrow hop would be most suited for hockey training. This would allow each athlete to control the height of each hop for each repetition.

Figure 2. Wheelbarrow Hop Exercise

(2) Abdominal Shockers

This exercise is recommended to train the trunk muscles and the side abdominal region (Bompa, 1993). For this exercise, the legs of each subject are pushed in an alternating fashion from side to side. Since abdominal strength can influence shooting performance, this exercise would be sport-specific training. It is illustrated in Figure 3.

Figure 3. Abdominal Shockers

(3) Two-Handed (Underhand) Side Throw Using a 4 Kg Medicine Ball

The use of medicine balls or plyoballs is sometimes used during rehabilitation to train the body for sport-specific movements involving large accelerations of the upper body (Cordasco et al., 1996; O'Connor, 1999; Richards and Kibler, 1997; Wilk et al., 1996). A series of throwing and torso twisting exercises is used to replicate a throwing motion, to improve flexibility, to promote shoulder muscle endurance, to teach weight transfer, and to train the legs and arms to accelerate (Courson et al., 1999; Grieve 1970; Richards and Kibler, 1997; Stewart and Page, 1997; Wilk et al., 1996). In addition, the medicine ball has been shown to improve proprioceptive skill and neuromuscular control of the shoulder joint (Swanik and Swanik, 1999; Wilk and Arrigo, 1993).

To simulate the weight transfer and large accelerations involved in hockey shooting, the Two-handed (underhand) Side Throw using a 4 kg medicine ball could be utilized, as proposed by Wilk and Arrigo (1993) and Wilk et al. (1996). This exercise is currently used by leading experts in sports medicine (Figure 4) and is sport specific to hockey. Given limitations in terms of equipment, a medicine ball can be thrown against a mat instead of a trampoline, as shown in Figure 5.

Figure 4. Two-Handed (Underhand) Side Throw into a Trampoline from Wilk and Arrigo, (1993) and Wilk et al., (1996)

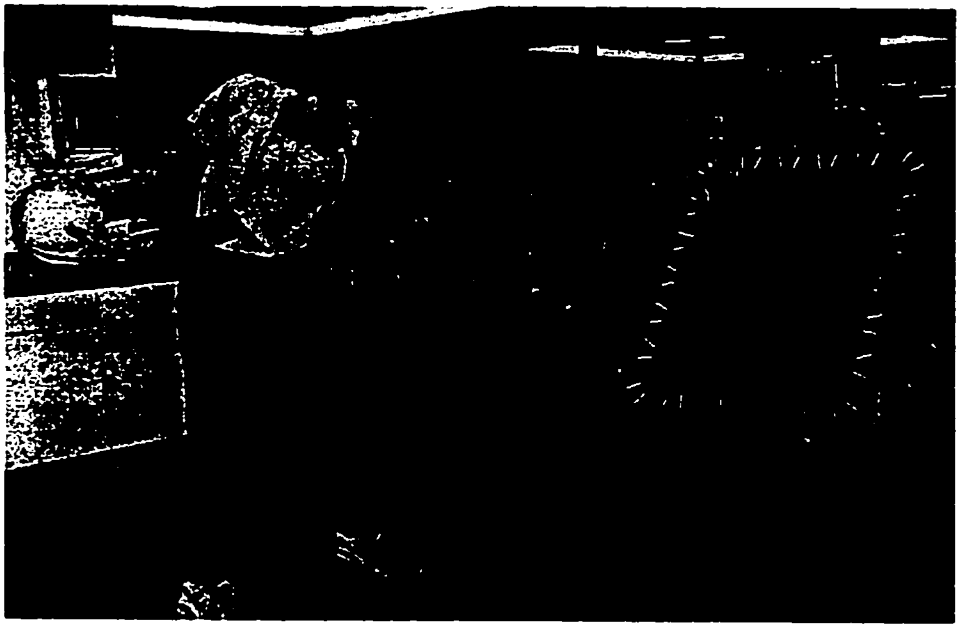


Figure 5. Two-Handed (Underhand) Side Throw Using a 4 Kg Medicine Ball into a Mat

(4) Plyometric Stick Slap Shots

Given the importance of sport-specific training, a weighted hockey stick should be an effective type of slap shot training. The basis for a weighted hockey stick exercise is consistent with the purpose of other common plyometrics exercises. It is well known that swinging movements, such as the cocking of the arm for a throw, involves stretch-shortening cycle movements (Wilk and Arrigo, 1993). These movements can be classified into three phases. The first phase is the eccentric phase, where a rapid pre-stretch is applied to the muscle, which stimulates the muscle spindle. The second phase is the amortization phase, which is the duration between the eccentric and concentric phases. It is recommended that this time be as short as possible, so that neurological and elastic effects, involved in the pre-stretch, are not lost as heat. The third phase is the concentric phase, which involves a powerful muscular contraction as a result of the pre-stretch (Chu, 1999; Snyder-Mackler, 1996; Wilk and Arrigo, 1993;).

With these characteristics as the foundation of the design, each player could perform a stretch-shortening task by swinging a heavy stick mounted with a 1.0-pound weight on the shaft, near the blade. This additional weight would not change the natural grip of the stick and should stimulate a larger pre-stretch than a normal hockey slap shot without a 1.0-pound weight. Since the stick is accelerated at high speeds, extreme stress is placed on the athlete. Consequently, a heavier stick would not be recommended. An illustration of the recommended hockey stick modification is illustrated in Figures 6a and 6b.

Figure 6a. Plyometric Stick Modification

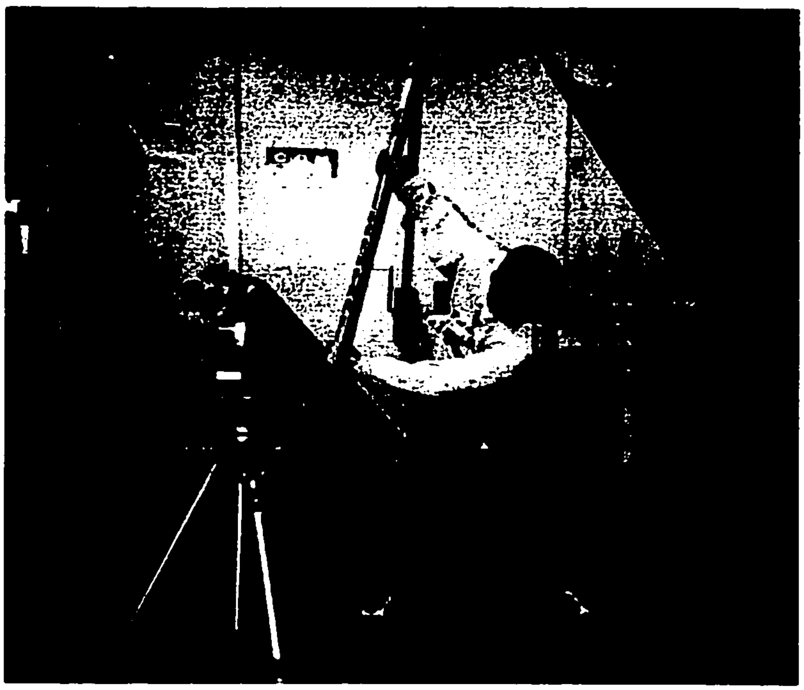


Figure 6b. Plyometric Stick Modification

Warm-ups, Stretching, and Cool-down

Most studies do not report a warm-up, stretching, or cool-down period, although the benefits of such a practice have been known for some time. A brief warm-up period, prior to slow static stretches, increases muscle elasticity to make stretching more effective (Stewart and Page, 1997) and decreases the risk of injury with plyometrics (Holcomb et al., 1998). Consequently, a 5-minute warm-up using some submaximal efforts for each plyometrics exercise, followed by light stretching of the chest, shoulders, side abdominals, quadriceps, and triceps (stretch held for 15-20 seconds) between sets; would prepare the muscle for more strenuous activity (Amiridis et al., 1997; Dintiman et al., 1997; McEvoy and Newton, 1998; Snyder-Mackler, 1996). In the past, a 2-minute cool-down has been used to adequately recover the muscles and prevent soreness by Hewett et al., (1996) and Hewett et al., (1999). A cool-down involving submaximal effort stick swings (non-weighted stick) and stretching should provide an appropriate cool-down from plyometrics hockey training.

Safety

The prevention of injury is the main concern for any training program. Although plyometrics is considered high intensity training, precautions can be taken to minimize risks. It is the inappropriate or misuse of plyometrics that can lead to avoidable injury (Holcomb et al., 1998; Pfeiffer, 1999). Thus, it is important to have a knowledgeable supervisor who understands the risk factors. Weight training, prior to the initiation of plyometrics, has also been argued to decrease the risk of injury, since it strengthens the body to withstand the stresses of plyometric training (Ebben and Watts, 1998; Holcomb et al., 1998). Therefore, hockey players with a weight-training program would be ideal for plyometrics training.

There are those who criticize the use of plyometrics by children (Horrigan and Shaw, 1989; King, 1991) and even athletes in general (Brzycki, 1988). However, Goss (1988) and Yessis (1990) argue that these concerns are largely based on anecdotal reports and stem from insufficient knowledge, a lack of safety precautions, and a general ignorance of the latest research. For younger athletes, the following safety precautions can be taken: (a) only general plyometrics such as 2-leg hops or skipping should be used; (b) low repetitions and large rest periods (8-10 minutes) between sets are safest; (c) and plyometrics on mats or grassy surfaces should be used if available (Booth, 1996; Lundin, 1987).

Moreover, it has been argued that injuries are a part of any sport, within the game or during training and that plyometrics can, in fact, strengthen the body to reduce the incidence injuries (Smythe, 1991; Wilson et al., 1996). For example, one study monitored incidence of injury in female athletes, throughout the high school soccer, volleyball and basketball seasons. This study demonstrated a decreased incidence of knee injury, after a specific plyometrics training program (Hewett et al., 1999). In bone studies, high-impact jumps have also demonstrated positive osteotropic effects in animals (Judex and Zernicke, 2000); in male and female premenopausal athletes (Daly et al., 1999; Dook et al., 1997); and in well-trained female athletes (Taaffe et al., 1997). However, excessive use of high-volume, high-intensity training has been shown to inhibit bone growth in immature bones for animals (Matsuda et al., 1986).

In general, to minimize risk of injury, safety precautions such as an adequate warm-up, stretching, and strengthening period should be followed to prevent avoidable injury.

Summary

In general, studies have shown that slap shot mechanics require the use of the chest, shoulders, arms, and abdominal muscles. Consequently, an effective plyometrics program, focused on improving slap shot velocity, should focus on sport-specific muscle groups using exercises such as Wheelbarrow Hops, Abdominal Shockers, Two-Handed (Underhand) Side Throws, and Plyometric Stick Slap Shots. A limited number of studies have investigated the effects of upper body plyometrics training; nonetheless, a review of literature reveals that a progressive program involving 1-3 sets of 8 and 10 repetitions may provide neural improvements in terms of slap shot performance. Given the busy schedule of university athletes, two training sessions per week involving an appropriate warm-up, stretch and cool–down would prove most practical for varsity athletes.

CHAPTER 3

METHODS AND PROCEDURES

Subjects

Twenty-one male university hockey players from the University of Windsor Hockey Team, volunteered to take part in the study. Two groups were formed: an experimental group and a control group. Players, who were able to fit the plyometrics training into their school and practice schedule, formed the experimental group (n=7). The control group was formed from the remaining players (n=14). The mean age, weight, and height for the control group was 23 $\pm$ 2 years, 89 $\pm$ 8 kg and 183 $\pm$ 5 cm, respectively. The mean age, weight, and height for the experimental group was 23 $\pm$ 2 years, 88 $\pm$ 6 kg, and 183 $\pm$ 5 cm, respectively. All subjects skated similar hours per week.

General Program Overview and Duration

Approximately 2-weeks were allocated for pre-testing, to test for isometric strength, prior to the start of training. Plyometrics training commenced on Monday November 27, 2000. Training sessions were held until Thursday February 8, 2001. Pre-test slap shot (puck) velocity was measured on Thursday October 19, 2000 and post-test slap shot velocity was collected on Friday February 16, 2001. Post-test strength data was collected for approximately 2-weeks after the last training session.

The experimental group participated in upper body plyometrics training in addition to normal hockey training. The control group participated in their regular training programs and did not participate in the upper body plyometrics program. The regular hockey-training program consisted of mostly hockey specific training (on-ice) with self-directed weight training, recommended by the coaching staff.

Training sessions were held twice weekly for the experimental group, although not all players were able to attend due to class conflict, injury or lack of adhesion to the program. The subjects who were involved in the experimental group performed a mean of 6 ± 2 training sessions.

Given the competitiveness of the university hockey program, athletes had been assigned a strength-training program by the coaching staff, prior to this study for off-season training. Nevertheless, to ensure safety and effective results, plyometrics training was conducted no earlier than mid November to ensure athletes were sufficiently strength trained (both on and off ice) to prevent avoidable injury. To ensure adequate strength, athletes who could not bench press their own body weight were excluded from plyometrics training, although this was not a problem for any of the athletes.

Personnel

The same personnel conducted all training sessions and collected all data. Thus, consistency of the training methods and the data collection protocol was ensured.

TESTS

Two testing sessions were held: a pre-test at the beginning of the study and a post-test held at the end of the study. All subjects were measured using a radar gun to measure puck velocity, in addition to the collection of isometric strength measures. Stick velocity was also collected using a radar gun, at the beginning and at the end of each training session for the experimental group. Prior to the each testing session, subjects were familiarized with the testing protocol by verbal instruction.

Isometric Maximal Voluntary Contraction (MVC)

After receiving a starting cue, the subject performed two to three trials of 4 to 6 second isometric maximal voluntary contractions, along a vertical plane, against a bar connected to a force transducer. The height of the bar, mounted with the force transducer, was measured and recorded during pre-testing so that each subject's elbow joint was approximately placed at a 90-degree angle. This height was used again during post-testing to maintain testing consistency. The body position used for testing is illustrated in Figures 7 through Figure 10. Figure 7 illustrates the body position used to measure chest strength. Figure 8 shows the body position for shoulder strength. Figure 9 and Figure 10 show the body positions used for biceps and triceps, respectively. Rest intervals between MVCs were 1-2 minutes and subjects were encouraged to exert themselves fully during each MVC.

Figure 7. Body Position used to Collect Isometric Chest Strength Data

Figure 8. Body Position used to Collect Isometric Shoulder Strength Data

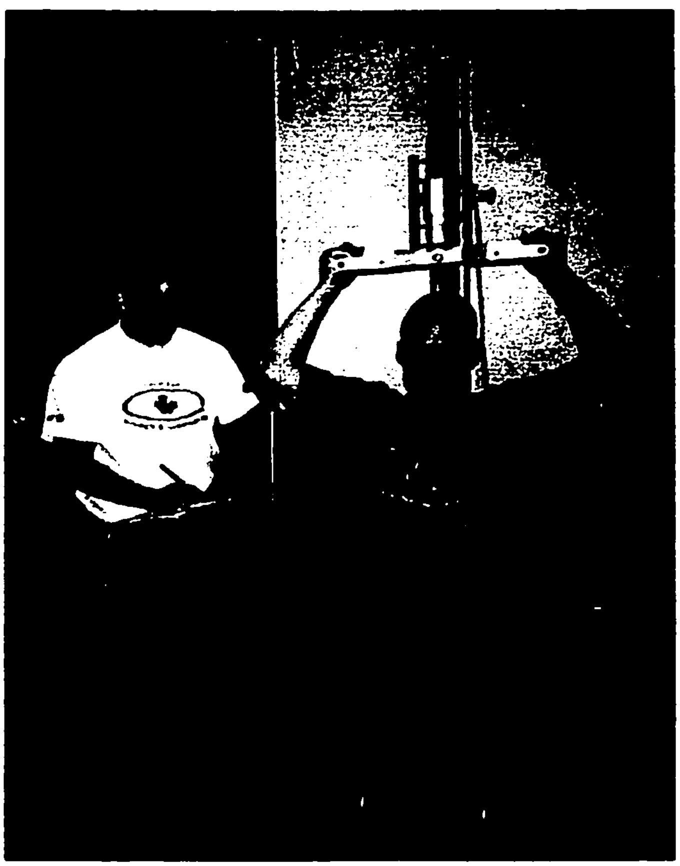


Figure 9. Body Position used to Collect Isometric Biceps Strength Data

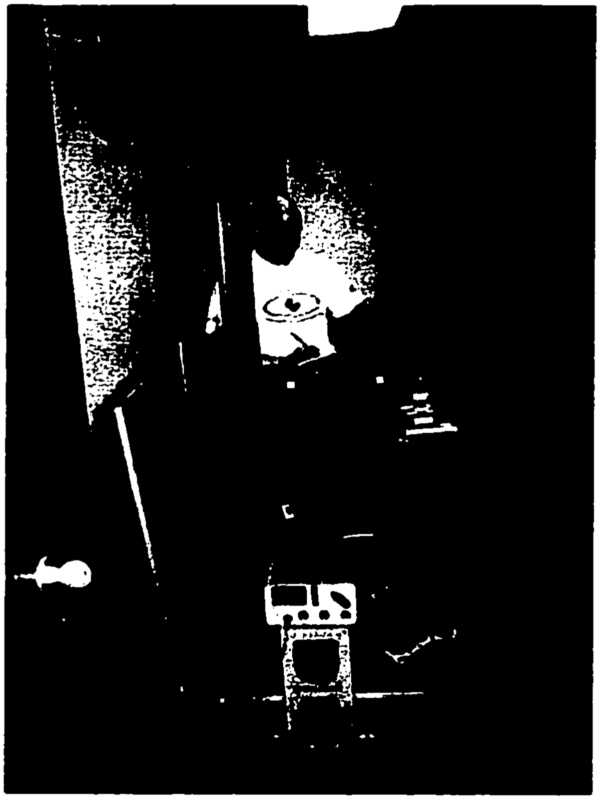
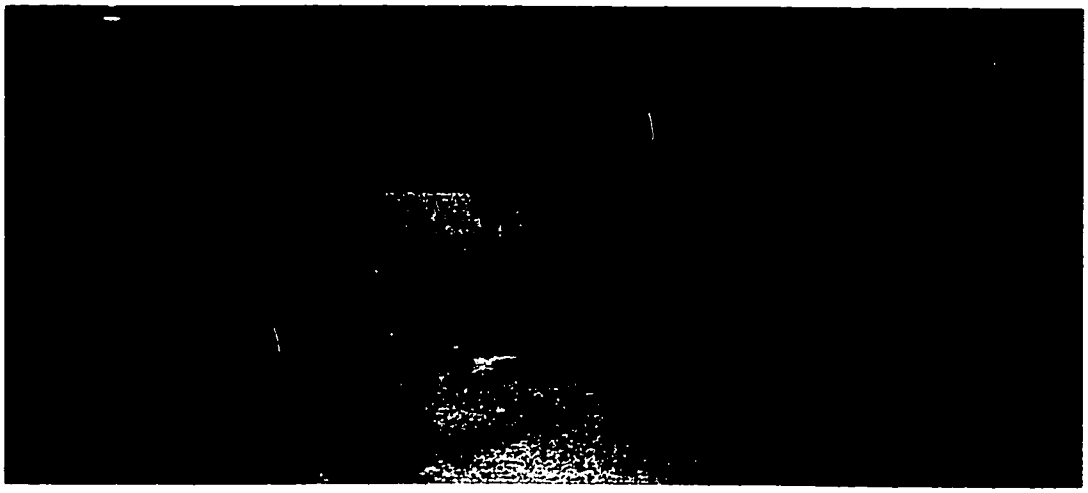


Figure 10. Body Position used to Collect Isometric Triceps Strength Data

On-Ice Radar Gun Tests

Players dressed in full practice hockey equipment, were positioned on the face-off circle closest to the goal line. The net was placed directly in front of the shooter, on the goal line, and the radar gun was positioned directly behind the net (Figure 11). This set-up was again used for post testing. After a 5-10 minute warm-up and stretching period, subjects performed a few submaximal slap shots-up to complete the warm-up. After the warm-up, subjects performed between 3-12 maximal effort slap shots from a stationary position. Any errant shots that did not pass directly in front of the radar gun were disregarded. Maximal slap shot (puck) velocity was collected and the top three slap shot (puck) velocities were analyzed. Maximal slap shots were followed by a 10-20 second rest interval. A hand-held Stalker ATS Radar Gun was used to collect data with a low cut-off velocity set at 80 km/h.

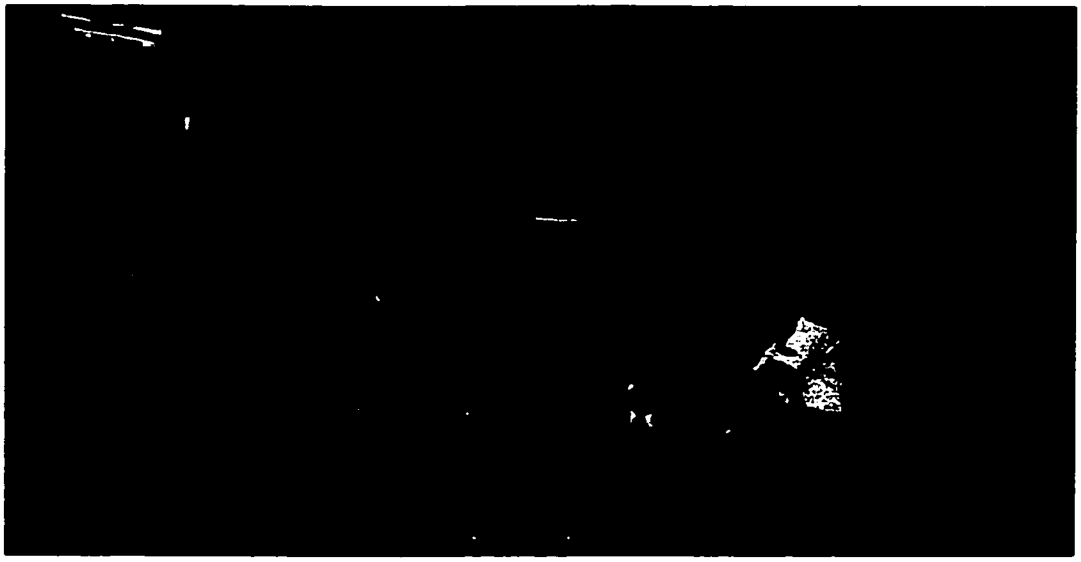
Figure 11. Set-up for On-Ice Slap Shot Testing



Off-Ice Radar Gun Tests

Subjects performed slap shots, without the use of a puck using a normal hockey stick. Stick velocity data was collected at the beginning of each plyometrics training session and used as a warm-up exercise to prepare the subject for the more intensive part of the workout involving the heavy stick. The radar gun was placed between 10-20 meters in front of the shooter and the shooter took repetitive slap shots until slight fatigue. The subjects were instructed to progressively try to attain a maximal stick swinging velocity using a normal hockey stick in a slap shot motion (rest interval 5-10 seconds between swings). A hand-held Stalker ATS Radar Gun was used to collect data with a low cut-off velocity set at 80 km/h. Approximately once a week the radar gun was tested for accuracy using two tests: a SELF TEST feature on the radar gun and the tuning fork that vibrates at 88.48 km/h, as recommended by the manufacturer. The set-up for in laboratory data collection is shown in Figure 12. This set-up was also used at the end of each training session to cool-down each subject, although this time, subjects progressed from maximal efforts to submaximal efforts. For statistical analysis, the average of the top three velocities was taken from the initial training sessions and compared to the average top three velocities obtained from the best training sessions.

Figure 12. In-Laboratory Set-up for the Collection of Stick Velocity



PROCEDURES FOR PLYOMETRIC TRAINING

The off-ice training program was divided into two stages. Stage 1 was performed at the University of Windsor Biomechanics Laboratory from Monday November 27, 2000 through Thursday January 18, 2001. Stage two was held rink-side at the University of Windsor practice facility from Monday Jan 22, 2001 to Thursday February 8, 2001. The second stage was created to make it easier for players to participate in training sessions. All sessions had a 1-3 minute recovery interval between sets.

Stage 1

After arriving in the Biomechanics Laboratory, subjects performed wheelbarrow hops and abdominal shocker exercises with a partner on a matted surface. Sets and repetitions were performed in a progressively intensive manner. Since many athletes missed sessions due to classes or injuries, each athlete progressed to the next level of difficulty at the discretion of the investigator, in consultation with each athlete. All athletes, however, used the same progressive program and a summary of the protocol and levels of difficulty are outlined in Table 1. Subjects were encouraged to perform the wheelbarrow hops and abdominal shockers with light to moderate intensity before commencing the intensive medicine ball throws and heavy stick swing exercises, to prevent injury.

Table 1. Progressively Intensive Upper-Body Plyometrics Training Program Used by all Subjects in the Experimental Group

Level of Difficulty	Sets	Repetitions
1	1	8
2	2	8
3	2	10
4	3	8
5	3	10

Following the wheelbarrow hops and abdominal shockers, subjects performed the two-handed (underhand) side throw using a 4 kg medicine ball, which was followed by plyometric (heavy stick) stick slap shots without a puck. The sets and repetitions, used for the heavy stick and medicine ball exercises, also progressed according to Table 1.

Radar gun data collection of stick velocity commenced on Monday December 11, 2000 and was performed until the last training session. This was done to track the improvements of players with detail, since many players were missing training sessions for various reasons. The radar gun set-up for the collection of data was discussed earlier in the section titled "Off-Ice Radar Gun Tests". Subjects performed the radar gun test after the completion of the wheelbarrow hops and abdominal shockers just prior to completing the two-handed (underhand) side throw and plycmetric stick slap shots. Stick velocity data were also collected at the end of the training session, before subjects left the laboratory.

Stage 2

Stage 2 of training took place at the practice arena of the men's hockey team. starting on Monday January 22, 2001. This change in training location was necessary to make it easier for subjects to fit the ploymetrics training program into their schedule. Due to the site change, the training protocol was slightly modified. The wheelbarrow hops and abdominal shockers were dropped from the training protocol due to limited space and equipment; the rest of the program remained the same. In short, subjects would warm-up by performing submaximal to maximal slap shots without a puck, followed by two-handed medicine ball throw and weighted stick slap shots. The sets and repetitions continued to follow the progression listed in Table 1. Afterwards, subjects would warm-down, with maximal to submaximal slap shots using a their normal hockey stick.

Video Feedback for Each Training Session

A video camera was used to film and provide feedback to the subjects during the rest period between sets. Only the weighted stick and medicine ball throws were filmed, to point out mistakes in training to be corrected for the next set. Mistakes that were corrected included: a subjective change in natural slap shot biomechanics; the execution of an exercise in a motion that was not similar to a slap shot; or a lack of focus on the cocking phase of the slap shot, which should show a rapid change in direction for the hockey stick. Figure 13 shows the camera set-up for the weighted hockey stick exercise and Figure 14 shows the camera set-up for the two-handed medicine ball throws.

Figure 13. Camera Set-up for the Plyometric Stick Slap Shots

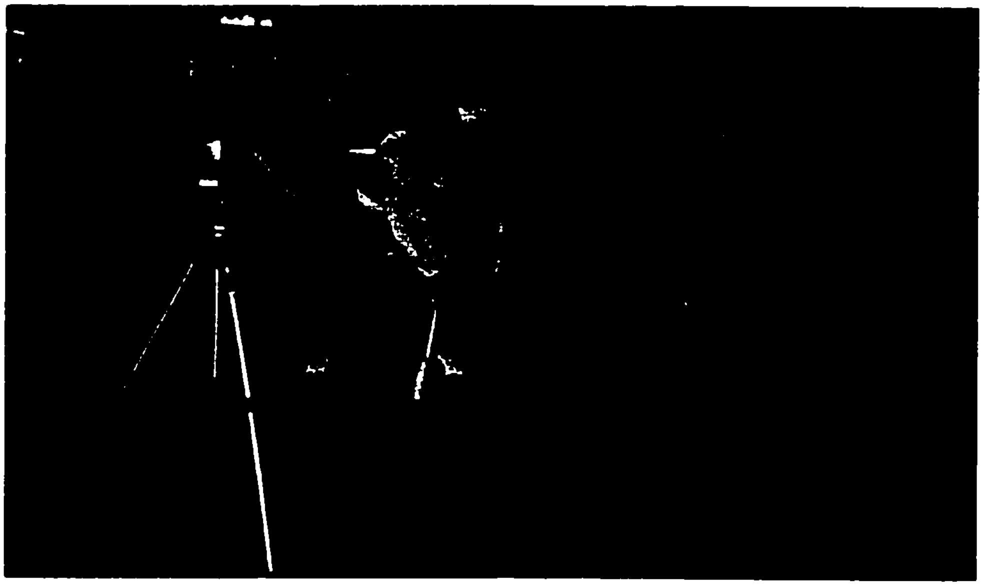
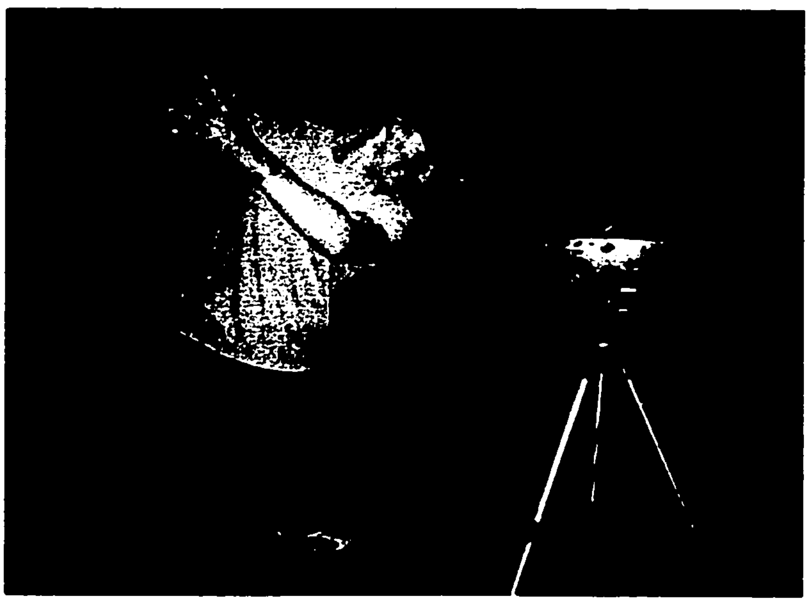


Figure 14. Camera Set-up for the Two-Handed (Underhand) Side Throw Using a 4 Kg Medicine Ball



STATISTICAL EXPERIMENTAL DESIGN

This study used a two factor ANOVA with repeated measures on pre-and post-training. The independent variables were the group factor with two levels (experimental; control) and the time factor with two levels (pre-training; post-training). The dependent variables included: isometric strength results of the chest, shoulders, biceps and triceps; on-ice slap shot velocity; and off-ice stick swing velocity. At the start and end of training, each group was compared using a one-way ANOVA to determine whether there were any differences between groups. A paired T-test was also used to evaluate in-laboratory stick velocity improvements from pre- to post-training, for the experimental group. Pearson (2-tailed) correlations were performed to find the correlations between strength measures and slap shot (puck and stick) velocity. In addition, Pearson (2-tailed) correlations were also used to check the correlation between changes in stick velocity and changes in puck velocity (on-ice).

All statistical analysis was performed using SPSS Version 10.0 for Windows. Table 2 illustrates the 2*2 experimental design. F-ratios were evaluated for two main effects (Group and Test Occasion) and for the interaction between group and test occasion. The criterion level of significance was set at $p \leq 0.05$.

Table 2. The 2*2 Experimental Design

	Pre-test	Post-test
Experimental Group		
Control Group		

CHAPTER 4

RESULTS AND DISCUSSION

The following sections are based on the analysis of raw data, located in the appendices. The appendices include statistical output data (Appendices A through K), attendance and training data (Appendix L), puck velocity data (Appendices M and N), stick velocity data (Appendices O and P) and isometric strength data (Appendices Q and R).

RESULTS: THE EFFECTS OF SHORT-TERM PLYOMETRICS TRAINING ON ISOMETRIC STRENGTH

Pre-training isometric strength data produced by the experimental group (n=7) were compared to the control group (n=6) using a 1-way ANOVA (Appendix A) to determine if strength differences existed between groups before the study began or at the end of the study. At the beginning of the study, it was found that there was no statistical difference ($p>0.05$) between groups for chest strength ($p=0.386$), shoulder strength ($p=0.335$), biceps strength ($p=0.797$), and triceps strength ($p=0.450$). Post-training data also showed no statistical differences between groups for isometric chest strength ($p=0.695$), shoulder strength ($p=0.439$), biceps strength ($p=0.722$), and triceps strength ($p=0.097$). Therefore, none of the groups statistically differed in strength at the start or end of the study. Strength comparisons between groups using a 1-way ANOVA are summarized in Table 3.

Table 3. Isometric Strength Differences Between Groups at Pre- and Post-Testing

	Mean Pre-Test Data of Maximal Isometric Strength (kg)			Mean Post-Test Data of Maximal Isometric Strength (kg)		
Test Condition	Experimental Group (N=7)	Control Group (N= 6)	P-Value	Experimental Group (N=7)	Control Group (N=6)	P-Value
Chest	106.8 ± 8.6	114.5 ± 20.5	0.386	106.4 ± 13.6	110.0 ± 19.5	0.695
Shoulders	80.9 ± 5.9	88.2 ± 17.3	0.335	82.3 ± 6.8	88.2 ± 17.3	0.439
Biceps	79.5 ± 17.3	82.3 ± 16.8	0.797	85.0 ± 23.6	89.5 ± 21.4	0.722
Triceps	51.4 ± 8.2	56.4 ± 14.5	0.450	55.9 ± 10.0	67.3 ± 12.7	0.097

A 2-way ANOVA (Appendices B through E) with repeated measures was used to evaluate strength changes over the duration of the study. Statistical analysis showed no statistical improvement ($p>0.05$) in chest strength ($p=0.223$) and no interaction effect between groups ($p=0.327$). Shoulder strength also did not improve from pre to post-testing ($p=0.465$) and showed no interaction effect ($p=0.512$). In contrast, biceps strength did statistically change ($p<0.05$) from pre to post testing ($p=0.045$), but no interaction effect was found ($p=0.715$). Triceps strength also changed ($p<0.05$) from pre- to post-testing ($p=0.011$), although no interaction effect was found ($p=0.228$). Strength changes over the duration of the study are summarized in Table 4.

Table 4. Isometric Strength Changes from Pre- to Post-Testing for Experimental and Control Groups

Test Condition	Group	Mean Pre-Training Maximal Strength (kg)	Mean Post-Training Maximal Strength (kg)	P-Value	Interaction (Group* Testing)
Chest	Experimental (N=7)	106.8 ± 8.6	106.4 ± 13.6	0.223	0.327
	Control (N=6)	114.5 ± 20.5	110.0 ± 19.5		
Shoulders	Experimental (N=7)	80.9 ± 5.9	82.3 ± 6.8	0.465	0.512
	Control (N=6)	88.2 ± 17.3	88.2 ± 17.3		
Biceps	Experimental (N=7)	79.5 ±17.3	85 ± 23.6	0.045*	0.715
	Control (N=6)	82.3 ± 16.2	89.5 ± 21.4		
Triceps	Experimental (N=7)	51.4 ± 8.2	55.9 ± 10.0	0.011*	0.228
	Control (N=6)	56.4 ± 14.5	67.3 ± 12.7		

* Significant at the $p<0.05$ level.

Based on Table 4, the experimental group improved 1.7% on shoulder strength, 6.9% on biceps, and 8.8% on triceps strength. In contrast, chest strength decreased slightly by 0.4%, although only improvements for biceps and triceps strength were statistically significant changes. The control group also showed gains in biceps strength (8.8 %) and triceps strength (19.4%); however, no changes in shoulder strength were found. Similar to the experimental group, a decrease of 4.0 % (non-significant) was found for chest strength in the control group.

DISCUSSION

Strength Changes and the Concept of Periodization

The lack of significant in-season strength gains, recorded for the chest and shoulders, was not unexpected. Many athletes spend in-season time trying to maintain strength gains developed during the off-season so that no change or loss of strength will occur. This phenomenon is associated with the concept of periodization, a commonly advocated method of training for competitive athletes in all sports (Wilmore and Costill, 1994; Twist, 1997). Periodization refers to changes in a training program over a period of time, designed to prevent an individual from becoming stale or over-trained (Bompa, 1993; Wilmore and Costill, 1994). Periodization generally emphasizes four stages of pre-season training lasting approximately six weeks per phase. Stage one is generally a muscular hypertrophy phase characterized by high volume training (3-5 sets of 8-20 repetitions). Stage two is a strength phase, characterized by high intensity training involving 3-5 sets of 2-6 repetitions. Phase three is a power stage involving high intensity training of 3-5 sets involving 2-3 repetitions. Phase four is a peaking phase, performed at the highest intensity and is characterized by 1-3 sets of 1-3 repetitions (Wilmore and Costill, 1994). Once the athletic season begins, extra curricular time is limited due to practices and games, so athletes move to an in-season "maintenance phase" that focuses on maintaining strength benefits gained during off-season training (Bompa, 1993; Dintiman et al., 1997;

Wilmore and Costill, 1994). In short, the maintenance of chest and shoulder strength by the hockey players is a typical characteristic of a competitive in-season periodization program.

The gains in biceps and triceps strength for this study are not completely explainable, since little research exists on hockey players. There are no current studies that have investigated strength changes of competitive hockey players over the duration of the season. Biomechanics research by Hayes (1965) suggests that the biceps and triceps muscles are involved in shooting performance. Since hockey players perform more repetitions of shooting during the in-season, the biceps and triceps muscles may have become more trained (a sport-specific strength gain). However, the chest and shoulder muscles are also major muscle groups involved in the slap shot, so increased repetitions alone does not account for the strength gains in the biceps and triceps only. The biceps and triceps, however, may have experienced greater gains since they experience greater workloads during the in-season than the off-season, particularly during in-season activities such as pinning a player into the boards; shoving, clutching and pulling opponents from the puck, or other stick-work and body contact activities experienced along the boards. These activities would be less common during the off-season for a hockey player. As a result the biceps and triceps may become less trained during the off-season, only to become re-trained during the hockey season to show significant gains. On the other hand, chest and shoulder strength may remain constantly strong throughout the year, since chest and shoulder strength training is more commonly advocated for hockey players in the off-season, rather than triceps and biceps training (Bjornaraa, 1981; Twist, 1997). Therefore, the biceps and triceps would have a greater opportunity to improve with the increased use of the arms during the in-season, compared to the consistently strong chest and shoulder muscles. This may explain why the small, non-significant percent changes were found for the chest and shoulders muscles, compared to the larger significant changes in biceps and triceps strength. To verify this hypothesis, normative data needs to collected and published concerning strength changes experienced by competitive hockey players over the course of an in-season and off-season.

Strength Changes and Short-term Plyometrics Studies

The effects of a short-term plyometrics training program on human performance, has seen little attention. A limited number of studies have investigated this topic including Dean et al. (1998), Fowler et al. (1995), and Hutchinson et al. (1998). Of these researchers, only Fowler et al. (1995) included isometric strength as one of the dependant variables.

To study the effects of short-term, consistent plyometrics, Fowler et al. (1995) designed a sophisticated study involving a group of 18 male physical education students who trained four times weekly for three weeks (12 sessions total). The group was divided into an experimental group (low-body weight-training combined with low body plyometrics; n=9) and a control group (low body weight training only; n=9). Results showed that both groups increased ($p<0.05$) in isometric strength for the hip extensor muscles at a 120-degree hip angle (33.0 % control; 16.5% experimental group) and knee extensor muscles at a 100-degree knee angle (17.5 % control; 9.5% experimental group). These gains were statistically the same for both groups (no interaction at the $p=0.05$ level) except for knee extension strength, which was larger in the experimental group. However, improved isometric knee flexion strength showed gains only for the control group. Therefore, The authors showed that short-term plyometrics were not associated with isometric strength for low limb extension and flexion tasks since the plyometrics training resulted in no special advantages over the control group in terms of isometric strength, which showed the same gains statistically.

The results from the current study are consistent with the results reported by Fowler et al. (1995). The gains in isometric biceps and triceps strength for the hockey players were not likely a due to the plyometrics training, since short-duration plyometrics training has been shown to have no effect on strength gains. Further, the results of this study and those of Fowler et al. (1995), support the basis of plyometrics training, which is to increase the velocity of muscle contraction, rather than the strength of muscle contraction.

Strength and Long-term Plyometrics Studies

A number of studies have investigated the effects of long-term plyometrics training on a number of strength measures. Although these studies have included various measures of low-limb isometric strength, they all support the general concept that plyometrics training is not intended to increase strength.

Lack of Differences Between Experimental and Control Groups for Strength Gains

Consistent with the strength changes recorded for the hockey players, many studies have found that strength changes were not due to plyometrics training since both the experimental (plyometrics) and control (non-plyometrics) groups showed the same statistical gains in strength, regardless of plyometrics training.

For example, in a highly stratified study, Bauer et al. (1990) studied the effects of plyometrics training on 37 physical educations student (22 males and 15 females). Bauer et al. (1990) reported that standard strength training with free weights (n=8) was equally as effective as free weight training combined with plyometrics (n=7). Both groups showed similar increases ($p<0.05$) in isometric quadriceps strength (at knee angle of 90-degrees), over 10-weeks of training, performed 3 times per week (30 sessions total). A mean gain of 18.9% was reported for the free weight training group and mean gain of 18.7% was reported for the combined training group. These gains were not statistically different, since there was no interaction effect reported at the $p=0.05$ level.

Similarly, Clutch et al. (1983) studied effects of plyometrics training on 12 male students participating in a university weight training class. Subjects were trained in one of three training conditions. The conditions included a depth jump group from 0.3m (Group 1); a depth jump group from 0.75 m and 1.10 m (Group 2); and a control group which performed vertical jumps only (Group 3). Jump training was performed, twice weekly for 16-weeks (32 sessions total). Results showed significant gains in isometric knee extension ($p<0.001$) at a 125-degree knee angle for all groups, although no significant differences existed between groups were found. Baseline data were not published so is was not possible to calculate percent gains.

Based on the studies by Bauer et al., (1990) and Clutch et al. (1983), it is unlikely that plyometrics is responsible for training-induced isometric strength gains. Data from the hockey players were consistent with the results produced by others in terms of showing that isometric strength gains are not associated with plyometrics training.

Strength Gains for the Control Group but not the Experimental Group

Some long-term studies of plyometrics have shown that strength gains are, as expected, associated with weight training rather than plyometrics training. For example, Hakkinen and Komi (1986) studied 21 experienced, non-competitive weightlifters that were allocated to one of three groups. Two treatment groups were formed: Group 1 performed heavy low body weight training and Group 2 trained using a progressive plyometrics program consisting of a high repetition of various jumps. The treatment groups participated in these programs three times weekly for 24 weeks (72 sessions total). A control group was also formed of experienced weight lifters who carried out their normal physical activities but not the training protocol. Voluntary unilateral isometric knee extension force (90-degree knee angle) was shown to increase for Group 1 (heavy resistance training) which corresponded to a 13.9 % gain at the $p=0.05$ level. A 1.1 % gain in knee strength was reported for Group 2 (plyometrics training) and a 0.6% increase was noted for the control group, however, these gains were not statistically significant. These results show that strength changes were associated with weight training rather than plyometrics training.

Wilson et al. (1993) also found a lack of strength gains as a result of plyometrics training. Sixty-four subjects of unidentified gender were randomly allocated into four groups. The training groups trained two times per week for 10-weeks (20 sessions total) using the following protocol: Group 1 performed traditional weight training using heavy squats, Group 2 performed plyometrics training using progressive depth jump heights (0.2 to 0.8 m), and Group 3 trained at maximal power output on the Plyometric Power

System. A forth group (Group 4), served as the control group. The control group was instructed to maintain their normal daily activities throughout the 10-week period. Isometric squat rack data was collected after 5-weeks of training from subjects performing a squat from a 2.36 rad (135-degree) knee angle. Due to an injury during normal testing procedures, isometric data collection was discontinued at the 5-week mark. Results showed that there was no difference between groups for isometric strength at pre-testing. However, after 5-weeks of training, only the weight-training group significantly increased squat strength ($p>0.05$), which represented a 14.4% increase. Non-significant changes for the other groups after 5-weeks of training include a 0.7% gain for Group 2 (plyometrics group), a 2.0 % increase for Group 3 (maximal power group) and a 2.7 % decrease for Group 4 (control group).

The studies by Hakkinen and Komi (1986) and Wilson et al. (1993) show that strength gains are more likely to result from weight training rather than from plyometrics training. This is further evidence to support that the strength gains recorded from the hockey players were more likely due to strength training combined with normal hockey training rather than from the upper body plyometrics program.

No Strength Gains for the Experimental Group and Control Group

The final evidence indicating that plyometrics is not associated with strength gains is illustrated by researchers who have found no strength improvements from weeks of plyometrics training and no difference between the lack of improvements for the experimental (plyometrics) group and the control (non-plyometrics) group. For example, Paavolainen et al. (1990) investigated the effects of explosive jump training exercises involving roller-skis (Experimental Group; n=7) and the effects of normal sport training (Control Group; n=8) for 15 male cross-country skiers. Both groups trained 6-9 times per week for 6 weeks. Isometric muscle contractions of the leg extensors were collected at the knee and hip angles of 107 and 110-degrees respectively. Results showed a 4.1 % decrease in strength for the experimental group and a 6.0 % decrease in strength for the control group. These changes were not significant ($p>0.05$) for either group.

Another low-limb study by Benn et al. (1998) also found no strength adaptations for both a control group (performing progressively resisted isotonic loads on a Kin-Com) and an experimental group (performing stretch-shorten cycle leg exercises on modified leg press machine). Nine males and 22 females participated in the study and each person served as his or her own control. The control leg was randomly allocated to either the right or left leg. When the maximal voluntary isometric contraction leg data were collected (knee angle 45-degrees), it was found that quadriceps strength decreased by 0.1% for the experimental group and increased by 2.3% for the control group. Further, isometric hamstring strength was shown to increase by 6.7 % for the experimental group and improve 4.7 % for the control group. However, all changes reported for isometric quadriceps and hamstring strength were not significant ($p>0.05$) from pre to post-testing.

The reports by Benn et al. (1998) and Paavolainen et al. (1990) support lack of association between plyometrics training and strength training. Similar to the results produced by Benn et al. (1998) and Paavolainen et al. (1990), the hockey players in the experimental group showed no added benefits from plyometrics training in terms of strength. Based on the studies by Bauer et al. (1990), Benn et al. (1998), Clutch et al.

(1983), Hakkinen and Komi (1986), Paavolainen et al. (1990), and Wilson et al. (1993), it is apparent that plyometrics training is not responsible for strength gains. Therefore, it is unlikely that the strength gains recorded for the hockey players were due to short-term plyometrics training.

Unique Utility of Isometric Strength Data Concerning Plyometrics

Based on the studies above, it evident that isometric strength adaptations are not associated with plyometrics training. This finding is consistent with the aim of plyometrics: to improve the velocity of muscle contraction. However, isometric strength data may have a useful function when studying the effects of a plyometrics training protocol. A unique study by Wilson and Murphy (1996) showed that isometric strength data could be useful to determine which subjects could benefit the most from plyometrics training.

Wilson and Murphy (1996) randomly allocated twenty-four active males into one of two groups: a weight training only group (Group 1; n=12) and a low body plyometrics group (Group 2; n=12). All subjects trained two times per week for 10-weeks and were tested for maximal isometric squat at a knee angle of 2.36 rad (135-degrees). At the end of the study, subjects in each group were classified as either good achievers (produced high power output values) or poor achievers (produced low power output values), after completing a 6-second cycling sprint test. Good achievers in the weight-training group produced low isometric strength values (1750 $\pm$ 279 N) compared to poor achievers (2180 $\pm$ 341 N), a difference that was statistically significant ($p<0.05$). The results were opposite for the plyometrics group: good achievers produced high isometric force values (2320 $\pm$ 296 N) compared to poor achievers (1950 $\pm$ 474 N), a difference that approached statistical significance (p= 0.11). Therefore, the authors concluded that the effectiveness of a type of training (weight training verses plyometrics) could be predicted by collecting initial isometric strength test data. The application of these findings, proposed by the authors, was that subjects with poor cycling performances could be prescribed weight training or plyometrics training to improve neuromuscular performance (power output) depending on initial isometric strength scores, when normative data are eventually compiled.

As indicated by Wilson and Murphy (1996), isometric data may someday serve an important function in the prediction of results for a given plyometrics training protocol. Plyometrics may not directly affect isometric strength measures, however, isometric strength may be used to predict future success in tasks requiring high power output such as hitting, throwing and sprinting tasks in sport. Although more research is necessary, perhaps in the future isometric strength testing can be used as a screening process to determine which athletes would be more likely to show the greatest gains from plyometrics training to improve power output.

Summary

The goal of plyometrics is to train the nervous system to respond with maximal velocity to a pre-stretch. The results from the hockey players support this goal and show that the strength gains experienced by the players were not associated with plyometrics training. A short-term study by Fowler et al. (1995) was consistent with the findings of this study, which showed that short-duration plyometrics training would not improve isometric strength. Moreover, long-term studies by Bauer et al., (1990), Benn et al. (1998), Clutch et al. (1983), Hakkinen and Komi (1986), Paavolainen et al. (1990), and

Wilson et al. (1993) further supported the finding that plyometrics training is not related to isometric strength changes.

RESULTS: THE EFFECTS OF PLYOMETRICS TRAINING ON SLAP SHOT PUCK VELOCITY

Pre-training on-ice velocity data produced by the experimental group (n=5) were compared to the control Group (n=7) using a 1-way ANOVA (Appendix F) to determine if velocity differences existed between groups before the study began or at the end of the study. It was found that no statistical differences existed between groups for pre-test shooting velocity (p=0.928) and post-test shooting velocity (p=0.826). Therefore, none of the groups statistically differed in shooting velocity at the start or end of the study. Shooting velocity comparisons between groups using a 1-way ANOVA are summarized in Table 5.

Table 5. On-Ice Shooting Velocity Differences Between Groups at Pre- and Post-Testing

Mean Pre-Test Velocity (km/h)			Mean Post-Test Velocity (km/h)		
Experimental Group (N=5)	Control Group (N= 7)	P-Value	Experimental Group (N=5)	Control Group (N=7)	P-Value
118 ± 6	119 ± 7	0.928	123 ± 0	122 ± 8	0.826

A 2-Way ANOVA (Appendix G) with repeated measures was used to evaluate velocity changes over the duration of the study. Statistical analysis of pre-test velocity data showed an improvement in shooting velocity ($p=0.013$) over the duration of the study. However, no interaction effect was found between groups ($p=0.624$). Shooting velocity changes over the duration of the study are summarized in Table 6.

Table 6. On-Ice Shooting Velocity Changes from Pre- to Post-Testing for the Experimental and Control Group

Group	Mean Pre-Test Velocity (km/h)	Mean Post-Test Velocity (km/h)	P-Value	Interaction (Group* Test)
Experimental (N=5)	118 ± 6	123 ± 0	0.013*	0.624
Control (N= 7)	119 ± 7	122 ± 8		

* Significant at the $p<0.05$ level.

Based on Figure 6, the experimental group improved 4.2 % on shooting velocity, compared to a 2.5 % improvement for the control group. However, since there was no interaction effect, these changes were not statistically different between groups.

RESULTS: THE EFFECTS OF PLYOMETRICS TRAINING ON STICK VELOCITY

Stick velocity was collected from six subjects (experimental group) in the laboratory and analyzed using a Paired Samples T-Test (Appendix H) to examine if significant changes occurred over the duration of the training program. Results showed a significant increase ($p=0.005$) of 13.0% for stick velocity over the course of training. Stick velocity results are summarized in Table 7.

Table 7. In-Laboratory Stick Velocity Changes from Pre- to Post-Testing for the Experimental Group

Initial Maximal Mean Stick Velocity (km/h) (N=6)	Maximal Stick Velocity Post-Training (km/h) (N=6)	P-value
108 ± 11	122 ± 5	0.005*

* Significant at the $p<0.05$ level.

DISCUSSION

Given the purpose of plyometrics training, researchers have studied the effects of various plyometrics protocols to evaluate the effectiveness of training regimes. Some studies have investigated the effects of short-term plyometrics training and others have studied the consequences of long-term plyometrics training. The shared characteristic of many of these studies is that they have focused on testing the muscle's ability to perform dynamic tasks. Consequently, the following section will investigate the effects of plyometrics training on muscle speed, power, and coordination characteristics.

<u>Short-term Plyometrics Studies and the Effects on Dynamic Performance</u>

A limited number of studies have looked at the effects of a short-term plyometrics training program. Of these studies, none have investigated the effects of a staggered plyometrics training program, whereby subjects trained using plyometrics in a non-consistent manner over the duration of the study. The hockey players used this inconsistent training pattern in this study. However, there have been reports of short-term studies (lasting 4 weeks or less) whereby subjects trained in a consistent manner. For example, Dean et al, (1998) studied the effects of various jumps (countermovement, depth barrier and skip jumps) on 139 adolescents (n=94 males; n=45 females) who participated in a short-term, 4-week training program, twice weekly (8 sessions total). All subjects trained using plyometrics for 15 minutes which included a 3:1 rest work ratio for the jumps, although details of sets and repetitions were not specified. Pre- and post-training data was collected using the following dynamic tests: a 20-yard dash to test velocity and acceleration (n=139; 94 M, 45 F); a hexagon drill to test foot speed, coordination, and dynamic balance (n= 135; 91 M; 44 F); a spider test to test speed and agility (n=134; 91 M, 43); a sideways shuffle drill to test lateral movement and coordination; and a vertical jump to test explosive power generation (n=90; 57 M, 33 F). Post–training results for the girls as a group showed significant ($p<0.05$) improvements in performance for the 20-yard dash (10 % faster), the hexagon drill (18 % faster), the spider drill (2.3 % faster), the sideways shuffle (3.0% quicker) and the vertical jump (2.5% higher). Post–training data for the boys as a group revealed significant ($p<0.05$) improvements in performance for the following: the 20-yard (16 % faster), the hexagon drill (17.4 % faster), the spider drill (2.0 % faster), the sideways shuffle (3.1% quicker) and the vertical jump (3.7% higher). No interaction effects between group (boys and girls) and test occasion (pre- and post-testing) were found for increases. Therefore, the authors concluded that a relatively short training protocol, performed in a consistent manner, could yield small benefits as a result of short-term, consistent, plyometrics training.

Small improvements in dynamic performance was also reported by Fowler et al. (1995), who studied the effects of a short-term, consistent, plyometrics program on two groups of male physical education students who trained four times weekly for three weeks (12 sessions total). The control group trained using low body weights, performing 3-4 sets of 3-12 repetitions in a progressive manner. The experimental group trained combining both low body weight training and low body plyometrics (hops) against a wall using a seated pendulum swing. Pendulum training was performed using 4-6 sets of 4-12 repetitions. Results of dynamic testing showed a 2.6 % increase in countermovement jump height and a 2.6 % gain in countermovement jump power for the control group, although these changes were not statistically significant at the $p=0.05$ level. The experimental group showed a gain of 6.1 % for countermovement jump height and a 10.1 % increase in countermovement jump power. These changes were statistically significant at the $p<0.05$ level for countermovement jump height and at the $p<0.01$ level for countermovement jump power.

More impressive dynamic performance gains were reported by Hutchinson et al. (1998), who studied the effects of a consistent, 4-week plyometrics protocol using 8 adolescent female athletes on the USA Rhythmic Gymnastics National Team. Subjects were divided into one of two groups: an experimental group (n=6) or a control group (n=2). The experimental group participated in various jump exercises that were performed in a pool for 1-hour sessions, twice weekly (8 sessions total). The jump training involved various one-leg and two-leg hops using a high repetition of jumps (>60 jumps per session). The results of the experimental group showed a mean 16.2% gain in jump height ($P<0.207$), a mean 49.8% improvement in floor reaction time ($p<0.002$), and a mean 220.4% increase in explosive power (p-value not reported). No statistical improvements were reported for the control group.

Given the minimal amount of research on the effects of short-term, consistent, plyometrics training, general conclusions concerning the effects of a short-term program are difficult to derive. In general, it appears that short-term, consistently executed plyometrics can stimulate small improvements in dynamic performance as noted by Fowler et al. (1995) and Hutchinson et al. (1998). The hockey players allocated to the experimental group also showed small increases in dynamic shooting performance (a 13.0 % gain in stick velocity and a 4.2 % gain in puck velocity), compared to the 2.5 % increase in puck velocity for the control group. Unfortunately, the changes in puck velocity were not statistically significant.

The data collected from the hockey players in this study suggests that an inconsistent training program may be able to yield similar small gains in dynamic performance (although not identical), compared to a consistent short-term program. It is likely that more than 6 ± 2 sessions are required to generate statistically significant results (ie. for puck velocity), regardless of whether or not the short-term program was performed in a consistent or staggered format. More specifically, studies suggest that more than 8-sessions (Dean et al., 1998; Hutchinson et al., 1998) are required to transfer plyometrics training into statistically significant, small gains in dynamic sport-performance. On a practical note, coaches should be educated to realize that an effective plyometrics training program requires at least 8-sessions of commitment to yield sport-related neural benefits.

Long-term Plyometrics Studies and the Effects on Dynamic Performance

A majority of the research has examined the effects of long-term, consistent plyometrics training on dynamic performance measures. Many long-term studies have been performed using different methodologies and various exercises, and it is clear that plyometrics training can have benefits for dynamic muscle performance in terms of velocity, rate of muscle force generation, power and impulse abilities for the upper and lower body.

Velocity

Some investigations have indirectly studied the effects of plyometrics on the neuromuscular system by examining how quickly subjects can move an object through space after training. Using this technique allows for an indirect analysis of the muscle's ability to contract rapidly. To study the hockey players, indirect analysis using a radar gun was used to examine the neural adaptations among players.

A radar gun is simple test to study changes in velocity. This was the methodology used by McEvoy and Newton (1998) to study the effects of upper body plyometrics program on throwing velocity. For this study, McEvoy and Newton (1998) selected Eighteen National League baseball players from two teams, who were divided into one of two groups. One team (or group) served as a control group and participated in their normal preseason baseball training. The other team served as the experimental group and participated in normal preseason baseball training, as well as plyometrics. The plyometrics training included performing explosive squats and bench throws using a load of 30-50 % of 1-RM, 3-sessions per week, every 2-weeks (15 training sessions total). The experimental group trained using 3 sets of 6-8 repetitions on the Plyometric Power System for the 10-week study. Results showed that the experimental group statistically improved 2.0 $\pm$ 1.5 % from pre to post testing ($p<0.05$) while the control group decreased 0.4 $\pm$ 3.2 %, a non-significant decrease ($p<0.05$).

In a similar study, Cossor et al. (1999) examined 38 young swimmers (mean age 11.7 $\pm$ 1.16 years, gender not specified), who were equally divided into either an experimental group or a control group. The control group participated in 1.5 hours of swim training, three times weekly, for 20 weeks (60 sessions total). The experimental group supplemented 1.25 hours of swim training with 15 minutes of plyometrics training. The experimental group trained using 15 unspecified jump exercises for 2 sets of 10-15 repetitions. A Plyopower System (PPS) was used to test jump height and velocity of the PPS bar. An 8.7 % gain in jump velocity for the PPS bar was reported for the experimental group, a gain that was non-significant ($P>0.05$). For the control group, a 14.9% gain was observed which was also non-significant. The authors also noted that there were no other significant improvements and no differences for the groups in other dependent variables collected regarding swimming, kinetic, or other Plyopower System performance measures. Therefore, the authors concluded that equal benefits could be gained from both dry-land plyometric training and swim training.

The upper body study by McEvoy and Newton (1998) confirms that dynamic performance benefits can be derived from upper body plyometrics training and confirms that training sessions greater than 8 sessions are probably required to stimulate dynamic performance adaptations in the upper body. McEvoy and Newton (1998) also confirmed the effectiveness of using 3 sets of 8 repetitions in a progressive manner, the sets and repetitions used for the experimental group of hockey players. This again supports the argument that perhaps the hockey plyometrics program could have been more effective and statistically significant had the experimental group participated in more training sessions. However, the study by Cossor et al. (1999) showed that even a 60-session training program does not assure success in dynamic performance tests of velocity. Nonetheless, Cossor et al. (1999) was able to show that some benefits could be derived from plyometrics training since subjects who used plyometrics were able to produce swimming, kinetic, or other Plyopower System data that was similar to the group that had more pool training time. In essence, Cossor et al. (1999) showed that plyometrics could be used to substitute for normal pool training without negatively affecting swim performance. Implications from Cossor et al. (1999) suggest that perhaps in the future, plyometrics training could be designed to supplement ice time for hockey players.

Power and Impulse

Power and impulse data is another non-invasive method, used to estimate neural adaptations due to plyometrics. Changes in the ability to contract the muscles rapidly will be apparent in changes in power and impulse. As a result some studies have collected power and impulse data to indirectly study the effects of plyometrics training.

For example, Wagner and Kocak, (1997) studied the effects of plyometrics training on sixty healthy male students (aged 17-18) from a Turkish military school, who were divided into three groups of 20. Group 1 consisted of basketball players from the school who agreed participate in regular basketball training and a plyometrics program. Group 2 was a non-athletic group who participated in plyometrics training only. Group 3 served as a control group and received no training. Plyometrics training lasted twice weekly for 6-weeks (12 sessions total), and was progressive in nature so that subjects performed 2-5 sets of 3-7 reps for a total of 60-80 jumps per session. Subjects were tested using a Margaria-Kalamen Step Test (9-steps; 3 steps at a time) and results showed that the plyometrics groups significantly improved ($p<0.01$) power output by 19.4% and 17.7 % for Group 1 and Group 2, respectively. The control group showed a non-significant gain ($p>0.01$) in power, which corresponded to a 3.2 % rise. The authors showed a significant Group-by-Test interaction effect for all groups at the $p<0.001$ level. This shows that plyometrics can improve power output for both athletes and non-athletes, although athletes typically produce larger power output scores.

Lyttle et al. (1996) also investigated the effects of plyometrics, particularly on the ability to apply force rapidly to an object (impulse). Thirty-three men who participated in recreational athletics, but had not previously performed weight training, were randomly divided into one of three groups. The maximal power-training group (Group 1) performed weighted bench throws using a load that maximized the power output of the exercise. The combined group (Group 2), performed weight training bench press-style throws using a medicine ball. The control group (Group 3) was instructed to maintain their normal daily activities, including normal participation in recreational sports, but no weights or plyometrics training. Training consisted of 2 sessions per week for 8-weeks (16 sessions total) using 1-3 sets of 6-10 repetitions in a progressive manner (for the combined group) and 2-6 sets of 8 repetitions for the maximum power group. Results revealed that Group 1 increased 10.0%, Group 2 increased 24.7%, and Group 3 gained 7.2% on an upper body countermovement push-up test (impulse measured in N*s). Further, upper body gains for the concentric push-up test (impulse measured in N*s) were 22.3% 24.0% and 3.1 % for Group 1, Group 2, and Group 3, respectively. These gains were only significant for the plyometrics groups (Groups 1 and 2) and no interaction effects were found between these groups.

These studies support the concept that plyometrics can train subjects to generate force rapidly. The studies by Wagner and Kocak, (1997) and Lyttle et al. (1996) also suggest that the hockey players, with increased sessions of training, could have increased their hockey slap shots, since they should be able to move their sticks faster. Further, the studies by Wagner and Kocak, (1997) and Lyttle et al. (1996) showed that the sets and repetitions used by the hockey experimental group (1-3 sets for 8-10 repetitions) were in an effective range to stimulate neural adaptations with continued training. These studies further show that 8-12 training sessions would probably have been required to generate statistically significant benefits from plyometrics training.

Although the plyometrics training did not alter the on-ice performance, the in-lab training results suggest that plyometrics may have improved coordination of the ballistic shooting movements, to statistically improve stick velocity by 13%. Past research has shown that plyometrics training can stimulate improvements in coordination, particularly for explosive movements. Consequently, the improved in-lab performances by the hockey players may have been due to better coordination of the upper and lower body limbs as result of plyometrics training.

A study by Brown et al. (1986) supports the concept that plyometrics can improve ballistic actions, coordinated between the upper and lower limbs. Brown et al. (1986) randomly assigned twenty-six male high school basketball players into either a training group or a control group. The training group performed 3 sets of 10 repetitions of depth jumps (0.45m height), three times weekly for 12-weeks (36 sessions total). The control group participated in normal basketball training only. Groups were tested under two conditions: maximal countermovement vertical jumps using an arm swing (Condition 1) and maximal countermovement vertical jumps with arms restricted behind the back (Condition 2). Results showed that the plyometrics group improved vertical jump with arm assistance ($p<0.05$) to a larger magnitude than the control group. Moreover, the authors compared the relative increases in vertical jump in Condition 1 and 2, and found that approximately 57% of the vertical jump increase was due to improved neuromuscular coordination between the upper and lower limbs, and 43% of the gains were due to strength gains, for the plyometrics group. Statistically significant gains were

11.2 ± 10.6 % (arms restricted) and 12.5 ± 7.7% (arms unrestricted) for the plyometrics group and 5.4 ± 6.4% (arms restricted) and 5.9 ± 5.7% (arms unrestricted) for the control group.

Although more research is necessary, plyometrics may be able to improve coordination of ballistic movements between the upper and lower limbs. Improved ballistic coordination may explain the 13.0% improvement in maximal stick velocity recorded by the hockey plyometrics group during laboratory training sessions. In addition, interpretation of the hockey data from this study, and results by Brown et al. (1986), suggest that perhaps initial adaptations from plyometrics training are due to improved ballistic coordination, such as the synchronization of motor units (Behm, 1995). In other words, although the study by Brown et al. (1986) was 36-sessions, the subjects always trained at the same drop height (0.45m height) using the same volume (3 sets of 10 repetitions). Therefore, subjects could have made initial gains in ballistic coordination, similar to the hockey players (in perhaps 6-8 sessions), and then maintained these gains since training was not progressive in intensity to facilitate further neuromuscular adaptations.

In general, long-term training may show added benefits of not only improved coordination, but also improved velocity of muscle contraction. In other words, short-term plyometrics training effect may be mainly due to improved ballistic coordination (improved synchronization of motor units), whereas, long-term improvements may be due to both improved coordination (synchronization) and improved velocity and power output (a faster neural response).

Neural Retention Characteristics of Plyometrics Adaptations: Maintaining Gains Over Time

The results of this study add to the question of the retention of neural improvements. Some studies have suggested that gains attained through plyometrics training, can be retained. For example, Hakkinen and Komi (1986) allocated 29 active males, involved in weight training, into either a control group (n=8), a heavy weight-training group (n=11), or a plyometrics group (n=10). The plyometrics group performed various jumps, totaling 100-200 repetitions per session, three times weekly for 24 weeks (72 sessions total). The 24 weeks of training was followed by a 12-week detraining period. During detraining, the plyometrics group stopped controlled training but maintained normal daily activities. Results of unilateral (right-side) maximal isometric knee extension (knee angle 90 degrees) showed a significant decrease in time to reach a 30 % force level by 10.2 % for the plyometrics group ($p<0.05$). Time to reach a 30% force level for control group and the weight-training group also decreased by 10.4% and 11.4%, respectively; however, these changes were not statistically significant at the $p=0.05$ level. In terms of retaining gains as a result of plyometrics training, the improvements recorded for the plyometrics group were retained at the end of the 12-week detaining period, since no significant decrease ($p<0.05$) in rate of force development was found.

Another study by Hutchinson et al. (1998) showed a retention effect as a result of an intensive 4-week, jump plyometrics protocol (twice weekly) involving female athletes on the USA Rhythmic Gymnastics National Team. Hutchinson et al. (1998) showed that a high repetition leg hopping program resulted in a mean 16.2% gain in jump height ($P<0.207$), a mean 49.8% improvement in floor reaction time ($p<0.002$), and an average 220.4% increase in explosive power (p-value was not reported), compared to no statistical gains reported by the control (non-plyometrics) group. All of the gains reported were maintained after four months and one year after discontinued plyometrics training. These gains, attained through plyometrics training, may have been retainable because the gymnasts continued normal gymnastics training, which still involved jumping practice.

In short, the studies by Hutchinson et al. (1998) and Hakkinen and Komi (1986) suggest that neuromuscular gains, as a result of plyometrics training, may not be rapidly lost after plyometrics is stopped, as long as some sort of sport training continues. Although the hockey players in this study may not have shown statistical increases in on-ice shooting performance due to limited training (mean of 6 ± 2 sessions), another explanation is possible. The lack of statistical gains for on-ice shooting velocity suggests that plyometrics training may not have a retention effect, in terms of velocity and power output, if training has long gaps between sessions. On the other hand, ballistic coordination gains may be retainable between training sessions, as demonstrated by the statistically significant 13 % improvement in stick velocity for the hockey players. This further supports the suggestion that perhaps training-induced neural adaptations occur in two stages: a ballistic neural coordination phase and a velocity-power phase of improvement.

Without a long-term study of the training protocol used for the hockey players, it is difficult to conclude whether the benefits from plyometrics training can be retained from session to session in a staggered protocol or over long periods of detraining.

Summary

In summary, studies have investigated the effects of both short-term and long-term plyometrics training, by tracking changes using indirect techniques. These studies show that 8 sessions or more of plyometrics training, using 1-3 sets and 8-10 repetitions, could improve dynamic muscle performance for velocity, power and impulse measures. Data collected from the university hockey team also suggests that 1-3 sets of 8-10 repetitions might also be able to improve slap shot velocity; however, a long-term hockey study is still required. Data from the hockey players suggests that improved ballistic coordination may be due to the initial sessions of plyometrics training and that to facilitate statistical gains in slap shot velocity, more than 6 $\pm$ 2 sessions are required.

RESULTS: THE RELATIONSHIP BETWEEN ISOMETRIC STRENGTH AND ON-ICE SLAP SHOT VELOCITY

Pearson (2-tailed) correlations (Appendix I) were used to analyze the relationship between isometric strength and on-ice slap shot velocity, for nine subjects pooled from both the control and experimental groups. No significant correlations were found between pre-test shooting velocity and pre-test isometric chest strength ($r=0.496$; $p=0.175$), shoulder strength ($r=0.499$; $p=0.171$), biceps strength ($r=0.083$; $p=0.832$), and triceps strength ($r=0.122$; $p=0.755$). Post-test data also showed no significant correlations between post-test, on-ice shooting velocity and post-test, isometric chest strength ($r=0.539$; $p=0.134$), shoulder strength ($r=0.489$; $p=0.182$), biceps strength ($r=0.206$;

p=0.595), and triceps strength (r=0.622; p=0.074). A summary of the correlation data is shown in Table 8.

Table 8. Correlation Data for Isometric Strength Measures and On-Ice Slap Shot Velocity

Test Condition (N=9)	Correlation (r-value) for Pre-Test Slap Shot Velocity	P-value (Pre-test)	Correlation (r-value) for Post-Test Slap Shot Velocity	P-value (Post-test)
Chest	0.496	0.175	0.539	0.134
Shoulders	0.499	0.171	0.489	0.182
Biceps	0.083	0.832	0.206	0.595
Triceps	0.122	0.755	0.622	0.074

RESULTS: THE RELATIONSHIP BETWEEN ISOMETRIC STRENGTH AND IN-LABORATORY STICK VELOCITY

The relationship between in-laboratory, stick velocity and isometric strength was also analyzed using a Pearson (2-tailed) correlation (Appendix J) for the six subjects tested (experimental group). No significant correlations were found between pre-test stick velocity and pre-test isometric chest strength (r=0.175; p=0.740), shoulder strength (r=0.597; p=0.211), biceps strength (r = - 0.065; p=0.902), and triceps strength (r=0.705; p=0.118). Post-test data also showed no significant correlations between post-test, stick velocity and post-test isometric chest strength (r=0.201; p=0.702), shoulder strength (r=0.451; p=0.369), biceps strength (r=0.246; p=0.638), and triceps strength (r=0.499; p=0.313). A summary of the correlation data is presented in Table 9.

Table 9. Correlation Data for Isometric Strength Measures and In-laboratory Stick Swing Velocity

Isometric Strength (N=6)	Correlation (r-value) for Pre-Test Stick Swing Velocity	P-value (Pre-test)	Correlation (r-value) for Post-Test Stick Swing Velocity	P-value (Post-test)
Chest	0.175	0.740	0.201	0.702
Shoulders	0.597	0.211	0.451	0.369
Biceps	-0.065	0.902	0.246	0.638
Triceps	0.705	0.118	0.499	0.313

RESULTS: THE RELATIONSHIP BETWEEN CHANGES IN STICK VELOCITY AND CHANGES IN PUCK VELOCITY

The relationship between changes in stick velocity (in-laboratory) and the changes in slap shot velocity (on-ice) was analyzed using a Pearson (2-Tailed) correlation (Appendix K) on five subjects (experimental group). Results showed that stick velocity changes in the laboratory were positively correlated with changes in slap shot performance on the ice ($r = 0.977$; $p=0.04$). A summary of these results is presented in Table 10.

Table 10. Correlation Data for Changes in Stick Velocity (In-Laboratory) and Changes in (On-Ice) Puck Velocity

Subject	Pre-Test Stick Velocity (km\h)	Post-Test Stick Velocity (km\h)	Change For Stick (km\h)	Pre-Test Puck Velocity (km\h)	Post-Test Puck Velocity (km\h)	Change For Puck (km\h)	Correlation for Changes in Velocity (r-value)	P-value
1	123.00	126.00	3.00	126.00	123.00	-3.00	0.977	0.004*
2	119.00	130.00	11.00	122.00	123.00	1.00		
3	95.00	118.00	23.00	110.00	123.00	13.00		
4	102.00	121.00	19.00	116.00	123.00	7.00		
5	107.00	123.00	16.00	117.00	123.00	6.00		

* Correlation is significant at the $p<0.01$ level (2-tailed).

DISCUSSION

The relationship between isometric strength and velocity, both stick and puck velocity, is confounding. It would be expected that upper body isometric strength is associated with slap shot puck velocity and stick velocity; however, the strength measures in this study do not confirm this expectation. A possible explanation may be that isometric strength is too static a test to be significantly related to dynamic slap shot performance. Perhaps dynamic strength would be more associated with the ballistic motion of the slap shot. However, many published studies have used isometric strength to evaluate the effects of plyometrics (Bauer et al., 1990; Clutch et al., 1983; Fowler et al., 1995; Hakkinen and Komi, 1986; Wilson et al., 1993), including the effects on ballistic performance (Benn et al., 1998; Paavolainen et al., 1990; Wilson and Murphy, 1996).

Further, of the limited plyometrics studies that have measured strength, none have investigated correlation data between in-laboratory isometric strength and dynamic performance measures. Therefore, although the lack of significant correlation between isometric strength and slap shot velocity was unexpected, it may still accurately reflect the strength changes among competitive university hockey players. The results obtained from this study may not be unusual, however, more correlation studies need to be conducted and more normative data are required, so that the results of this study can be compared.

Some studies have collected data on dynamic strength, to study the effects of plyometrics. Typically, 1-repetition maximum (1-RM) data were collected, although correlations were not performed between dynamic strength and dynamic performance measures (Blakey and Southard, 1987; Clutch et al., 1983; Fowler et al., 1995; Fry et al., 1991; Heinonen et al., 1996; Hetu et al., 1998; Kramer et al., 1993; Lyttle et al., 1996; Polhemus and Burkhardt 1980; Wilson et al., 1996). Similar to the isometric data found for this study, 1-RM data does not consistently improve with effective plyometrics protocols. For example, it may be discovered that plyometrics may improve some performance measures such as vertical jump or running speed, although dynamic (1-RM) strength measures may not improve. Therefore, dynamic strength (1-RM) may not have been correlated with slap shot velocity either.

Similarly, a few studies have tried to evaluate plyometrics protocols by collecting dynamic strength via isokinetic tests (Bauer et al., 1990; Fry et al., 1991; Heiderscheit et al., 1996; Kramer et al., 1993; Wilson and Murphy, 1996 Wilson et al., 1993). However, results are also extremely variable since improvements depend on the speed of the isokinetic test and whether the subjects were tested eccentrically, concentrically, or both. In retrospect, perhaps dynamic strength may have proved to show better correlations to on and off-ice shooting performance, although it may be useful to collect many different isokinetic test measures along with 1-RM data.

In contrast, data showed a strong significant positive correlation ($r=0.977$; $p<0.004$), between changes in the stick velocity (in-laboratory) and changes in puck velocity (on-ice). This data suggests that the changes in the laboratory were related to changes on the ice. However, even though the experimental group showed a 4.2 % increase in puck velocity compared to the 2.5 % increase for the control group, these changes were not statistically significant. Therefore, it appears that the changes in the lab were not large enough to stimulate an interaction effect between group (experimental and control) and testing (pre- and post- testing). Nonetheless, the significant correlation is encouraging and it is necessary to follow up with a long-term study to understand what type of in-laboratory gains would be required to foster on-ice increases for an experimental group. It should also be noted that the data collected on the hockey players was limited to a small number of subjects. Thus, a larger scale study, involving more hockey players, would be useful to compare normative data to this study.

Summary

The lack of a significant relationship between isometric strength and puck velocity, as well as the lack of a relationship between isometric strength and stick velocity, is an unexpected finding for this study. Although many studies have used isometrics to evaluate plyometrics programs, perhaps a dynamic testing such as a 1-RM or isokinetics test would have provided more insight into the changes experienced by the hockey players. Nonetheless, a significant positive relationship was found between changes in puck velocity (on-ice) and changes in stick velocity (in-laboratory). This suggests that increases in stick velocity in the laboratory may translate into increases in puck velocity on the ice, although further study is required to understand exactly what magnitude of in-laboratory improvement is required to translate into on-ice increases in shooting performance.

VALIDITY AND RELIABILITY

To confirm the validity of collected data, all performance measures were compared to published results. Although almost no scientific normative data has been published on hockey players, a study by Roy and Dore (1975) did publish slap shot velocities of undergraduate physical education hockey players and junior level players who were 17 years old or older (n=19). They reported a mean puck velocity of 96.12 km/h. The mean puck velocity for the University of Windsor Men's hockey team was 118 km/h at pre-testing and 122 km/h at post-testing.

Although, no isometric strength data for a university hockey team has been published, Polhemus and Burkhardt (1980) reported a mean 1-RM pre-season bench press of 242.47 pounds (n=34) and 169.39 pounds for shoulder press (n=35) among Texas Tech university football players. This is comparable to the hockey team's mean (pre-test) isometric strength of 242.69 pounds and 185.46 pounds for the chest and shoulder press, respectively. For arm strength, there is lack of normative data involving isometric biceps and triceps strength for contact-sport athletes in the literature. This is not surprising since these muscle groups play a limited functional role in most major sports. Nonetheless, based on past research the puck velocities and isometric strength values appear to be valid for this study.

To confirm the reliability of testing, one subject performed a test-retest of the dependent variables (puck velocity and stick velocity) on subsequent sessions. Moreover, to confirm the reliability of the strength data, pre- and post-test isometric strength data for the pooled groups (n=13) was correlated. The results in Table 11 show that the data collected for this study are reliable for both strength and velocity.

Table 11. Reliability of Isometric Strength and Slap Shot Velocity

Performance Measures	Inter-trial Correlation	P-Value
Stick Velocity	0.904	0.035*
Puck velocity	0.794	0.002*
Isometric Chest Strength	0.898	0.000*
Isometric Shoulder Strength	0.964	0.000*
Isometric Biceps Strength	0.910	0.000*
Isometric Triceps Strength	0.688	0.009*

* Correlations significant at the $p<0.05$ level.

CHAPTER 5

SUMMARY AND CONCLUSIONS

A high velocity slap shot is a valuable skill to score goals for hockey players. As well, at high levels of competitive hockey, the ability to score goals can provide a player with millions of dollars per year in salary. The major goal of any exercise-training program is to reduce weaknesses that may hamper sport performance. If a player is deficient in upper body power, he or she will be a poor shooter, regardless of skill. Therefore, supplementary exercises directed to improve a player's ability to contract the muscles rapidly with maximal force, could improve upper body power. Upper body plyometrics is a training technique whereby an athlete uses light weights to move the limbs with maximal velocity. These exercises are designed to train the neuromuscular system to improve upper body power output and thereby increase slap shot velocity.

The purpose of this study was to investigate the effects of a short-term training program on slap shot velocity of male university hockey players. Twenty-one male university hockey players of the University of Windsor Lancers, volunteered to take part in this study. Seven players were allocated to the experimental group and fourteen players were allocated to the control group. The experimental group participated in a mean of 6 ± 2 sessions of plyometrics training. Subjects in both the control and experimental groups were pre- and post-tested for isometric strength of the chest, shoulders, biceps and triceps, as well as slap shot puck velocity. In addition, the experimental group was pre and post-tested in the laboratory for stick velocity.

This study was a 2 * 2 factorial design with repeated measures on pre- and post-testing. The independent variables were the group factor with two levels (control and experimental) and the time factor with two levels (pre- and post-testing). The dependent variables were puck velocity, stick velocity and isometric strength of the chest, shoulders, biceps and triceps. A 1-Way ANOVA was also used to measure differences between groups on dependent variables. A T-test was used to analyze improvements in stick velocity and Pearson (2-tailed) correlations were used to examine the relationship between strength, puck and stick velocities.

Results of the 2-Way ANOVA reveal that only biceps and triceps strength improved for both groups equally over the course of the study, as did puck velocity. Stick velocity was shown to increase for the experimental group. Correlation data revealed no relationship between either isometric strength and puck velocity, or strength and stick velocity. However, changes in stick velocity were positively correlated to changes in puck velocity. A 1-Way ANOVA revealed no differences between groups at the start or end of the study in terms of any strength or velocity measures.

It should be noted, however, that the results of this study were based on a small number of subjects. A larger number of subjects would increase the power of the statistical procedures, which may alter the statistical significance of the procedures. In essence, statistical results (p-values) that may have been insignificant may become significant with a larger sample size. Furthermore, this study may not have allowed a large enough separation of the independent variable (the two groups), caused by training. This would reflect the fact that that either the plyometrics training program for the experimental group was too short in duration or there were not enough training sessions per week. An increase in either of these two variables would ensure a greater separation of the independent variables (experimental group vs. control group), thereby enhancing the chances of finding statistically significant differences.

CONCLUSIONS

The following conclusions seem valid based on the findings of this study:

1. A short-term upper body plyometrics program (6 ± 2 sessions) has some benefits in terms of improving the ballistic coordination of the upper and lower limbs, although this number of training sessions was not enough to translate into statistically significant differences in slap shot (puck) velocity compared to normal hockey training.
2. Team isometric biceps and triceps strength statistically improved during the in-season period of the men's university hockey team, although chest and shoulder strength did not change.
3. Isometric strength is not related to puck velocity, nor is it related to stick velocity for the slap shot.
4. A positive relationship exists between changes in stick velocity and changes in puck velocity.

RECOMMENDATIONS

The following recommendations might be considered for further study:

1. It is suggested that more normative data be collected on strength changes, both isometric and dynamic, on competitive hockey players during the off-season and in-season
2. It is suggested that slap shot velocity and stick velocity changes be tracked over the off-season and in-season to provide normative data on competitive hockey players
3. It is suggested that the hockey training protocol, outlined in this study, be conducted on a larger group of subjects over a long duration to examine what type of stick velocity improvements are required to translate into increases in on-ice (puck) slap shot velocity.
4. It is suggested that more general research be performed on strength and conditioning aspects for competitive hockey players.

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APPENDICES

Appendix A. One-Way ANOVA Strength Data

Oneway

ANOVA

		Sum of Squares	df	Mean Square	F	Sig.
PRECHEST	Between Groups	931.079	1	931.079	.814	.386
	Within Groups	12581.690	11	1143.790		
	Total	13512.769	12			
POSTCHES	Between Groups	212.969	1	212.969	.162	.695
	Within Groups	14476.262	11	1316.024		
	Total	14689.231	12			
PRESHOUL	Between Groups	750.183	1	750.183	1.018	.335
	Within Groups	8103.048	11	736.641		
	Total	8853.231	12			
POSTSHOU	Between Groups	497.145	1	497.145	.645	.439
	Within Groups	8472.548	11	770.232		
	Total	8969.692	12			
PREBI	Between Groups	97.731	1	97.731	.070	.797
	Within Groups	15435.500	11	1403.227		
	Total	15533.231	12			
POSTBI	Between Groups	329.260	1	329.260	.134	.722
	Within Groups	27101.048	11	2463.732		
	Total	27430.308	12			
PRETRI	Between Groups	387.546	1	387.546	.613	.450
	Within Groups	6948.762	11	631.706		
	Total	7336.308	12			
POSTTRI	Between Groups	2065.648	1	2065.648	3.291	.097
	Within Groups	6903.429	11	627.584		
	Total	8969.077	12			

Appendix B. Two-Way ANOVA Chest Strength Data

General Linear Model

Within-Subjects Factors

Measure: MEASURE_1

STRENGTH	Dependent Variable
1	PRECHEST
2	POSTCHES

Between-Subjects Factors

		N
1=ply, 2=control	1.00	7
	2.00	6

Multivariate Tests[b]

Effect		Value	F	Hypothesis df	Error df	Sig.
STRENGTH	Pillai's Trace	.131	1.665[a]	1.000	11.000	.223
	Wilks' Lambda	.869	1.665[a]	1.000	11.000	.223
	Hotelling's Trace	.151	1.665[a]	1.000	11.000	.223
	Roy's Largest Roc	.151	1.665[a]	1.000	11.000	.223
STRENGTH * GROU	Pillai's Trace	.087	1.052[a]	1.000	11.000	.327
	Wilks' Lambda	.913	1.052[a]	1.000	11.000	.327
	Hotelling's Trace	.096	1.052[a]	1.000	11.000	.327
	Roy's Largest Roc	.096	1.052[a]	1.000	11.000	.327

a. Exact statistic

b.

Design: Intercept+GROUP
Within Subjects Design: STRENGTH

Mauchly's Test of Sphericity[b]

Measure: MEASURE_1

Within Subjects E	Mauchly's W	Approx. Chi-Square	df	Sig.	Epsilon[a]		
					Greenhouse-Geisser	Huynh-Feldt	Lower-bound
STRENGTH	1.000	.000	0	.	1.000	1.000	1.000

Tests the null hypothesis that the error covariance matrix of the orthonormalized transformed dep proportional to an identity matrix.

a. May be used to adjust the degrees of freedom for the averaged tests of significance. Correct Tests of Within-Subjects Effects table.

b.

Design: Intercept+GROUP
Within Subjects Design: STRENGTH

Tests of Within-Subjects Effects

Measure: MEASURE_1

Source		Type III Sum of Squares	df	Mean Square	F	Sig.
STRENGTH	Sphericity Assumed	200.571	1	200.571	1.665	.223
	Greenhouse-Geisser	200.571	1.000	200.571	1.665	.223
	Huynh-Feldt	200.571	1.000	200.571	1.665	.223
	Lower-bound	200.571	1.000	200.571	1.665	.223
STRENGTH * GROI	Sphericity Assumed	126.725	1	126.725	1.052	.327
	Greenhouse-Geisser	126.725	1.000	126.725	1.052	.327
	Huynh-Feldt	126.725	1.000	126.725	1.052	.327
	Lower-bound	126.725	1.000	126.725	1.052	.327
Error(STRENGTH)	Sphericity Assumed	1325.429	11	120.494		
	Greenhouse-Geisser	1325.429	11.000	120.494		
	Huynh-Feldt	1325.429	11.000	120.494		
	Lower-bound	1325.429	11.000	120.494		

Tests of Within-Subjects Contrasts

Measure: MEASURE_1

Source	STRENGTH	Type III Sum of Squares	df	Mean Square	F	Sig.
STRENGTH	Linear	200.571	1	200.571	1.665	.223
STRENGTH * GROU	Linear	126.725	1	126.725	1.052	.327
Error(STRENGTH)	Linear	1325.429	11	120.494		

Tests of Between-Subjects Effects

Measure: MEASURE_1

Transformed Variable: Average

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
Intercept	1495688.092	1	1495688.092	639.369	.000
GROUP	1017.322	1	1017.322	.435	.523
Error	25732.524	11	2339.320		

Appendix C. Two-Way ANOVA Shoulder Strength Data

General Linear Model

Within-Subjects Factors

Measure: MEASURE_1

STRENGTH	Dependent Variable
1	PRESHOUL
2	POSTSHOU

Between-Subjects Factors

		N
1=ply, 2=control	1.00	7
	2.00	6

Multivariate Tests[b]

Effect		Value	F	Hypothesis df	Error df	Sig.
STRENGTH	Pillai's Trace	.050	.574[a]	1.000	11.000	.465
	Wilks' Lambda	.950	.574[a]	1.000	11.000	.465
	Hotelling's Trace	.052	.574[a]	1.000	11.000	.465
	Roy's Largest Roc	.052	.574[a]	1.000	11.000	.465
STRENGTH * GROL	Pillai's Trace	.040	.460[a]	1.000	11.000	.512
	Wilks' Lambda	.960	.460[a]	1.000	11.000	.512
	Hotelling's Trace	.042	.460[a]	1.000	11.000	.512
	Roy's Largest Roc	.042	.460[a]	1.000	11.000	.512

a. Exact statistic

b.

Design: Intercept+GROUP

Within Subjects Design: STRENGTH

Mauchly's Test of Sphericity[b]

Measure: MEASURE_1

					Epsilon[a]		
Within Subjects E	Mauchly's W	Approx. Chi-Square	df	Sig.	Greenhouse-Geisser	Huynh-Feldt	Lower-bound
STRENGTH	1.000	.000	0	.	1.000	1.000	1.000

Tests the null hypothesis that the error covariance matrix of the orthonormalized transformed depend proportional to an identity matrix.

a. May be used to adjust the degrees of freedom for the averaged tests of significance. Corrected t Tests of Within-Subjects Effects table.

b.

Design: Intercept+GROUP

Within Subjects Design: STRENGTH

Tests of Within-Subjects Effects

Measure: MEASURE_1

Source		Type III Sum of Squares	df	Mean Square	F	Sig.
STRENGTH	Sphericity Assume	16.199	1	16.199	.574	.465
	Greenhouse-Geiss	16.199	1.000	16.199	.574	.465
	Huynh-Feldt	16.199	1.000	16.199	.574	.465
	Lower-bound	16.199	1.000	16.199	.574	.465
STRENGTH * GRO	Sphericity Assume	12.968	1	12.968	.460	.512
	Greenhouse-Geiss	12.968	1.000	12.968	.460	.512
	Huynh-Feldt	12.968	1.000	12.968	.460	.512
	Lower-bound	12.968	1.000	12.968	.460	.512
Error(STRENGTH)	Sphericity Assume	310.417	11	28.220		
	Greenhouse-Geiss	310.417	11.000	28.220		
	Huynh-Feldt	310.417	11.000	28.220		
	Lower-bound	310.417	11.000	28.220		

Tests of Within-Subjects Contrasts

Measure: MEASURE_1

Source	STRENGTH	Type III Sum of Squares	df	Mean Square	F	Sig.
STRENGTH	Linear	16.199	1	16.199	.574	.465
STRENGTH * GROUI	Linear	12.968	1	12.968	.460	.512
Error(STRENGTH)	Linear	310.417	11	28.220		

Tests of Between-Subjects Effects

Measure: MEASURE_1

Transformed Variable: Average

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
Intercept	902261.283	1	902261.283	610.192	.000
GROUP	1234.360	1	1234.360	.835	.380
Error	16265.179	11	1478.653		

Appendix D. Two-Way ANOVA Biceps Strength Data

General Linear Model

Within-Subjects Factors

Measure: MEASURE_1

STRENGTH	Dependent Variable
1	PREBI
2	POSTBI

Between-Subjects Factors

		N
1=ply, 2=control	1.00	7
	2.00	6

Multivariate Tests[b]

Effect		Value	F	Hypothesis df	Error df	Sig.
STRENGTH	Pillai's Trace	.318	5.120[a]	1.000	11.000	.045
	Wilks' Lambda	.682	5.120[a]	1.000	11.000	.045
	Hotelling's Trace	.465	5.120[a]	1.000	11.000	.045
	Roy's Largest Ro	.465	5.120[a]	1.000	11.000	.045
STRENGTH * GROU	Pillai's Trace	.013	.141[a]	1.000	11.000	.715
	Wilks' Lambda	.987	.141[a]	1.000	11.000	.715
	Hotelling's Trace	.013	.141[a]	1.000	11.000	.715
	Roy's Largest Ro	.013	.141[a]	1.000	11.000	.715

a. Exact statistic

b.

Design: Intercept+GROUP
Within Subjects Design: STRENGTH

Mauchly's Test of Sphericity[b]

Measure: MEASURE_1

					Epsilon[a]		
Within Subjects E	Mauchly's W	Approx. Chi-Square	df	Sig.	Greenhouse-Geisser	Huynh-Feldt	Lower-bound
STRENGTH	1.000	.000	0	.	1.000	1.000	1.000

Tests the null hypothesis that the error covariance matrix of the orthonormalized transformed deper proportional to an identity matrix.

a. May be used to adjust the degrees of freedom for the averaged tests of significance. Correctec Tests of Within-Subjects Effects table.

b.

Design: Intercept+GROUP
Within Subjects Design: STRENGTH

Tests of Within-Subjects Effects

Measure: MEASURE_1

Source		Type III Sum of Squares	df	Mean Square	F	Sig.
STRENGTH	Sphericity Assume	1242.880	1	1242.880	5.120	.045
	Greenhouse-Geiss	1242.880	1.000	1242.880	5.120	.045
	Huynh-Feldt	1242.880	1.000	1242.880	5.120	.045
	Lower-bound	1242.880	1.000	1242.880	5.120	.045
STRENGTH * GRO	Sphericity Assume	34.111	1	34.111	.141	.715
	Greenhouse-Geiss	34.111	1.000	34.111	.141	.715
	Huynh-Feldt	34.111	1.000	34.111	.141	.715
	Lower-bound	34.111	1.000	34.111	.141	.715
Error(STRENGTH)	Sphericity Assume	2670.274	11	242.752		
	Greenhouse-Geiss	2670.274	11.000	242.752		
	Huynh-Feldt	2670.274	11.000	242.752		
	Lower-bound	2670.274	11.000	242.752		

Tests of Within-Subjects Contrasts

Measure: MEASURE_1

Source	STRENGTH	Type III Sum of Squares	df	Mean Square	F	Sig.
STRENGTH	Linear	1242.880	1	1242.880	5.120	.045
STRENGTH * GROU	Linear	34.111	1	34.111	.141	.715
Error(STRENGTH)	Linear	2670.274	11	242.752		

Tests of Between-Subjects Effects

Measure: MEASURE_1

Transformed Variable: Average

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
Intercept	881570.265	1	881570.265	243.245	.000
GROUP	392.880	1	392.880	.108	.748
Error	39866.274	11	3624.207		

Appendix E. Two-Way ANOVA Triceps Strength Data

General Linear Model

Within-Subjects Factors

Measure: MEASURE_1

STRENGTH	Dependent Variable
1	PRETRI
2	POSTTRI

Between-Subjects Factors

		N
1=ply, 2=control	1.00	7
	2.00	6

Multivariate Tests[b]

Effect		Value	F	Hypothesis df	Error df	Sig.
STRENGTH	Pillai's Trace	.459	9.340[a]	1.000	11.000	.011
	Wilks' Lambda	.541	9.340[a]	1.000	11.000	.011
	Hotelling's Trace	.849	9.340[a]	1.000	11.000	.011
	Roy's Largest Roc	.849	9.340[a]	1.000	11.000	.011
STRENGTH * GROL	Pillai's Trace	.129	1.628[a]	1.000	11.000	.228
	Wilks' Lambda	.871	1.628[a]	1.000	11.000	.228
	Hotelling's Trace	.148	1.628[a]	1.000	11.000	.228
	Roy's Largest Roc	.148	1.628[a]	1.000	11.000	.228

a. Exact statistic

b.

Design: Intercept+GROUP
Within Subjects Design: STRENGTH

Mauchly's Test of Sphericity[b]

Measure: MEASURE_1

					Epsilon[a]		
Within Subjects E	Mauchly's W	Approx. Chi-Square	df	Sig.	Greenhouse-Geisser	Huynh-Feldt	Lower-bound
STRENGTH	1.000	.000	0	.	1.000	1.000	1.000

Tests the null hypothesis that the error covariance matrix of the orthonormalized transformed deper proportional to an identity matrix.

a. May be used to adjust the degrees of freedom for the averaged tests of significance. Correctec Tests of Within-Subjects Effects table.

b.

Design: Intercept+GROUP
Within Subjects Design: STRENGTH

Tests of Within-Subjects Effects

Measure: MEASURE_1

Source		Type III Sum of Squares	df	Mean Square	F	Sig.
STRENGTH	Sphericity Assumed	1904.179	1	1904.179	9.340	.011
	Greenhouse-Geiss	1904.179	1.000	1904.179	9.340	.011
	Huynh-Feldt	1904.179	1.000	1904.179	9.340	.011
	Lower-bound	1904.179	1.000	1904.179	9.340	.011
STRENGTH * GROI	Sphericity Assumed	331.872	1	331.872	1.628	.228
	Greenhouse-Geiss	331.872	1.000	331.872	1.628	.228
	Huynh-Feldt	331.872	1.000	331.872	1.628	.228
	Lower-bound	331.872	1.000	331.872	1.628	.228
Error(STRENGTH)	Sphericity Assumed	2242.667	11	203.879		
	Greenhouse-Geiss	2242.667	11.000	203.879		
	Huynh-Feldt	2242.667	11.000	203.879		
	Lower-bound	2242.667	11.000	203.879		

Tests of Within-Subjects Contrasts

Measure: MEASURE_1

Source	STRENGTH	Type III Sum of Squares	df	Mean Square	F	Sig.
STRENGTH	Linear	1904.179	1	1904.179	9.340	.011
STRENGTH * GROU	Linear	331.872	1	331.872	1.628	.228
Error(STRENGTH)	Linear	2242.667	11	203.879		

Tests of Between-Subjects Effects

Measure: MEASURE_1

Transformed Variable: Average

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
Intercept	415389.015	1	415389.015	393.580	.000
GROUP	2121.322	1	2121.322	2.010	.184
Error	11609.524	11	1055.411		

Appendix F. One-Way ANOVA Data of On-Ice Slap Shot Velocity

Oneway

ANOVA

		Sum of Squares	df	Mean Square	F	Sig.
ICEVEL3	Between Groups	.402	1	.402	.009	.928
	Within Groups	470.514	10	47.051		
	Total	470.917	11			
ICEVEL4	Between Groups	2.917	1	2.917	.051	.826
	Within Groups	572.000	10	57.200		
	Total	574.917	11			

Appendix G. Two-Way ANOVA Data of On-Ice Slap Shot Velocity

General Linear Model

Within-Subjects Factors

Measure: MEASURE_1

VELOCITY	Dependent Variable
1	ICEVEL3
2	ICEVEL4

Between-Subjects Factors

		N
1=ply, 2=control	1.00	5
	2.00	7

Multivariate Tests[b]

Effect		Value	F	Hypothesis df	Error df	Sig.
VELOCITY	Pillai's Trace	.479	9.206[a]	1.000	10.000	.013
	Wilks' Lambda	.521	9.206[a]	1.000	10.000	.013
	Hotelling's Trace	.921	9.206[a]	1.000	10.000	.013
	Roy's Largest Roo	.921	9.206[a]	1.000	10.000	.013
VELOCITY * GROU	Pillai's Trace	.025	.256[a]	1.000	10.000	.624
	Wilks' Lambda	.975	.256[a]	1.000	10.000	.624
	Hotelling's Trace	.026	.256[a]	1.000	10.000	.624
	Roy's Largest Roo	.026	.256[a]	1.000	10.000	.624

a. Exact statistic

b.

Design: Intercept+GROUP
Within Subjects Design: VELOCITY

Mauchly's Test of Sphericity[b]

Measure: MEASURE_1

					Epsilon[a]		
Within Subjects E	Mauchly's W	Approx. Chi-Square	df	Sig.	Greenhouse-Geisser	Huynh-Feldt	Lower-bound
VELOCITY	1.000	.000	0	.	1.000	1.000	1.000

Tests the null hypothesis that the error covariance matrix of the orthonormalized transformed deper proportional to an identity matrix.

a. May be used to adjust the degrees of freedom for the averaged tests of significance. Correctec Tests of Within-Subjects Effects table.

b.

Design: Intercept+GROUP
Within Subjects Design: VELOCITY

Tests of Within-Subjects Effects

Measure: MEASURE_1

Source		Type III Sum of Squares	df	Mean Square	F	Sig.
VELOCITY	Sphericity Assume(	98.743	1	98.743	9.206	.013
	Greenhouse-Geiss(	98.743	1.000	98.743	9.206	.013
	Huynh-Feldt	98.743	1.000	98.743	9.206	.013
	Lower-bound	98.743	1.000	98.743	9.206	.013
VELOCITY * GRO	Sphericity Assume(	2.743	1	2.743	.256	.624
	Greenhouse-Geiss(	2.743	1.000	2.743	.256	.624
	Huynh-Feldt	2.743	1.000	2.743	.256	.624
	Lower-bound	2.743	1.000	2.743	.256	.624
Error(VELOCITY)	Sphericity Assume(	107.257	10	10.726		
	Greenhouse-Geiss(	107.257	10.000	10.726		
	Huynh-Feldt	107.257	10.000	10.726		
	Lower-bound	107.257	10.000	10.726		

Tests of Within-Subjects Contrasts

Measure: MEASURE_1

Source	VELOCITY	Type III Sum of Squares	df	Mean Square	F	Sig.
VELOCITY	Linear	98.743	1	98.743	9.206	.013
VELOCITY * GROUF	Linear	2.743	1	2.743	.256	.624
Error(VELOCITY)	Linear	107.257	10	10.726		

Tests of Between-Subjects Effects

Measure: MEASURE_1

Transformed Variable: Average

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
Intercept	338484.576	1	338484.576	3619.161	.000
GROUP	.576	1	.576	.006	.939
Error	935.257	10	93.526		

Appendix H. Paired T-Test Data of Stick Velocity

T-Test

Paired Samples Statistics

		Mean	N	Std. Deviation	Std. Error Mean
Pair 1	LABVEL1	108.3333	6	10.6521	4.3487
	LABVEL2	122.1667	6	5.4191	2.2123

Paired Samples Correlations

	N	Correlation	Sig.
Pair 1 LABVEL1 & LABVEL2	6	.806	.053

Paired Samples Test

	Paired Differences					t	df	ig. (2-tailed
	Mean	td. Deviatio	Std. Error Mean	95% Confidence Interval of the Difference Lower	Upper			
Pair 1 LABVEL1 - LAB	13.8333	7.0545	2.8800	21.2366	-6.4300	-4.803	5	.005

Appendix I. Correlation Data for Strength and Puck Velocity

Correlations

Correlations

		RECHES	OSTCHE	RESHOU	OSTSHO	PREBI	POSTB	PRETR	OSTTR	EVEL	EVEL
PRECH	Pearson Co	1.000	.898*	.848*	.878*	.756*	.631*	.560*	.739*	.496	.694*
	Sig. (2-tailed	.	.000	.000	.000	.003	.021	.047	.004	.175	.038
	N	13	13	13	13	13	13	13	13	9	9
POSTCI	Pearson Co	.898*	1.000	.684*	.800*	.832*	.703*	.410	.628*	.267	.539
	Sig. (2-tailed	.000	.	.010	.001	.000	.007	.165	.022	.488	.134
	N	13	13	13	13	13	13	13	13	9	9
PRESH	Pearson Co	.848*	.684*	1.000	.964*	.654*	.563*	.616*	.707*	.499	.508
	Sig. (2-tailed	.000	.010	.	.000	.015	.045	.025	.007	.171	.163
	N	13	13	13	13	13	13	13	13	9	9
POSTSI	Pearson Co	.878*	.800*	.964*	1.000	.780*	.702*	.551	.698*	.430	.489
	Sig. (2-tailed	.000	.001	.000	.	.002	.007	.051	.008	.248	.182
	N	13	13	13	13	13	13	13	13	9	9
PREBI	Pearson Co	.756*	.832*	.654*	.780*	1.000	.910*	.535	.674*	.083	.253
	Sig. (2-tailed	.003	.000	.015	.002	.	.000	.060	.011	.832	.511
	N	13	13	13	13	13	13	13	13	9	9
POSTBI	Pearson Co	.631*	.703*	.563*	.702*	.910*	1.000	.401	.608*	.201	.206
	Sig. (2-tailed	.021	.007	.045	.007	.000	.	.174	.028	.605	.595
	N	13	13	13	13	13	13	13	13	9	9
PRETRI	Pearson Co	.560*	.410	.616*	.551	.535	.401	1.000	.688*	.122	.035
	Sig. (2-tailed	.047	.165	.025	.051	.060	.174	.	.009	.755	.929
	N	13	13	13	13	13	13	13	13	9	9
POSTTI	Pearson Co	.739*	.628*	.707*	.698*	.674*	.608*	.688*	1.000	.691*	.622
	Sig. (2-tailed	.004	.022	.007	.008	.011	.028	.009	.	.039	.074
	N	13	13	13	13	13	13	13	13	9	9
ICEVEL	Pearson Co	.496	.267	.499	.430	.083	.201	.122	.691*	1.000	.794*
	Sig. (2-tailed	.175	.488	.171	.248	.832	.605	.755	.039	.	.002
	N	9	9	9	9	9	9	9	9	12	12
ICEVEL	Pearson Co	.694*	.539	.508	.489	.253	.206	.035	.622	.794*	1.000
	Sig. (2-tailed	.038	.134	.163	.182	.511	.595	.929	.074	.002	.
	N	9	9	9	9	9	9	9	9	12	12

**Correlation is significant at the 0.01 level (2-tailed).

*Correlation is significant at the 0.05 level (2-tailed).

Appendix J. Correlation Data for Strength and Stick Velocity

Correlations

Correlations

		PRECHEST	POSTCHES	PRESHOU	POSTSHOU	PREBI	POSTBI	PRETRI	POSTTRI	LABVEL1	LABVEL2
PRECHES	Pearson Correla	1.000	.898**	.848**	.878**	.756**	.631*	.560*	.739**	.175	.437
	Sig. (2-tailed)	.	.000	.000	.000	.003	.021	.047	.004	.740	.386
	N	13	13	13	13	13	13	13	13	6	6
POSTCHE	Pearson Correla	.898**	1.000	.684**	.800**	.832**	.703**	.410	.628*	-.079	.201
	Sig. (2-tailed)	.000	.	.010	.001	.000	.007	.165	.022	.882	.702
	N	13	13	13	13	13	13	13	13	6	6
PRESHOU	Pearson Correla	.848**	.684**	1.000	.964**	.654*	.563*	.616*	.707**	.597	.853*
	Sig. (2-tailed)	.000	.010	.	.000	.015	.045	.025	.007	.211	.031
	N	13	13	13	13	13	13	13	13	6	6
POSTSHO	Pearson Correla	.878**	.800**	.964**	1.000	.780**	.702**	.551	.698**	.275	.451
	Sig. (2-tailed)	.000	.001	.000	.	.002	.007	.051	.008	.598	.369
	N	13	13	13	13	13	13	13	13	6	6
PREBI	Pearson Correla	.756**	.832**	.654*	.780**	1.000	.910**	.535	.674*	-.065	.121
	Sig. (2-tailed)	.003	.000	.015	.002	.	.000	.060	.011	.902	.820
	N	13	13	13	13	13	13	13	13	6	6
POSTBI	Pearson Correla	.631*	.703**	.563*	.702**	.910**	1.000	.401	.608*	.131	.246
	Sig. (2-tailed)	.021	.007	.045	.007	.000	.	.174	.028	.804	.638
	N	13	13	13	13	13	13	13	13	6	6
PRETRI	Pearson Correla	.560*	.410	.616*	.551	.535	.401	1.000	.688**	.705	.663
	Sig. (2-tailed)	.047	.165	.025	.051	.060	.174	.	.009	.118	.151
	N	13	13	13	13	13	13	13	13	6	6
POSTTRI	Pearson Correla	.739**	.628*	.707**	.698**	.674*	.608*	.688**	1.000	.612	.499
	Sig. (2-tailed)	.004	.022	.007	.008	.011	.028	.009	.	.196	.313
	N	13	13	13	13	13	13	13	13	6	6
LABVEL1	Pearson Correla	.175	-.079	.597	.275	-.065	.131	.705	.612	1.000	.806
	Sig. (2-tailed)	.740	.882	.211	.598	.902	.804	.118	.196	.	.053
	N	6	6	6	6	6	6	6	6	6	6
LABVEL2	Pearson Correla	.437	.201	.853*	.451	.121	.246	.663	.499	.806	1.000
	Sig. (2-tailed)	.386	.702	.031	.369	.820	.638	.151	.313	.053	.
	N	6	6	6	6	6	6	6	6	6	6

**. Correlation is significant at the 0.01 level (2-tailed).

*. Correlation is significant at the 0.05 level (2-tailed).

Appendix K. Data for the Correlation Between Stick Velocity Changes and Puck Velocity Changes

Correlations

Correlations

		ICECHG	LABCHG
ICECHG	Pearson Correlation	1.000	.977**
	Sig. (2-tailed)	.	.004
	N	5	5
LABCHG	Pearson Correlation	.977**	1.000
	Sig. (2-tailed)	.004	.
	N	5	5

**. Correlation is significant at the 0.01 level (2-tailed).

Appendix L. Hockey Attendance, Sets and Repetition Raw Data

Subject	Date & Sets:Reps
1	Nov 27 & 1:8 Nov 29 & 2:8 Dec 5 & 2:10 Dec7 & 3:8
2	Nov 29 & 1:8 Dec 5 & 2:8 Jan 30 & 2:10 Feb 8 & 3:8
3	Nov 27 & 1:8 Nov 29 & 2: 8 Dec 7 & 2:8 Jan16 & 2:10 Jan 18 & 2:10 Jan 31 & 3:8 Feb 1 & 3:8 Feb 6 & 3:10
4	Dec 11 & 1:8 Jan 30 & 2:8 Feb 6 & 2:10 Feb 8 & 3:8
5	Nov 28 & 1:8 Dec 4 & 2:8 Jan 8 & 2:10 Jan10 & 2:10 Jan 16 & 3:8 Jan 18 & 3:8 Jan 22 & 3:10 Jan 24 & 3:10
6	Nov 28 & 1:8 Dec 4 & 2:8 Dec 6 & 2:10 Feb 1 & 3: 8 Feb 6 & 3:10 Feb 8 & 3:10
7	Nov 29 & 1:8 Dec 4 & 2:8 Dec 6 & 2:10 Dec 13 & 3:8 Feb 8 & 3:10

Appendix M. Puck Velocity (Km/h) Raw Data

Subject	Pre-Test Velocity	Average Velocity (Pre)	Post-Test Velocity	Average Velocity (Post)
1	127; 125; 126	126	121; 126; 122	123
2	124; 120; 121	122	121:123; 124	123
3	113; 107; 111	110	119; 127; 123	123
4	121; 124; 125	123	124; 125; 123	124
5	115; 120; 114	116	121; 123; 124	123
6	122; 114; 116	117	124; 122; 123	123
7	132; 133; 132	132	141; 142; 142	142
8	111; 111; 111	111	110; 116; 112	113
9	119; 118; 121	119	123; 124; 125	124
10	114; 113; 109	112	118; 115; 111	115
11	122; 117; 117	119	116; 119; 121	119
12	115; 117; 110	114	114; 120; 117	117

Appendix N. Puck Velocity (Km/h) Statistical Data

Means

Case Processing Summary

	Cases					
	Included		Excluded		Total	
	N	Percent	N	Percent	N	Percent
ICEVEL3 * 1=ply, 2=control	12	52.2%	11	47.8%	23	100.0%
ICEVEL4 * 1=ply, 2=control	12	52.2%	11	47.8%	23	100.0%

Report

1=ply, 2=control		ICEVEL3	ICEVEL4
1.00	Mean	118.2000	123.0000
	N	5	5
	Std. Deviation	6.0992	.0000
2.00	Mean	118.5714	122.0000
	N	7	7
	Std. Deviation	7.3225	9.7639
Total	Mean	118.4167	122.4167
	N	12	12
	Std. Deviation	6.5430	7.2295

Appendix O. Stick Velocity (Km/h) Raw Data

Subject	Pre-Test Velocity & Date of Velocity	Average Velocity (Pre)	Post-Test Velocity & Date of Velocity	Average Velocity (Post)
1	118; 124; 128 (Jan 30)	123	123; 125; 129 (Feb 8)	126
2	117; 118; 122 (Jan 16)	119	128; 131; 132 (Jan 31)	130
3	89; 94; 101 (Dec 11)	95	121 (Feb 6); 117; 117 (Feb 8)	118
4	92; 104; 111 (Jan 8)	102	121 (Jan 16); 119; 123 (Jan 22)	121
5	101; 105; 105 (Feb 1)	104	113; 117 (Feb 6) 114 (Feb 8)	115
6	103; 106; 111 (Dec 13)	107	121; 122; 127 (Feb 8)	123

Appendix P. Stick Velocity Statistical Data

Means

Case Processing Summary

	Cases					
	Included		Excluded		Total	
	N	Percent	N	Percent	N	Percent
LABVEL1 * 1=ply, 2=control	6	26.1%	17	73.9%	23	100.0%
LABVEL2 * 1=ply, 2=control	6	26.1%	17	73.9%	23	100.0%

Report

1=ply, 2=control		LABVEL1	LABVEL2
1.00	Mean	108.3333	122.1667
	N	6	6
	Std. Deviation	10.6521	5.4191
Total	Mean	108.3333	122.1667
	N	6	6
	Std. Deviation	10.6521	5.4191

Appendix Q. Isometric Strength Raw Data

	Chest in kg (lbs)		Shoulders in kg (lbs)		Biceps in kg (lbs)		Triceps in kg (lbs)	
Subject	Pre	Post	Pre	Post	Pre	Post	Pre	Post
1	111.8 (246)	118.2 (260)	88.2 (194)	88.6 (195)	79.5 (175)	86.4 (190)	55.9 (123)	59.5 (131)
2	109.1 (240)	98.6 (217)	81.4 (179)	78.2 (172)	68.2 (150)	71.8 (158)	59.5 (131)	63.6 (140)
3	102.7 (226)	99.1 (218)	85.5 (188)	85.0 (187)	75.9 (167)	89.1 (196)	56.4 (124)	58.2 (128)
4	100.5 (221)	96.8 (213)	73.6 (162)	71.4 (157)	70.9 (156)	65.5 (144)	48.2 (106)	46.4 (102)
5	93.2 (205)	85.5 (188)	80.0 (176)	77.7 (171)	66.8 (147)	85.5 (188)	36.8 (81)	57.7 (127)
6	112.3 (247)	111.0 (244)	83.6 (184)	85.9 (189)	73.2 (161)	68.2 (150)	37.3 (82)	40.9 (90)
7	92.3 (203)	91.4 (201)	73.2 (161)	78.2 (172)	71.4 (157)	78.2 (172)	44.1 (97)	51.4 (113)
8	118.6 (261)	128.6 (283)	82.3 (181)	90.0 (198)	117.7 (259)	134.5 (296)	57.3 (126)	70.5 (155)
9	133.6 (294)	132.7 (292)	111.8 (246)	112.3 (247)	104.1 (229)	105.9 (233)	65.9 (145)	81.8 (180)
10	128.2 (282)	120.9 (266)	88.2 (194)	88.2 (194)	82.7 (182)	81.8 (180)	54.5 (120)	80.5 (177)
11	84.1 (185)	87.3 (192)	63.2 (139)	62.7 (138)	59.5 (131)	52.3 (115)	53.6 (118)	51.8 (114)
12	120.5 (265)	122.3 (269)	82.7 (182)	87.7 (193)	83.6 (184)	106.4 (234)	48.2 (106)	59.5 (131)
13	127.3 (280)	110.9 (244)	102.3 (225)	100.0 (220)	95.5 (210)	104.5 (230)	78.2 (172)	72.3 (159)

Appendix R. Isometric Strength Statistical Data

Means

Case Processing Summary

	Cases					
	Included		Excluded		Total	
	N	Percent	N	Percent	N	Percent
PRECHEST * 1=ply, 2=control	13	56.5%	10	43.5%	23	100.0%
POSTCHES * 1=ply, 2=control	13	56.5%	10	43.5%	23	100.0%
PRESHOUL * 1=ply, 2=control	13	56.5%	10	43.5%	23	100.0%
POSTSHOU * 1=ply, 2=control	13	56.5%	10	43.5%	23	100.0%
PREBI * 1=ply, 2=contro	13	56.5%	10	43.5%	23	100.0%
POSTBI * 1=ply, 2=control	13	56.5%	10	43.5%	23	100.0%
PRETRI * 1=ply, 2=control	13	56.5%	10	43.5%	23	100.0%
POSTTRI * 1=ply, 2=control	13	56.5%	10	43.5%	23	100.0%

Report

1=ply, 2=contr		PRECHEST	POSTCHES	PRESHOUL	POSTSHOU	PREBI	POSTBI	PRETRI	POSTTRI
1.00	Mean	234.8571	233.7143	178.4286	181.4286	175.0000	186.5714	112.7143	122.7143
	N	7	7	7	7	7	7	7	7
	Std. Deviatio	19.4373	29.5844	12.5546	14.8420	37.9166	52.0476	18.1633	22.4775
2.00	Mean	251.8333	241.8333	193.6667	193.8333	180.5000	196.6667	123.6667	148.0000
	N	6	6	6	6	6	6	6	6
	Std. Deviatio	45.4199	42.9531	37.8347	37.8175	36.9039	46.5775	31.5257	27.8280
Total	Mean	242.6923	237.4615	185.4615	187.1538	177.5385	191.2308	117.7692	134.3846
	N	13	13	13	13	13	13	13	13
	Std. Deviatio	33.5569	34.9872	27.1619	27.3400	35.9783	47.8107	24.7257	27.3390

Appendix S. Subject Consent Form

I ______________________________ (name of participant – please print) have willingly volunteered to participate in this study. I understand that I will be required to perform sport-specific plyometrics training using a medicine ball and a weighted hockey stick. Furthermore, I understand that my identity and individual results will be kept in confidence and that I can withdraw from the study at anytime, without penalty whatsoever, and without having to give any reasons. I realize that the physical demands of plyometrics training are not much different than my normal training regime and that I will not become harmed in any way due to my participation in this study.

I have had the experimental protocol explained to me and consent to participation.

Signature of Participant: ____

Date: ____

Signature of Researcher: ____

VITA AUCTORIS

Name:	Mitchell Alan Fergenbaum
Date of Birth:	January 27, 1974.
Place of Birth:	Toronto, Ontario, Canada
Education:	Ontario Secondary School Diploma Unionville High School Unionville, Ontario, Canada
	Bachelor of Arts (Honors Kinesiology) University of Western Ontario London, Ontario, Canada
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