

**The Effect of Maximal Strength Training versus Maximal Strength and  
Electrostimulation Training on Lower Body Strength, Sprinting Time, and Skating  
Times**

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# EFFECT OF MAXIMAL STRENGTH TRAINING

## ABSTRACT

The purpose of the study was to compare and contrast the effectiveness of a traditional maximal strength (MS) training protocol with a maximal strength and electrostimulation (MSES) training regimen on lower body strength, sprinting time, and on ice skating times. Fifteen male ( $21.5 \pm 1.5$  years) and 13 female ( $18.5 \pm 3.3$  years) competitive ice hockey players were recruited from Midget AA, Junior B, Senior A, and collegiate teams. Participants were stratified by sex and randomized into two groups prior to completing a crossover training study consisting of two 4-week, 8-session training interventions: MS/MSES and MSES/MS. On and off ice assessment batteries were performed at three time points: Pre, Post 1 (week 4), and Post 2 (week 8). Lower body strength was assessed using vertical jump (VJ; cm), horizontal jump (HJ; cm), and one repetition maximum deadlift (DL; kg) and front squat (FS; kg) measures. Sprinting time was assessed using a 20-m sprint (s) and skating times were assessed using five skating drills measuring two-step acceleration and total times (s). Primary 2 (sequence) x 3 (time; Pre, Post 1, Post 2) repeated measures analyses of variance (RM-ANOVA) were conducted to determine if significant differences existed between training sequences ( $p < .05$ ). Secondary 2 (sequence) x 2 (time; Pre, Post 1) RM-ANOVAs were conducted to determine if significant differences existed between MS and MSES interventions at Post 1. Significant 2 x 3 interactions were revealed for the VJ and stop/start left drill, however no significant differences were evident between sequences at Post 1 or Post 2. Significant main effects of time (groups collapsed) were revealed for the HJ, DL, FS, and combination drill that indicated significant improvement from Pre to Post 2. Significant 2 x 2 interactions were revealed for the VJ, FS, and stop/start right drill, however there

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were no significant differences between sequences at Post 1. Two of the seventeen variables assessed revealed significant differences between training sequences and four were significantly different between MS and MSES at Post 1. Five RM's confirmed that significant improvements were demonstrated in strength over 8 weeks of training, however strength increases did not transfer to improvements in sprint or skating times.

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# EFFECT OF MAXIMAL STRENGTH TRAINING

## ABBREVIATIONS

ES – Electrostimulation

MVC – Maximal voluntary contraction

MS – Maximal strength

RFD – Rate of force development

VRT – Variable resistance training

VJ – Vertical jump

HJ – Horizontal jump

DL – Deadlift

FS – Front squat

MSES – Maximal strength training plus ES training

1RM – One repetition maximum

5RM – Five repetition maximum

RFID – Radio Frequency Identification

RPE – Rating of Perceived Exertion

# EFFECT OF MAXIMAL STRENGTH TRAINING

## INTRODUCTION

The evolution of sport performance has been driven by the development and integration of advanced training regimens. Through research and implementation, the effectiveness of traditional training practices, such as strength training, has been consistently challenged by quantifying physiological responses of different training protocols and comparing and contrasting the outcomes. Novel or alternative training methodologies have been investigated to supplement or augment traditional training regimens and potentially enhance outcomes. Electrostimulation (ES) training was originally developed as a rehabilitation modality to provide a strength and hypertrophy stimulus following injury however, more recently, research investigating the use of ES training to augment traditional training regimens and enhance muscular strength in athletic populations has been conducted with positive outcomes (Flipovic, Kleinoder, Dormann, & Mester, 2012; Maffiuletti, 2010; McBride, Triplett-McBride, Davie, & Newton, 2002).

Studies investigating the effect of combining ES with sport-specific training have been investigated across various sports and results have demonstrated improvements in isolated physiological measures, such as vertical jump height and concentric strength, with accompanying improvements in sport-specific performance measures as summarized by Flipovic, Kleinoder, Dormann, and Mester (2012). Examples include greater upper body strength and decreased swim times in swimmers (Pichon, Chatard, Martin, & Cometti, 1995); greater quadriceps strength, higher vertical jump height, and decreased sprint/agility times in tennis players (Maffiuletti et al., 2009); higher vertical jump height in volleyball players (Maffiuletti, Dugnani, Folz, Di Pierno, & Mauro, 2002); greater quadriceps strength and higher kick velocity in soccer players (Billot,

Martin, Paizis, Cometti, & Babault, 2010); and greater lower body strength, and higher vertical jump and gymnastics-specific jump heights in gymnasts (Deley, Cometti, Fatnassi, Paizis, & Babault, 2011). The research outcomes cited have provided some support for the use of ES to enhance strength, power, and sport-specific measures and support the use of isolated ES training.

Ice hockey is a high intensity and dynamic sport where players must possess significant amounts of full-body strength and power to aid in skating speed, shooting, and puck battles, while maintaining significant aerobic and anaerobic fitness (Twist & Rhodes, 1993). Various predictors of lower body strength have been correlated with faster skating speed, including vertical jump height (Runner, Lehnhard, Butterfield, Tu, & O'Neill, 2015), horizontal jump distance, and off ice sprint times (Farlinger, Kruisselbrink, & Fowles, 2007; Krause et al., 2012). It can therefore be suggested that ES training could augment strength gains and has the potential to enhance on ice skating speed. A study investigating the effects of isolated ES on skating times reported significant increases in isokinetic quadriceps strength of up to 48.9% and significant decreases in 10-m skating time of 4.8% for male professional hockey players following three weeks of training (Brocherie, Babault, Cometti, Maffiuletti, & Chatard, 2005). The results are intriguing yet currently limited to a single study. Further investigation was warranted to investigate whether implementing ES as a novel methodology to augment traditional training practices is more effective for enhancing lower body strength and on ice skating speed than traditional methodologies alone.

Therefore the purpose of the study was to compare and contrast the effectiveness of a traditional maximal strength (MS) training protocol with a maximal strength and

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electrostimulation (MSES) training regimen on lower body strength, sprinting time, and on ice skating times.

## REVIEW OF LITERATURE

### **2.1 Training for Strength Development**

Strength training is a widely practiced form of physical activity undertaken to increase levels of muscular strength, enhance athletic performance across various sports, aid injury prevention and rehabilitation, and alter body composition. Types of strength training include: strength endurance, hypertrophy, maximal strength (MS) and explosive strength (power) (Stone, Stone, & Sands, 2007). MS is often described as the fundamental building block for other expressions of strength and is defined as the peak level of force that can be produced (dynamically or isometrically) in a given movement (Bompa & Haff, 2009; Fleck & Kraemer, 1997; Tan, 1999). To increase levels of MS, the principle of progressive overload is applied throughout a training program in an effort to drive neurological and morphological adaptations over the course of weeks or months (Moritani & deVries, 1979). Neurological adaptations typically occur during the initial weeks of a strength training program where trainees often see rapid increases in MS in the absence of significant hypertrophy (Hakkinen, 1985; Ploutz, Tesch, Biro, & Dudley, 1994). Prolonged exposure to MS training can result in increased cross-sectional area of the targeted muscles, however training specifically for MS is more likely to create neurological, rather than morphological adaptations (McDonagh & Davies, 1984; Tesch, 1987).

The rate of physiological adaptations depends upon numerous individual factors including age, sex, genetics, training background, training loads, and current state of fatigue (Baechle & Earle, 2008). These variables can make it difficult to predict the neurological and morphological changes that a trainee may undergo during a period of MS training and to compare and contrast the outcomes of different training protocols.

Understanding certain strength training program design variables can aid in the development of a training program that will introduce an appropriate stimulus to target the desired physiological adaptations.

### **2.2 Strength Training Program Design Variables**

Desired adaptations to strength training, including increases in muscle mass (hypertrophy), muscular endurance, maximal strength (MS) and power production, can be elicited by manipulating frequency, intensity, and volume within a program. Frequency of training describes the number of training sessions per week within the program and can vary from twice per week for a beginner with a goal of increasing muscular endurance to more than four times per week for an advanced trainee striving to improve power production (Baechle & Earle, 2008). Intensity is typically defined as the magnitude of resistance, or load, that equates to a certain percentage of a trainee's one repetition maximum (1RM) for a given exercise (Bompa & Haff, 2009). As with frequency, intensity can be manipulated to target a specific strength goal. For example, loads of less than 65% of 1RM train muscular endurance, 65-80% of 1RM train hypertrophy and 80-90% of 1RM train maximal strength (Fleck & Kraemer, 1997; Zatsiorsky & Kraemer, 2006). Training volume shares an inverse relationship with intensity where higher training loads are typically associated with lower volumes and vice versa within a traditional linear periodization plan (Stone et al., 1999). Volume can be defined based on different variables and by different frames of reference (i.e. volume per session, per muscle group, per training phase, etc.). For example, Bompa and Haff (2009) recommend expressing volume in kilograms where volume load is equal to sets multiplied by repetitions multiplied by load lifted whereas Fleck and Kraemer (1997)

suggest calculating the total repetitions performed by multiplying the sets and repetitions. Research investigating the effects of manipulating volume on training outcomes has demonstrated training volume is a substantial contributor to muscle hypertrophy and strength (Chestnut & Docherty, 1999; Goto et al., 20014; Klemp et al., 2016) however there is a level of diminishing returns where further increases in volume no longer elicit a beneficial stimulus (Fry, Kraemer, Gordon, et al., 1994; Fry, Kraemer, Van Borselen, et al., 1994). To summarize, the implementation of frequency, intensity, and volume within a training program must be appropriately prescribed to elicit the physiological adaptations necessary for the training goal.

### **2.2.1 Maximal Strength Training Set and Repetition Schemes**

Several studies have attempted to reveal the most effective formula of sets, repetitions and frequency to elicit the greatest increase in MS. The general recommendations for MS training typically fall within the ranges of 3-6 sets at a load of 70-100% of a participant's 1RM (Baechle & Earle, 2008; Bompa & Haff, 2009; Fleck & Kraemer, 1997). For example, early work by Berger (1962) tested different set and repetition templates to determine the arrangement that most effectively enhanced MS in the bench press exercise. Training occurred three times per week over 12 weeks with the variation in programs ranging from 1, 2 and 3 sets each executed with either 2, 6 or 10 repetitions for a total of nine different set and repetition schemes. Participants who completed three sets utilizing a load that allowed them to complete six repetitions had the greatest improvements in 1RM compared to the other groups. Similarly, Campos et al. (2002) divided 32 participants into four groups: low repetition (4 sets of 3-5 repetitions), intermediate repetition (3 sets of 9-11 repetitions), high repetition (2 sets of 20-28



repetitions) and a non-exercising control group. After eight weeks of training (twice per week for the first four weeks and three times per week for the second four weeks), the low repetition group had the greatest gains in 1RM for the three exercises utilized (leg press, squat and knee extension). An interesting meta-analysis performed by Rhea, Brent, Burkett, and Ball (2003) to determine the optimal dose response for strength development found an intensity of 60% of 1RM, frequency of three times per week and four sets per muscle group elicited the greatest MS gains in untrained individuals. Alternatively, an intensity of 80% of 1RM, frequency of twice per week and four sets per muscle group elicited the greatest MS gains in trained individuals. Thus, research is inconclusive in identifying the optimal program prescription in optimizing MS development. The general recommendations for MS training fall within the ranges of 3-6 sets at a load of 70-100% of a participant's 1RM (Bompa & Haff, 2009), typically allowing participants to complete 1-10 repetitions.

### **2.3 Effectiveness of Maximal Strength Training in Untrained Participants Versus Athletes**

The effectiveness of a MS training program is most commonly determined by assessing the change in participants' 1RM pre and post training intervention. Among 13 studies conducted analyzing strength changes following training in the bench press exercise, final improvement ranged from 7 to 44% and averaged 23% in untrained participants (Fleck & Kraemer, 1997). The range of MS improvements decreases when the participants are trained athletes with resistance training experience. Comfort, Haigh, and Matthews (2012) found a 17% increase in squat strength following eight weeks of MS training. Further, Hoffman, Kraemer, Fry, Deschenes, and Kemp (1990) trained

college-level football players in a 10-week strength training study and found only 3-4% improvement in MS. These results are not surprising as it has often been suggested within the literature that beginners progress in strength improvement at a faster rate than advanced trainees due to rapid neurological adaptations and improved proficiency with exercise technique (Hakkinen, 1985; Sale, 1988). Thus, as advanced trainees, athletes may require alternate strategies to further enhance strength levels compared to non-athlete trainees.

### **2.3.1 Maximal Strength and Athletic Performance**

The ability to express high levels of power is a strongly desired quality among athletes as movements within many sports, such as sprinting, throwing, jumping or skating require explosive movements and rapid changes of direction (Haff & Nimphius, 2012; Stone, Moir, Glaister, & Sanders, 2002; Young, 2006). Power is the product of force and velocity, suggesting improvement in either force output or velocity has potential to enhance maximal power output (Fleck & Kraemer, 1997; Haff & Nimphius, 2012). In terms of training type, force output is improved through MS training, whereas velocity is improved through rate of force development (RFD) training (Cormie, McGuigan, & Newton, 2011; Duchateau & Hainaut, 1984).

Much debate exists within the literature about whether power development is most effectively enhanced through MS or RFD training. Some studies exist that suggest a relationship between MS and power output among athletes from various sports. A cross-sectional study performed by Brechue, Mayhew, and Piper (2010) on football players revealed a relationship between higher relative lower body MS and faster acceleration and sprint times. A similar cross-sectional study performed by Carlock et al. (2004)

found lower body power calculated using a vertical jump assessment could accurately predict MS weightlifting ability in national-level weightlifters. Finally, Chelly et al. (2009) used an eight week MS training intervention on male soccer players that resulted in improvement in both MS and power measurements including sprint velocity and squat jump height. Similar to MS training, the effectiveness of RFD training using plyometric exercises to elicit increases in power output among athletes is well established in the literature (Bompa, 1996; Chu, 1983; Lundin, 1985). Therefore, research suggests that MS and RFD training are both effective methodologies for enhancing power development in athletes. However, a periodized annual training plan for athletes typically dedicates more time to strength development during the off season than RFD training. Athletes are commonly prescribed four to eight weeks within the preparatory phase solely for strength development, to lay a foundation for power to be built in later phases (Bompa & Haff, 2009), further suggesting the importance of effective MS training practices.

### **2.4 Advanced Training Practices**

An emphasis on the development of MS has become a common trend among strength and conditioning professionals, leading to the utilization of novel training methodologies, such as variable resistance training (VRT) and ES to supplement or augment traditional MS training with the intent of eliciting enhanced physiological response and adaptation. VRT utilizes heavy elastic bands attached to the barbell and a fixed object to increase the resistance during the ascending phase and decrease the resistance through the descending phase of a repetition (Tobin, 2014). Consequently, load exposure progressively increases through the concentric phase of a repetition, complementing the length tension relationship of the involved muscles and strength curve of the movement. In other words,

resistance is highest when the prime-mover muscles are in a mechanically advantageous position to produce maximal force (Rassier, MacIntosh, & Herzog, 1999). Studies suggest that VRT can be more effective than traditional MS training in enhancing MS (Joy, Lowery, Oliveira de Souza, & Wilson, 2013) and peak power (Joy et al., 2013; Rhea, Kenn, & Dermody, 2009).

### **2.5 Electrostimulation Training**

ES utilizes electrical impulses through multiple surface electrodes to trigger tetanic muscular contractions of the targeted muscle groups. ES has been largely adopted as a research tool to investigate muscular function (Jubeau et al., 2008) and a rehabilitation method to accelerate the return of strength and muscle mass following injury (Snyder-Mackler, Delitto, Stralka, & Bailey, 1994), but has also been applied across the fields of cardiovascular, neurological, geriatric and space medicine (Maffiuletti, 2010).

#### **2.5.1 Muscular Physiology of Electrostimulation Training**

The physiological mechanisms that occur when a muscle undergoes ES have been studied to better understand the increases in strength that have been demonstrated following ES training. Preliminary research performed by Enoka and Trimble (1991) suggested that ES preferentially recruited type II, or fast-twitch, muscle fibers. The authors suggested that the type II fibers were recruited first because they contained more motor units than type I and were therefore more excitable and easily activated. This proposition directly opposed the recruitment order of voluntary (VOL) muscular contractions that obey Hennemen's size principle that states smaller, slower, type I fibers are activated before the faster, larger, type II fibers (Henneman, Somjen, & Carpenter, 1965). The hypothesis put forth by Enoka and Trimble has since been disproven with

several studies demonstrating that ES recruits muscle fibers in a nonselective or random order that is temporally synchronous, and spatially fixed (Adams, Harris, Woodard, & Dudley, 1993; Bickel, Gregory, & Dean, 2011; Binder-Macleod, Halden, & Jungles, 1995; Gregory & Bickel, 2005; Jubeau, Gondin, Martin, Sartorio, & Maffiuletti, 2007). In other words, ES activates muscle fibers based on the proximity of the motor units to the electrodes and will maintain the same activation pattern unless the positions of the electrodes are moved. Thus, the ES muscular activation pattern does differ from VOL, however not by preferentially activating type II fibers. The nonselective recruitment still provides advantages in strength applications in that all fibers, regardless of size, can be activated at relatively low force levels as opposed to VOL contractions that need high levels of force to fatigue the type I fibers before activation of type II fibers can occur.

### **2.5.2 Electrostimulation Training for Strength**

Electrostimulation training has been commonly used as a rehabilitation tool to assist in the return to baseline strength levels following significant injury or surgery (Snyder-Mackler et al., 1994). Studies investigating the effectiveness of ES in enhancing MS in healthy populations have demonstrated positive results in increasing isometric, concentric, and eccentric strength 10-40% from pre-training levels of the targeted muscle groups (Doucet, Lam, & Griffin, 2012; McBride et al., 2002; Vanderthommen & Duchateau, 2007). Despite promising outcomes, drawbacks of ES training have been illustrated including increased muscular damage compared to VOL contractions (Jubeau et al., 2008; Nosaka, Aldayel, Jubeau, & Chen, 2011) and higher levels of neuromuscular fatigue (Doucet et al., 2012). Comparisons of strength training between VOL contractions and involuntary contractions via ES have often revealed similar outcomes (Zhou,

Oakman, & Davies, 2002), however some studies have displayed an advantage for VOL contractions (Hortobagyi, Scott, Lambert, Hamilton, & Tracy, 1999). The effectiveness of combining VOL and ES training compared to isolated VOL training and isolated ES training has not been shown to offer an advantage in increasing strength (Nobbs & Rhodes, 1986), however the studies conducted VOL and ES training in similar manners (i.e. both utilized isometric contractions of the quadriceps), meaning there was likely not enough variation in the training stimulus to avoid diminishing returns on strength. Currently, there are no studies that investigate the combination of isometric ES training with dynamic VOL training that implement dynamic muscular contractions similar to those commonly used in MS training.

### **2.5.3 Electrostimulation Training in Athletes**

Research dating back to the 1970s has investigated the efficacy and effectiveness of ES as a tool to increase strength in elite athletes (Ward & Shkuratova, 2002). The results of combining ES with sport-specific training has resulted in improved sport-specific performance across a multitude of sports with various physiological demands. Such examples include decreases in 25 and 50-m swimming times in competitive swimmers (Pichon et al., 1995), faster shuttle run times in national level tennis players (Maffiuletti et al., 2009), increases in squat, spike, and countermovement jump heights in volleyball players (Maffiuletti et al., 2002), increases in kick velocity in soccer players (Billot et al., 2010), and increases in gymnastic-specific jumps in young gymnasts (Deley et al., 2011). The necessity of strength and power production for successful performance is a common link across these sports, suggesting the ability of ES to enhance MS development could be the driving force behind its effectiveness in improving sport-specific performance.

## 2.6 Strength Demands of Ice Hockey

Ice hockey is a physically demanding contact sport that requires players to possess various physiological capabilities in order to compete. The intermittent bursts of high intensity skating and physical play throughout a game challenge a player's cardiovascular fitness, strength, and power, while simultaneously requiring rapid displays of motor skill and reaction ability (Twist & Rhodes, 1993). Current off season training practices of hockey players place considerable emphasis on lower body strength development (W.P. Ebben, Carroll, & Simenz, 2004) due to the substantial demand on the musculature of the lower body, most notably the quadriceps and hamstring muscle groups during skating (de Boer et al., 1987).

Surprisingly, previous studies attempting to identify the relationship between absolute and relative leg strength and skating speed have been inconclusive. Behm, Wahl, Button, Power, and Anderson (2005) found a correlation and Potteiger, Smith, Maier, and Foster (2010) found no correlation. However, Behm et al. (2005) measured skating speed using a "flying start," meaning initial acceleration was unaccounted for. Considerable literature correlates maximal lower body squat strength with running acceleration and sprint times in athletes (McBride et al., 2009; Wisloff, Castagna, Helgerud, Jones, & Hoff, 2004), suggesting Behm et al. (2005) may have found a correlation if on ice acceleration was measured. Interestingly, Gilenstam, Thorsen, and Henriksson-Larse (2011) found a correlation between relative leg strength and skating speed in females, but not males. The findings of Potteiger et al. (2010) and Gilenstam et al. (2011) are surprising as maximal isokinetic knee extensor torque has been highly correlated with sprint speed in athletes (Dowson, Nevill, Lakomy, Nevill, & Hazeldine, 1998) and sprint

speed has been correlated with on ice skating speed (Behm et al., 2005; Farlinger et al., 2007; Krause et al., 2012).

### **2.6.1 Current Hockey Training Practices**

Research on training practices of hockey players often focuses on enhancing a single physiological quality through a specific training protocol (i.e. anaerobic fitness through high intensity interval training or RFD through plyometric training). Because of the relationships between lower body strength and skating speed as well as MS and sprinting, some researchers have designed training programs to enhance these qualities with the intention of transferring improvement to faster on ice skating speeds. For example, a few studies have examined the effects of RFD training through plyometric protocols on skating speed. Lockwood and Brophy (2004) found a 4-week plyometric intervention decreased 40-m skating sprint time in junior hockey players. In an 8-week crossover intervention comparing skating specific and regular plyometric exercises, Farlinger and Fowles (2008) found improvement in 35-m skating sprint times in both groups. Reymont, Bonis, Lundquist, and Tice (2006) used a 4-week plyometric training intervention on collegiate hockey players and found higher single leg vertical jump heights and improved anaerobic power scores, although improvement in skating speed was not assessed. Finally, Fergenbaum (2001) examined the effects of a short-term upper body plyometric training on upper body isometric strength, slap shot velocity, and stick velocity in male collegiate hockey players. Improvement was found in slap shot and stick velocity.

There has been less research investigating the effects of MS training and the effects on ice skating speed. A study performed by Greer, Serfass, Picconatto, and Blatherwick (1992) utilized a 7-week resistance training and on ice skating speed training



intervention on bantam-age hockey players. The training group significantly decreased on ice acceleration, maximal speed, and cornering skating times and significantly increased vertical jump height compared with no improvements in the control group. Thus positive effects of isolated plyometric and MS training on skating speed are suggested by these studies however the training prescription for a hockey player requires an appropriate balance of several physiological qualities periodized within an annual training plan. A survey of National Hockey League (NHL) strength and conditioning coaches revealed 91% follow a periodized model that includes the programming of plyometrics and sprint work to train speed, Olympic lifting variations to train strength and power, and core and flexibility work to maintain muscular balance (Ebben et al., 2004), illustrating that training a hockey player requires a holistic approach. Although NHL strength coaches typically follow a periodized model, the training of youth hockey players in the industry often falls short of encompassing all the physiological qualities needed to excel on the ice with narrow focuses on one aspect of training (i.e. strength, speed, etc.).

### **2.6.2 Electrostimulation Training in Hockey**

Electrostimulation (ES) training has been shown to improve scores in several physiological assessments including isometric, concentric, and eccentric muscular strength, squat jump, countermovement jump and sprint time in athletes (Flipovic et al., 2012). Research has revealed that higher levels of lower body strength and power, including quadriceps strength, squat jump and off ice sprint times are correlated with improved skating speed (Behm et al., 2005; Farlinger et al., 2007), meaning ES training may strongly translate to on ice performance. In addition, hockey demands high levels of fitness from the aerobic and anaerobic systems, taxing both slow-twitch (type I) and fast-

twitch (type II) muscle fibers (Green, 1978). It is widely accepted that ES activates both slow- and fast-twitch muscle fibers at low force levels (Jubeau et al., 2007), further suggesting ES training would address the physiological needs of hockey players. Brocherie et al. (2005) found three weeks of ES training significantly increased isokinetic quadriceps strength and significantly decreased 10-m skating sprint time in male professional hockey players. The results suggest ES may be a potentially effective training tool for hockey players, although research is currently limited to a single study and warrants further investigation.

## 2.7 Purpose

The purpose of the study was to compare and contrast the effectiveness of a traditional maximal strength (MS) training protocol with a maximal strength and electrostimulation (MSES) training regimen on lower body strength, sprinting time, and on ice skating times. Effectiveness was defined as a significant improvement in off ice lower body strength, a sprinting time, and on ice skating time measures.

The first null hypothesis states that there were no significant differences in off ice lower body strength, sprinting time, and on ice skating times (SSS) between training sequences (MS/MSES, MSES/MS).

$$H_1 = SSS_{BASELINE} = SSS_{MS/MSES} = SSS_{MSES/MS}$$

The second null hypothesis states there was no significant difference in off ice lower body strength, sprinting time, and on ice skating times (SSS) between MS training and MSES training at Post 1.

$$H_2 = SSS_{BASELINE} = SSS_{MS} = SSS_{MSES}$$

## 2.8 Significance of the Study

The study has the potential to advance current knowledge and the application of effective training practices for developing lower body strength and enhancing both off ice sprinting and on ice skating times in ice hockey players. Outcomes may also contribute to our knowledge in implementing alternate training regimens with athletes, namely utilizing ES in combination with MS, compared to traditional MS training.

### **2.9 Limitations**

- a) All off and on ice assessments were maximal effort tests; participants may not have been motivated to exert their maximal effort if they did not appreciate the benefit of the study.
- b) The study took place in season meaning volume of on ice activities was higher than during the off season when MS training would typically be performed. This could potentially have created more overall training volume than the participants could recover and adapt from.
- c) Other activities with the exception of additional lower body strength training were not controlled during the study. Some participants were engaging in other physical activity (i.e. high school sports, university intramurals, etc.) that could have potentially affected assessment performance and adaptation to training.

## METHODOLOGY

## 3.1 Study Design

A crossover design was implemented consisting of two 4-week training blocks, each including 8 sessions, scheduled twice a week. Male and female participants were randomly assigned to one of the two sequences: MS training followed by MS with ES training (MS/MSES) or MS with ES training followed by MS training (MSES/MS) (Figure 1). A battery consisting of lower body strength measures, off ice sprinting time, and on ice skating times were scheduled at baseline (Pre) and at the end of each 4-week, 8-session training block (Post 1 and Post 2).

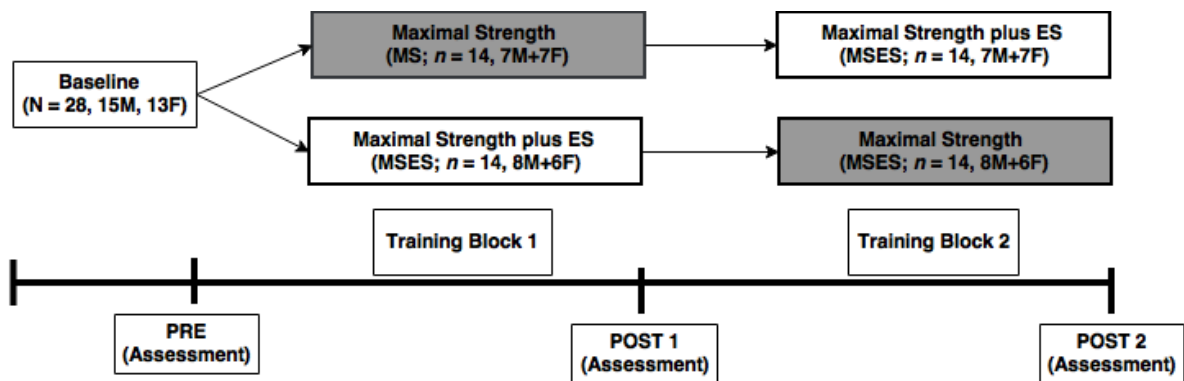


Figure 1. Participants were randomly assigned and completed two 8-session training interventions in opposite order (MS/MSES or MSES/MS).

## 3.2 Participants

Fifteen male and 13 female competitive hockey players completed the study. Inclusion criteria required players to be playing Midget AA, Junior B, Senior A, or collegiate level and have a minimum of one year of strength training experience with a certified trainer. Participants were playing the positions of forward, defense, or goalie and were injury free at the beginning of the study. Participants completed a participant profile questionnaire detailing playing and training history (Appendix A) and a Physical

Activity Readiness Questionnaire (Appendix B) prior to the commencement of the study. All participants provided informed consent and participants under the age of 18 required parental consent to participate (Appendix C). Height (cm) and body mass (kg) were measured prior to the initial off ice assessment session (Table 1). The study received ethical clearance from the Brock University Research Ethics Board (File # 15-029).

### **3.3 Assessment Protocols**

*Off Ice Assessments:* The order of the protocols and assessments used remained consistent across the three assessment sessions (Pre, Post 1, and Post 2) and were guided by the researcher. The off ice assessment battery consisted of a standardized warm up including 5 minutes of cycling with light tension and 5 minutes of dynamic stretching. Four lower body strength assessments and a single off ice sprint assessment were performed in the following order: vertical jump, horizontal jump, 20-m sprint, one repetition maximum (1RM) deadlift, and 1RM front squat.

- I. Vertical jump (VJ) height was measured using a Vertec<sup>TM</sup> device (Sports Imports, Columbus, Ohio) following the protocol outlined by Johnson and Nelson (1986). Participants were given three attempts with 3 minutes rest between each attempt. The highest jump (cm) was recorded. To calculate the VJ height, standing reach height was subtracted from the highest jump height.
- II. Horizontal jump (HJ) was measured using a measuring tape secured to the training centre floor following the protocol outlined by Johnson and Nelson (1986). Participants were given three attempts with 3 minutes rest between each attempt. The longest HJ (cm) was recorded by measuring the distance from the start line to their closest heel.

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- III. The 20-m sprint was timed using an Alge™ timing light system (Alge-Timing, Lustenau, Austria). Participants were positioned at the start line and instructed to run as fast as possible to the 20-m end line. They were given two trials with 3 minutes rest between trials and the fastest time (s) was recorded.
- IV. One repetition maximum (1RM) strength assessments were conducted for two purposes: (i) to quantify lower body strength and (ii) to determine training loads. One RM assessments were performed on two lifts, deadlift and front squat using the protocol outlined by Baechle and Earle (2008).

Verbal encouragement was provided for the participants during all assessments to promote maximal effort. Adequate rest was provided between each assessment. The off ice assessment battery took approximately 60 minutes to complete.

*On Ice Assessments:* The order of the assessments and protocols used remained consistent across the three assessment sessions (Pre, Post 1, and Post 2) and were guided by the researcher. All drills were performed with full equipment, with sticks, and without pucks while skating on skates sharpened to their individual preference for game-like conditions. Participants were fitted with a small wireless device known as a Radio Frequency Identification (RFID) tag to individually identify each participant with their respective skating times. A 10-minute standardized warm up was completed including a 5-minute free skate where the players were permitted to skate as desired and a 5-minute skate guided by the researcher consisting of a 75% of maximal effort forward sprint, stops and starts, quick turns, backwards skate and a maximal effort forward sprint. Five on ice drills representing skating skills commonly used in game play were performed: forward linear speed, backwards linear speed, stop/start (left and right), and a

combination drill (Appendix D). The forward linear speed drill was repeated in order to assess the reliability of the recorded skating times. A Swift™ timing light system was used to measure first interval time or what is referred to as two-step acceleration (IT; s) and total time to complete the drill to measure overall skating time (TT; s). If a participant fell or did not complete a drill, he/she was given adequate rest and repeated the drill. Verbal encouragement was provided to players during all drills to promote maximal effort. Adequate rest was provided between each drill. The on ice assessment battery took approximately 60 minutes to complete.

### **3.4 Training Protocols**

Participants were assigned to one of the two training sequences: MS/MSES or MSES/MS. Participants completed two 4-week training blocks, each consisting of 8 sessions, scheduled twice a week. Training sessions were approximately 40 and 60 minutes for MS and MSES respectively. A minimum of 48 hours rest was scheduled between sessions to allow adequate recovery before the next session.

*Maximal Strength Training:* All MS sessions included three lower body exercises: a deadlift variation, a front squat variation, and a unilateral exercise (Appendix E). These exercises were selected to include a hip-dominant pattern (deadlift) and a knee-dominant pattern (front squat). Further, a unilateral exercise was included due to the single-leg demands of the skating stride. Participants performed 3 sets of 5-6 repetitions at an intensity of 75-85% of the participants' 1RM with 2 minutes of rest between sets, as recommended by Stone et al. (2007). Progressive overload was implemented by increasing intensity (training loads) according to the 2-for-2 rule where the athlete increased the load 2.5kg if he/she successfully performed two or more repetitions over

the repetition goal for a given exercise during two consecutive sessions (Baechle & Earle, 2008). Total volume of each MS training block was calculated using the formula, volume = sets x repetitions x exercises x sessions (Fleck & Kraemer, 1997), resulting in 384 repetitions for the lower body. Therefore, throughout each training block, MS volume remained constant whereas intensity was overloaded by increasing training loads (Figure 2 and 3).

*Maximal Strength and Electrostimulation Training:* All MSES sessions included the MS protocol outlined above plus ES training for the quadriceps muscle group. A Compex Mi-Sport device (MediCompex SA, Ecublens, Switzerland) was used to administer the ES. All participant preparation for ES training was conducted and supervised by the researcher. One familiarization session was scheduled prior to the first MSES session to teach participants how to control the ES intensity, locate the motor points of the targeted muscles, and provide an initial ES stimulus to the quadriceps by undergoing 15 ES contractions. Participants were seated in a chair with their backs supported, feet flat on the floor, and knees flexed at 90 degrees. They were positioned with their toes against a fixed box to ensure no movement of the lower limb occurred during stimulation. For the familiarization ES session only, a probe and Compex's Motor Point program was utilized to locate the motor points of the vastus medialis and vastus lateralis muscles. All participants were given their own set of electrodes for the duration of the study. Replacements were provided if an electrode became damaged, lost or worn. Areas where the electrodes were to be placed on the skin were sanitized and dry shaved to allow for clean contact between the skin and adhesive electrode. Two small electrodes (5x5-cm, one snap connection) were placed on the quadriceps, 10-cm distal from the inguinal



crease and two negative lead wires were snapped to the electrodes. Two small electrodes were placed over each motor point and two positive lead wires were connected. The quadriceps were stimulated isometrically using the following parameters: pulse width (380 $\mu$ s), frequency (104Hz), duty cycle (3 second contraction with 0.75 second ramp up and 0.5 second ramp down with 28 seconds between contractions), and number of contractions per session (30). These parameters were determined by the pre-set Complex Explosive Strength I program and held constant throughout the study. Intensity was controlled by participants who were encouraged to approach the maximal tolerable level to ensure the stimulus elicited a training effect (Snyder-Mackler et al., 1994). Total volume of ES in each MSES training block was calculated using the formula, volume = contractions x sessions, resulting in 240 contractions of the quadriceps. Therefore, within each MSES training block, volume remained constant whereas intensity was overloaded by increasing the stimulation level of the ES (Figure 2 and 3).

### **3.5 Training Logs**

Participants were required to complete a training log for the duration of the study (Appendix F). Logging consisted of tracking sessions and recording the load (kg) and repetitions completed for each exercise to assist in tracking progression and ensuring the application of appropriate overload. Rating of Perceived Exertion (RPE) on a scale of 1 to 10 for all sessions was also self-reported (Borg, 1998). Participants were required to complete all 16 sessions. If a participant missed a session they made it up within 48 hours of the original scheduled session.

### **3.6 Statistical Analysis**

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Data were analyzed using the Statistical Package for the Social Sciences (SPSS) software, version 22 (IBM, Chicago, IL). Descriptive statistics, including mean and standard deviation, were calculated for all participant characteristics (age, years; height, cm; body mass, kg; hockey experience, years; training experience, years) and assessment scores. For participant characteristics and assessment scores, two-sided t-tests were performed comparing the two sequence groups to determine whether the groups were balanced at Pre. The Fisher's Exact test (two-sided) was performed to compare the frequency of each gender between the two sequences at baseline.

Primary 2 (sequence; MS/MSES, MSES/MS) x 3 (time; Pre, Post 1, Post 2) repeated measures analyses of variance (RM-ANOVA) were conducted to determine whether there were significant 2 x 3 interactions for off and on ice assessment scores. If significant 2 x 3 interactions were revealed for any of the assessment scores, Bonferroni post-hoc analyses were performed to determine where the significant differences were located. If significant 2 x 3 interactions were not revealed, the main effects collapsed across group were analyzed to determine if significant effects of time were present. For all analyses, an alpha level was set at  $p < 0.05$ .

Secondary 2 (sequence; MS/MSES, MSES/MS) x 2 (time; Pre, Post 1) RM-ANOVAs were conducted to determine if significant differences in off and on ice assessment scores existed between MS and MSES interventions after Training Block 1. If significant 2 x 2 interactions were revealed, follow up Bonferroni post-hoc analyses were performed to determine where the significant differences were located. If significant 2 x 2 interactions were not revealed, the main effects collapsed across group were analyzed to determine if significant effects of time were present.

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A RM-ANOVA was conducted separately for each sequence (MS/MSES, MSES/MS) across the 3 time points (Pre, Post 1, Post 2) to determine the within group differences between Training Block 1 and 2 for five repetition maximum (5RM) training loads. This analysis was performed to confirm maximal strength adaptations were occurring throughout the 8-weeks of training. Training loads as a percent of Pre 1RM at Pre, Post 1, and Post 2 were calculated by sex to determine if training load magnitudes were increased similarly between male and female participants. Rating of Perceived Exertion scores for each training intervention (MS and ES) were summarized using mean and standard deviation. Each possible numerical score was reported as a percentage frequency of total possible scores to confirm exertion and effort levels were adequate during training.

## RESULTS

**4.1 Descriptive Statistics**

Thirty players were initially recruited to participate. Two players did not complete the study due to hockey-related injuries and scheduling conflicts, resulting in 28 participants who completed the required 16 training sessions. (males,  $n = 15$ ; females,  $n = 13$ ).

Descriptive statistics (mean  $\pm$  SD) for all variables were completed. Comparisons of sex, age (years), height (m), body mass (kg), playing experience (years), and training experience (years) between the two sequences (MS/MSES and MSES/MS) are illustrated in Table 1. Two-sided t-tests revealed no significant differences in participant characteristics, off ice or on ice assessment scores between the groups at Pre (Table 2 and 3).

**4.2 Effect of Training Sequence****4.2.1 Lower Body Strength Assessments**

Mean and SD values by sequence are illustrated in Table 2. The VJ (cm) showed a statistically significant 2 (sequence; MS/MSES, MSES/MS)  $\times$  3 (time; Pre, Post 1, Post 2) interaction ( $p=0.004$ ). Follow up Bonferroni post-hoc analysis of VJ height scores revealed no significant difference between groups at Post 1 ( $p=0.792$ ) or Post 2 ( $p=0.219$ ). Mean differences in VJ height by group are reported in Table 4. Significant increases in VJ heights were revealed from Post 1 to Post 2 ( $p=0.000$ ; 3.60cm) and Pre to Post 2 ( $p=0.001$ ; 4.64cm) for the MS/MSES group and Pre to Post 1 ( $p=0.001$ ; 5.31cm) and Pre to Post 2 ( $p=0.001$ ; 5.77cm) for the MSES/MS group.

The HJ, DL, and FS showed no 2  $\times$  3 interaction, however significant main effects for time were revealed (Table 5). Follow up Bonferroni post-hoc analysis revealed that all

subjects (collapsed across group) showed significant improvement in HJ and DL from Pre to Post 1 ( $p=0.000$ ;  $p=0.000$ ), Post 1 to Post 2 ( $p=0.003$ ;  $p=0.002$ ) and Pre to Post 2 ( $p=0.000$ ;  $p=0.000$ ). In addition, all subjects (collapsed across group) showed significant improvement in FS from Pre to Post 1 ( $p=0.000$ ) and Pre to Post 2 ( $p=0.043$ ) and no significant change from Post 1 to Post 2 ( $p=1.000$ ).

#### 4.2.2 Off Ice Sprint and On Ice Skating Assessments

A Pearson's product moment correlation revealed a strong positive correlation for interval time (IT;  $r = 1.00$ ;  $p = 0.000$ ) and total time (TT;  $r = 0.99$ ;  $p = 0.000$ ) between the two forward sprint drills for the on ice assessments. This analysis was conducted to support the reliability of the test measure.

Mean and SD values by sequence are illustrated in Table 3. The stop/start left (SSL) TT showed statistically significant 2 (sequence; MS/MSES, MSES/MS) x 3 (time; Pre, Post 1, Post 2) interaction ( $p=0.021$ ). Follow up Bonferroni post-hoc analysis of SSL TT revealed no significant difference between groups at Post 1 ( $p=0.070$ ) or Post 2 ( $p=0.698$ ). The mean differences and in SSL TT by group are reported for each time point in Table 4. A significant decrease in SSL TT was revealed from Pre to Post 2 for the MSES/MS group ( $p=0.047$ ;  $-0.159$ s). Although statistically significant, the 0.159s difference is likely negligible in the context of game play and would not make a measureable difference in player on ice performance.

The 20-m sprint and combination drill IT and TT showed no 2 x 3 interaction, however significant main effects for time were revealed (Table 5 and 6). Follow up Bonferroni post-hoc analysis revealed that all subjects (collapsed across group) showed significant increases in 20-m sprint time from Pre to Post 1 ( $p=0.008$ ), Post 1 to Post 2

( $p=0.001$ ), and Pre to Post 2 ( $p=0.000$ ). Further significant main effects for time revealed significant decreases in skating time for both the combination drill IT and TT from Pre to Post 1 ( $p=0.000$ ;  $p=0.002$ ) and Pre to Post 2 ( $p=0.000$ ;  $p=0.000$ ) and no significant change from Post 1 to Post 2 ( $p=0.134$ ;  $p=0.134$ ).

### **4.3 Effect of MS versus MSES for Training Block 1**

#### **4.3.1 Lower Body Strength Assessments**

A 2 (sequence; MS/MSES, MSES/MS) x 2 (time; Pre, Post 1) RM-ANOVA was used to determine the effect of MS training versus MSES training at Post 1. The VJ (cm) and FS (kg) showed a statistically significant 2 x 2 interaction from Pre to Post 1 ( $p=0.005$ ;  $p=0.019$ )(Table 2). Follow up Bonferroni post-hoc analysis revealed no significant differences between MS and MSES groups at Post 1 for VJ ( $p=0.792$ ) or FS ( $p=0.739$ ). A significant increase in VJ was revealed from Pre to Post 1 for the MSES only ( $p=0.001$ ; 5.31cm). Significant increases in FS were revealed from Pre to Post 1 for the MS group ( $p=0.002$ ; 3.85kg) and the MSES group ( $p=0.000$ ; 8.59kg)(Table 4).

#### **4.3.2 Off Ice Sprint and On Ice Skating Assessments**

The stop/start right (SSR) TT drill showed a statistically significant 2 x 2 interaction from Pre to Post 1 ( $p=0.032$ )(Table 3). Follow up Bonferroni post-hoc analysis revealed no significant differences between MS and MSES groups at Post 1 for SSR TT ( $p=0.073$ ). A significant decrease in SSR TT was revealed from Pre to Post 1 for the MS group only ( $p=0.022$ ; -0.085s)(Table 4).

### **4.4 Within Group Training Load Analysis by Sequence**

A RM-ANOVA for each sequence using all time points (Pre, Post 1, and Post 2) was used to determine within group differences for five repetition maximum (5RM)

training loads to confirm maximal strength adaptations were occurring throughout the 8-weeks of training. Within group analysis of the DL (kg) and FS (kg) 5RM training loads showed significant differences at all time points for both sequences (Table 7). A comparison of training load progression as a comparison to Pre 1RM loads indicated female participants increased their 5RM training loads in the deadlift and front squat to a greater magnitude than male participants at Post 1 and Post 2 (Table 8).

### **4.5 Rating of Perceived Exertion (RPE) Scores**

The RPE percent frequencies are illustrated in Table 9. Mean RPE scores were  $8.0 \pm 1.2$  and  $8.2 \pm 1.3$  following MS and ES training respectively, suggesting participants perceived similar levels of exertion during both training interventions.

## DISCUSSION

Optimizing athletic performance relies heavily on the ability to prescribe and implement training methodologies that elicit the desired physiological adaptations with the intention of translating conditioning to sport performance. Although traditional maximal strength (MS) training protocols have been shown to be effective in athletes participating in various sports (Chelly et al., 2009; Comfort et al., 2012; Hoffman et al., 1990) and could potentially contribute to the development of a hockey player (Behm et al., 2005; Greer et al., 1992), sport science research investigating alternative training methods, such as electrostimulation (ES) training are still somewhat inconclusive. The purpose of the study was to compare and contrast the effectiveness of a traditional maximal strength (MS) training protocol with a maximal strength and electrostimulation (MSES) training regimen on lower body strength, sprinting time, and on ice skating times. Effectiveness was defined as a significant improvement in off ice lower body strength, sprinting time, and on ice skating time measures.

Male (n = 15) and female (n = 13) competitive hockey players playing at Midget AA, Junior B, Senior A, and collegiate levels were assigned to one of two training sequences, MS/MSES or MSES/MS and completed a total of 16 training sessions. The number of males and females were balanced in each group and although there was no statistical difference in subject characteristics at Pre, the range of age (years), body mass (kg), playing experience (years), and training experience (years) within each group was disparate. The female participants were younger and had fewer years of training experience compared to the more experienced male participants and as a result increased their deadlift (DL; kg) and front squat (FS; kg) training loads as a percentage of their Pre one repetition maximum (1RM) more than male participants at Post 1 and Post 2 (Table



8). A greater difference in improvement was more apparent at Post 1 for females (DL, 11.8%; FS, 16.6%) versus males (DL, 4.7%; FS, 4.9%) likely due to rapid neurological gains that beginner trainees experience compared to advanced trainees (Hakkinen, 1985; Sale, 1988). The difference in magnitude of improvement was still evident from Post 1 to Post 2, however was less pronounced between females (DL, 6.0%; FS, 9.6%) and males (DL, 5.2%; FS, 4.9%). The variation within the group may have influenced the response or adaptation to training stimuli by participants of different strength levels and training experience. For example, there is evidence to suggest that novice athletes with less training experience tend to gain strength at a more rapid rate than those with advanced training experience (Comfort et al., 2012; Fleck & Kraemer, 1997; Hakkinen, 1985; Sale, 1988).

The primary 2 (sequence) x 3 (time) repeated measures analyses of variance (RM-ANOVAs) revealed that only 2 (vertical jump, VJ, cm; stop/start left total time; SSL TT, s) of 17 assessment measures revealed significant interaction effects. Neither VJ nor SSL TT was significantly different at Post 2 between sequences suggesting that both groups responded to 8 weeks of training in a similar manner. Analysis of the main effects collapsed across groups illustrated a significant improvement in VJ, horizontal jump (HJ; cm), DL and FS; further suggesting that both groups improved similarly over 8 weeks of training regardless of the training sequence (MS/MSES or MSES/MS). Studies investigating the effect of MS training have demonstrated that rapid neurological adaptations tend to occur in the initial weeks of MS training eliciting faster strength improvements than later MS training phases (Borst et al., 2001; Fleck & Kraemer, 1997; Hakkinen, 1985). Within the current study, a progressive overload stimulus was applied

by increasing the intensity (training loads) between 13% and 17% over 8 weeks for the front squat and deadlift exercises. When comparing MS/MSES and MSES/MS, within group analysis of the 5RM training loads indicated that both groups significantly improved DL and FS at Post 1 and Post 2 suggesting that the overload was sufficient to elicit a strength response over the 8 weeks of training. Participants were significantly stronger following each training block regardless of training sequence (Table 5).

Total training volume was calculated for both sequences (MS volume = sets x repetitions x # of exercises x # of sessions; ES volume = 30 contractions/session x # of sessions). The intervention combining MS and ES training resulted in a higher training volume than MS training only (384 and 624 and 384 repetitions respectively) (Figure 2 and 3). Consequently, it may have been expected that the MSES/MS sequence may have elicited a greater response from Pre to Post 1 and MS/MSES from Post 1 to Post 2 due to training volume alone. However rapid gains in strength were seen in both groups in the initial 4 weeks. In the second 4 weeks of training, when the MS/MSES group was introduced to the ES and a subsequent increase in training volume, there were no differences in outcome measures. Therefore, the sequence of training, or MS/MSES versus MSES/MS, and subsequent fluctuations in training volume over 8 weeks did not yield significantly different outcomes suggesting that training sequence did not contribute to the effectiveness of the prescribed training.

A secondary analysis [2 (sequence) x 2 (time) RM-ANOVAs] was conducted in order to directly compare the effectiveness of MS to MSES. Significant interactions were revealed for the VJ and FS. Both MS and MSES groups significantly improved from Pre to Post 1 for the FS however only the MSES group significantly improved in VJ.

Improved FS and VJ corresponds with previous research by Bruchue et al. (2010), Carlock et al. (2004), and Peterson, Alvar, and Rhea (2006) associating higher MS levels in the squat exercise with higher VJ heights in athletes. When comparing the magnitude of improvement from Pre to Post 1 between groups, the group undergoing MSES training appeared to improve at a greater magnitude for the VJ (5.3cm versus 1.3cm) and FS (8.59kg versus 3.85kg). As discussed earlier, the group undergoing MSES training performed a greater training volume than the MS group in the first training block, and this may have contributed to the greater magnitude of improvement. Literature reviewing the dose-response of volume necessary to optimize MS adaptations indicates 3-5 sets per exercise for a total of 12-18 sets per training session are effective (Rhea, Alvar, & Burkett, 2002; Rhea et al., 2003). In the current study, participants performed 3 sets of 5 repetitions for a total of 15 sets per training session. There is some literature to support greater magnitudes of strength improvement for participants performing 4 or 5 sets compared to 3, although diminishing returns also exist with additional volume (Rhea et al., 2002; Rhea et al., 2003). Thus, the participants in the MSES group may have benefited from the additional training volume in the first training block that would have made the volume comparable to a 4 or 5 set training protocol.

The biomechanical demands of the strength assessments may have contributed to the lack of a significant interaction between MS and MSES groups in the HJ and DL. The biomechanics of the VJ and FS include similar joint angles that require greater knee flexion and less hip flexion (Vanezis & Lees, 2005; Yavuz, Erdag, Amca, & Aritan, 2015) than the HJ (Wu, Wu, Lin, & Wang, 2003) and DL (Escamilla et al., 2000). The result is a quadriceps-dominant muscular activation pattern emerging from the greater

knee flexion and less hip flexion during the VJ (Vanezis & Lees, 2005) and FS (Escamilla et al., 2001; Luera, Stock, & Chappell, 2014; Schaub & Worrell, 1995). Alternatively, a hamstrings-dominant muscular activation pattern emerges due to the greater hip flexion and less knee flexion during the HJ (Wu et al., 2003) and DL (Ebben, 2009; Escamilla et al., 2000; Wright, Delong, & Gehlsen, 199). The difference in quadriceps versus hamstrings-dominance during the assessments is important for two reasons and may provide possible explanations for the lack of significant findings in the HJ and DL and greater magnitude of improvement in VJ and FS following MSES versus MS. First, the ES was applied to only the quadriceps muscle group, meaning the quadriceps were the only muscle group receiving an additional training stimulus. Second, the ES was applied while the participant was in a seated position that would more closely represent the mechanical position of the participant during the initiation of the concentric phase of the VJ and FS. Therefore, due to the quadriceps stimulation and position of the participant during ES, the quadriceps-dominant VJ and FS may have been more specific to the training stimulus resulting in significant improvement following MSES over MS compared to the more hamstrings-dominant HJ and DL assessments.

The lack of significant improvement in the off ice 20-m sprint and most on ice skating measures are contrary to previous studies suggesting that ES training may have potential to enhance sport specific speed. Research implementing isolated ES training have demonstrated faster shuttle run times in national level tennis players (Maffiuletti et al., 2009) and faster 10-m skating times in professional hockey players (Brocherie et al., 2005) following ES training using similar equipment and stimulation parameters as the current study. The two skating drills that did reveal significant improvements were the

stop/start and combination drills that require the execution of more than one skating skill when compared to the forward and backward linear speed drills. Improvement in only these drills may suggest that participants decreased skating times by performing the skating skills, such as stopping and turning, within the drill more efficiently. Thus within the current study, it does not appear the strength adaptations elicited from MS or MSES training contributed to changes in skating performance.

Unlike the earlier comparison of the VJ and FS to the HJ and DL, the lack of improvement in time measures cannot be explained through biomechanical differences in the current study. The DL (Escamilla et al., 2000) and 20-m sprint (Mero, Komi, & Gregor, 1992) are both hip-dominant movements that require higher activation of hamstring musculature, whereas the FS (Escamilla et al., 2001; Luera et al., 2014; Schaub & Worrell, 1995) and skating stride (de Boer et al., 1987) are both knee-dominant movements that require higher activation of quadriceps musculature. Thus, despite improving strength performance in the DL and FS, improved performance in sprinting and on ice skating was not seen even though there were similarities in biomechanical patterns. A further explanation for the lack of improvement in sprinting and skating measures could be the differences in velocity of movement between the training exercises and the time-based assessments. Since the training targeted development of MS, the loads utilized ranged between 75-85% of the participants' 1 repetition maximum (1RM) and resulted in high levels of force produced that were executed at a low velocity. Further, the ES training portion of the MSES training utilized isometric contractions that differ greatly from the explosive concentric actions of the muscles during sprinting (Mero et al., 1992) and skating (de Koning, de Boer, de Groot, & van Ingen Schenau, 1987).

Consequently, the velocity of training movements may have been too slow to have specific transfer to off ice sprinting and skating. Previous studies implementing 4-8 weeks of MS training to improve sprinting and rate of force development (RFD) in athletes have also shown mixed results and little translation to improved sprint times post intervention (Chelly et al., 2009; Hoffman et al., 1990; Ronnestad, Kvamme, Sunde, & Raastad, 2008). Despite studies correlating MS to time-based measures (Brechue et al., 2010; Carlock et al., 2004; Cronin & Hansen, 2005), some authors have proposed that although MS training is fundamental for an athlete due to the relationship between strength and power, for transference to sport performance similar training velocities need to be utilized to that of the specific sport (Cormie et al., 2011; Siff, 2000; Stone et al., 2002; Young, 2006).

The results of the current study provide further understanding and have practical implications regarding strength development and the need for training to be velocity- and biomechanically-specific for training adaptations to transfer to sport activities. Since the two sequences of training, MS/MSES and MSES/MS, revealed little difference in on and off ice variables over the 8-week study, a strength and conditioning practitioner utilizing a combination of MS and MSES training during a MS training block could implement either sequence potentially without any variation in effectiveness. Further, the greater magnitudes of improvement displayed in VJ and FS following MSES compared to MS may suggest the combination of MS training with ES training applied to the quadriceps muscles following training may be more likely to affect movements that are quadriceps-dominant versus hamstrings-dominant. Since the hamstrings are a main driver in horizontal force production (Morin et al., 2015), the application of MSES training on the

quadriceps to sport-specific movements may be very limited since most require horizontally-directed movement such as sprinting (Morin et al., 2015) and changing directions (Brughelli, Cronin, Levin, & Chaouachi, 2008) in athletes. Further, the low velocity of the high force MS training and lack of movement during the isometric ES training did not transfer to the high velocity sprint and skating assessments suggesting the velocity of movements in training also need to be specific to those attempting to be improved.

The largest limitation within the current study would be the heterogeneous nature of the full sample with male and female participants. In an effort to mitigate the heterogeneous strength levels and training experiences at baseline, male and female participants were stratified into each sequence (MS/MSES, MSES/MS) to balance for sex and then randomly distributed. Randomization was performed to even out all other confounding variables at baseline and resulted in no significant differences between the two sequence groups at baseline (Table 1). Thus, the stratification and randomization process was able to possibly mitigate some variation caused by the confounding variables (sex, age, height, body mass, playing experience, and training experience), creating two similar groups at baseline. However, despite two homogeneous sequence groups, the variation in individuals within a sequence may have potentially affected the ability to compare the outcomes to the training interventions. Furthermore, a wash out period would have allowed participants to be reassessed for strength levels prior to Training Block 2, meaning each participant would have had pre and post measurements for MS and MSES training. This would have strengthened the design however a long washout period of 4-8 weeks may have been needed to return participants to baseline strength

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levels (Hakkinen & Komi, 1983; Mujika & Padilla, 2000) and was not feasible due to scheduling logistics and participant commitment. Finally, the lack of an ES only training group limited the ability to differentiate the effectiveness of MS only, ES, only and MSES. Two limitations existed within the assessments: (i) sensitivity of measurement equipment and (ii) utilization of maximal effort assessments. The equipment used for some of the off ice assessments lacked the sensitivity of laboratory-grade equipment. For example, a Vertec<sup>TM</sup> was used to measure VJ and is only capable of measuring 1/2” increments. Although laboratory-grade equipment would have improved the accuracy of the assessment outcomes, it was not feasible to use in the current study and may not be accessible to many strength and conditioning practitioners. Since changes in performance off and on the ice were being assessed, participants were required to exert their maximal effort. Although it was ensured participants understood this concept and verbal encouragement was provided, if full effort was not given it may have had a detrimental effect on the result of an assessment. Similar concerns could be applied to training sessions where players needed to attempt greater loads each week to see strength improvements. To mitigate this issue, participants were asked to record their Rating of Perceived Exertion (RPE) following each MS and ES training session to monitor exertion levels and ensure adequate effort (Table 9). The final limitation was the execution of the study during the participants’ competitive season. Participants were practicing and playing games 3 to 6 times per week in addition to the MS or MSES training sessions. This amount of cumulative training volume may have been too great for some players to fully recover between sessions, meaning there would not have been the adaptation to the training stimulus required to produce improvements in off and on ice performance.



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Overall, the results of the current study produced very few significant interaction results compared to significant main effects suggesting that participants improved in strength over 8 weeks of training. Despite improvements in strength assessments, participants did not improve sprinting or skating times meaning increasing MS in athletes who previously have strength training experience is unlikely to contribute to improved high-velocity activities and sport performance. Thus, practitioners must consider an athlete's training background and implement appropriate periodization strategies that utilize a power phase following a MS phase to harness the improved strength and have it transfer to sport performance.

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## TABLES

Table 1:

*Participant Descriptive Statistics by Sequence*

	MS/MSES (N=14) Mean (SD)	MSES/MS (N=14) Mean (SD)	<i>p</i> -value
Sex, n (%):			
Male	8 (57.1)	7 (50.0)	1.000
Female	6 (42.9)	7 (50.0)	
Age (yrs)	20.7 (2.3)	19.6 (3.3)	1.000
Height (m)	1.76 (0.14)	1.75 (0.13)	0.300
Body Mass (kg)	80.2 (14.6)	70.0 (17.4)	0.889
Hockey Experience (yrs)	15.4 (2.5)	14.4 (3.9)	0.350
Training Experience (yrs)	4.3 (1.9)	4.4 (3.0)	0.396

Note. Sex *p*-value is from a Fisher's Exact test, all other *p*-values are from a 2-sided *t*-test.



Table 2:

*2 (Sequence) x 3 (Time) and 2 (Sequence) x 2 (Time) RM-ANOVA Off Ice Results*

	Pre Mean (SD)	Post 1 Mean (SD)	Post 2 Mean (SD)	<i>p</i> -value (Baseline)	<i>p</i> -value (3 x 2 Interaction)	<i>p</i> -value (2 x 2 Interaction)
20-m Sprint (s):						
MS/MSES	3.12 (0.25)	3.19 (0.25)	3.41 (0.31)	0.147	0.482	0.772
MSES/MS	3.26 (0.25)	3.35 (0.31)	3.49 (0.23)			
Vertical Jump (cm):						
MS/MSES	51.8 (10.5)	53.0 (10.3)	57.31 (11.3)	0.209	0.004	0.005
MSES/MS	46.9 (9.8)	52.2 (6.9)	52.6 (8.2)			
Horizontal Jump (cm):						
MS/MSES	219.5 (35.7)	224.9 (37.6)	230.4 (37.8)	0.919	0.127	0.138
MSES/MS	220.8 (30.0)	228.9 (29.2)	230.1 (28.6)			
Deadlift (kg):						
MS/MSES	118.6 (37.0)	129.6 (35.5)	133.8 (36.1)	0.931	0.738	0.776

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MSES/MS	117.2 (44.2)	127.4 (41.1)	130.0 (40.6)			
Front Squat (kg):						
MS/MSES	92.1 (32.5)	96.6 (32.6)	101.4 (32.1)	0.491	0.357	0.019
MSES/MS	84.1 (28.7)	90.6 (37.7)	92.7 (28.2)			

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Table 3:

2 (Sequence) x 3 (Time) and 2 (Sequence) x 2 (Time) RM-ANOVA On Ice Results

	Pre	Post 1	Post 2	<i>p</i> -value (Baseline)	<i>p</i> -value (3 x 2 Interaction)	<i>p</i> -value (2 x 2 Interaction)
Forward Sprint 1 IT (s):						
MS/MSES	0.673 (0.108)	0.693 (0.089)	0.755 (0.086)	0.489	0.629	0.678
MSES/MS	0.708 (0.154)	0.751 (0.092)	0.769 (0.086)			
Forward Sprint 1 TT (s):						
MS/MSES	4.892 (0.262)	4.917 (0.246)	4.988 (0.254)	0.114	0.159	0.662
MSES/MS	5.115 (0.436)	5.122 (0.430)	5.126 (0.581)			
Forward Sprint 2 IT (s):						
MS/MSES	0.640 (0.098)	0.730 (0.069)	0.729 (0.095)	0.618	0.883	0.748
MSES/MS	0.664 (0.148)	0.740 (0.097)	0.759 (0.106)			
Forward Sprint 2 TT (s):						
MS/MSES	4.858 (0.294)	4.918 (0.239)	4.937 (0.245)	0.138	0.831	0.849
MSES/MS	5.068 (0.418)	5.137 (0.449)	5.129 (0.471)			

## EFFECT OF MAXIMAL STRENGTH TRAINING

## Backward Sprint IT (s):

MS/MSES	0.901 (0.107)	0.948 (0.114)	0.928 (0.135)			
MSES/MS	0.938 (0.152)	0.903 (0.112)	0.922 (0.105)	0.461	0.268	0.083

## Backward Sprint TT (s):

MS/MSES	6.089 (0.345)	6.182 (0.345)	6.178 (0.401)			
MSES/MS	6.298 (0.591)	6.286 (0.585)	6.318 (0.659)	0.265	0.470	0.221

## Stop/Start Left IT (s):

MS/MSES	0.745 (0.098)	0.735 (0.067)	0.793 (0.068)			
MSES/MS	0.770 (0.073)	0.763 (0.119)	0.792 (0.068)	0.450	0.905	0.839

## Stop/Start Left TT (s):

MS/MSES	5.570 (0.291)	5.553 (0.325)	5.598 (0.323)			
MSES/MS	5.830 (0.521)	5.809 (0.439)	5.671 (0.611)	0.118	0.021	0.827

## Stop/Start Right IT (s):

MS/MSES	0.737 (0.099)	0.743 (0.082)	0.775 (0.067)	0.591	0.999	0.994
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EFFECT OF MAXIMAL STRENGTH TRAINING

MSES/MS	0.756 (0.092)	0.763 (0.119)	0.792 (0.068)			
Stop/Start Right TT (s):						
MS/MSES	5.603 (0.289)	5.519 (0.287)	5.610 (0.351)			
MSES/MS	5.759 (0.432)	5.817 (0.525)	5.715 (0.673)	0.274	0.084	0.032
Combination Drill IT (s):						
MS/MSES	2.023 (0.111)	1.916 (0.124)	1.846 (0.097)			
MSES/MS	2.039 (0.184)	1.942 (0.132)	1.940 (0.142)	0.787	0.083	0.763
Combination Drill TT (s):						
MS/MSES	20.189 (1.389)	19.853 (1.183)	19.687 (1.297)			
MSES/MS	21.172 (2.393)	20.843 (2.121)	20.319 (2.805)	0.195	0.306	0.968

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Table 4:

*Within Group (MS/MSES; MSES/MS) Results and Mean Differences*

	Pre to Post 1		Post 1 to Post 2		Pre to Post 2	
	Mean		Mean		Mean	
	<i>p</i> -value	Difference	<i>p</i> -value	Difference	<i>p</i> -value	Difference
Vertical Jump (cm):						
MS/MSES	0.323	1.25	0.000	3.60	0.001	4.64
MSES/MS	0.001	5.31	1.000	0.45	0.001	5.77
Front Squat (kg):						
MS/MSES	0.002	3.85	-	-	-	-
MSES/MS	0.000	8.59	-	-	-	-
Stop/Start Left TT (s):						
MS/MSES	1.000	-0.038	0.414	0.066	0.899	0.028
MSES/MS	1.000	-0.022	0.357	-0.138	0.047	-0.159
Stop/Start Right TT (s):						

## EFFECT OF MAXIMAL STRENGTH TRAINING

MS/MSES	0.022	-0.085	-	-	-	-
MSES/MS	0.300	0.059	-	-	-	-

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Note: Within group p-values and mean differences were only calculated for variables with a significant 2 x 3 or 2 x 2 interaction.

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Table 5:

*Main Effects of Time for 2 x 3 RM-ANOVA Off Ice Results*

	<i>p</i> -value (Main Effect)	<i>p</i> -value (Pre to Post 1)	<i>p</i> -value (Post 1 to Post 2)	<i>p</i> -value (Pre to Post 2)
20-m Sprint (s)	0.000	0.008	0.001	0.000
Vertical Jump (cm)	-	-	-	-
Horizontal Jump (cm)	0.000	0.000	0.003	0.000
Deadlift (kg)	0.000	0.000	0.002	0.000
Front Squat (kg)	0.004	0.000	1.000	0.043

Note: Main effects of time were only analyzed for variables that did not reveal a significant interaction in the 3 x 2 RM-ANOVA.



Table 6:

*Main Effects of Time for 2 x 3 RM-ANOVA On Ice Results*

	<i>p</i> -value (Main Effect)	<i>p</i> -value (Pre to Post 1)	<i>p</i> -value (Post 1 to Post 2)	<i>p</i> -value (Pre to Post 2)
Forward Sprint 1 IT (s)	0.065	-	-	-
Forward Sprint 1 TT (s)	0.072	-	-	-
Forward Sprint 2 IT (s)	0.145	-	-	-
Forward Sprint 2 TT (s)	0.087	-	-	-
Backward Sprint IT (s)	0.969	-	-	-
Backward Sprint TT (s)	0.417	-	-	-
Stop/Start Left IT (s)	0.603	-	-	-
Stop/Start Left TT (s)	-	-	-	-
Stop/Start Right IT (s)	0.134	-	-	-
Stop/Start Right TT (s)	0.911	-	-	-
Combination Drill IT (s)	0.000	0.000	0.134	0.000

## EFFECT OF MAXIMAL STRENGTH TRAINING

Combination Drill TT (s)	0.000	0.002	0.144	0.000
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Note: Main effects of time were only analyzed for variables that did not reveal a significant interaction in the 3 x 2 RM-ANOVA.

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Table 7:

*RM-ANOVA and Within Group Analysis of Training Loads versus 1RM Loads by Sequence*

	Pre Mean (SD)	Post 1 Mean (SD)	Post 2 Mean (SD)	<i>p</i> -value (Time Main Effect)	<i>p</i> -value (Pre to Post 1)	<i>p</i> -value (Post 1 to Post 2)	<i>p</i> -value (Pre to Post 2)
Deadlift:							
MS/MSES							
Training Loads	102.0 (35.8)	111.2 (36.5)	117.2 (37.6)	0.000	0.000	0.000	0.000
1RM	118.6 (37.0)	129.6 (35.5)	133.8 (36.1)	0.000	0.003	0.003	0.001
MSES/MS							
Training Loads	90.2 (30.0)	99.8 (29.5)	106.1 (31.9)	0.000	0.000	0.000	0.000
1RM	117.2 (44.2)	127.4 (41.1)	130.0 (40.6)	0.000	0.000	0.002	0.001
Front Squat:							
MS/MSES							
Training Loads	69.3 (25.1)	81.8 (27.3)	85.9 (25.8)	0.000	0.000	0.000	0.000
1RM	92.1 (32.5)	96.6 (32.6)	101.4 (32.1)	0.000	0.007	0.002	0.000
MSES/MS							
Training Loads	59.4 (18.6)	68.1 (19.0)	73.5 (17.9)	0.000	0.000	0.000	0.000
1RM	84.1 (28.7)	90.6 (37.7)	92.7 (28.2)	0.174	0.048	1.000	0.000

Table 8:

*Training Loads as Percentage of Pre 1RM by Sex*

	Deadlift (%)			Front Squat (%)		
	Pre	Post 1	Post 2	Pre	Post 1	Post 2
Combined	81.5	89.4	94.6	73.0	85.0	90.4
Males	76.1	82.4	87.4	70.1	75.8	80.7
Females	78.6	90.4	96.4	73.3	89.9	99.3

Table 9:

*Rating of Perceived Exertion (RPE) Frequency Percentages by Training Intervention*

	Mean (SD)	RPE Score Frequencies							
		3	4	5	6	7	8	9	10
MS	8.0 (1.2)	0.7%	1.6%	1.3%	5.8%	16.1%	44.9%	19.9%	9.8%
ES	8.2 (1.3)	0.4%	1.3%	1.3%	5.8%	16.1%	34.8%	24.1%	16.1%

Note: MS, maximal strength; ES, electrostimulation

FIGURES

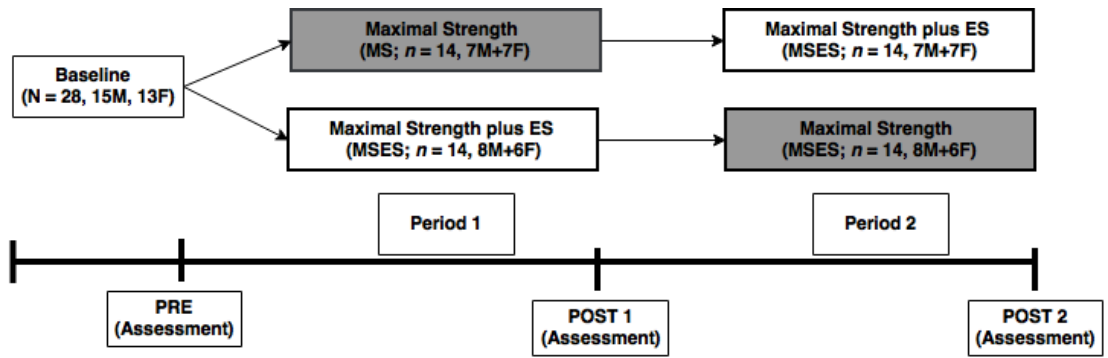


Figure 1. Cross over study design (MS/MSES or MSES/MS)

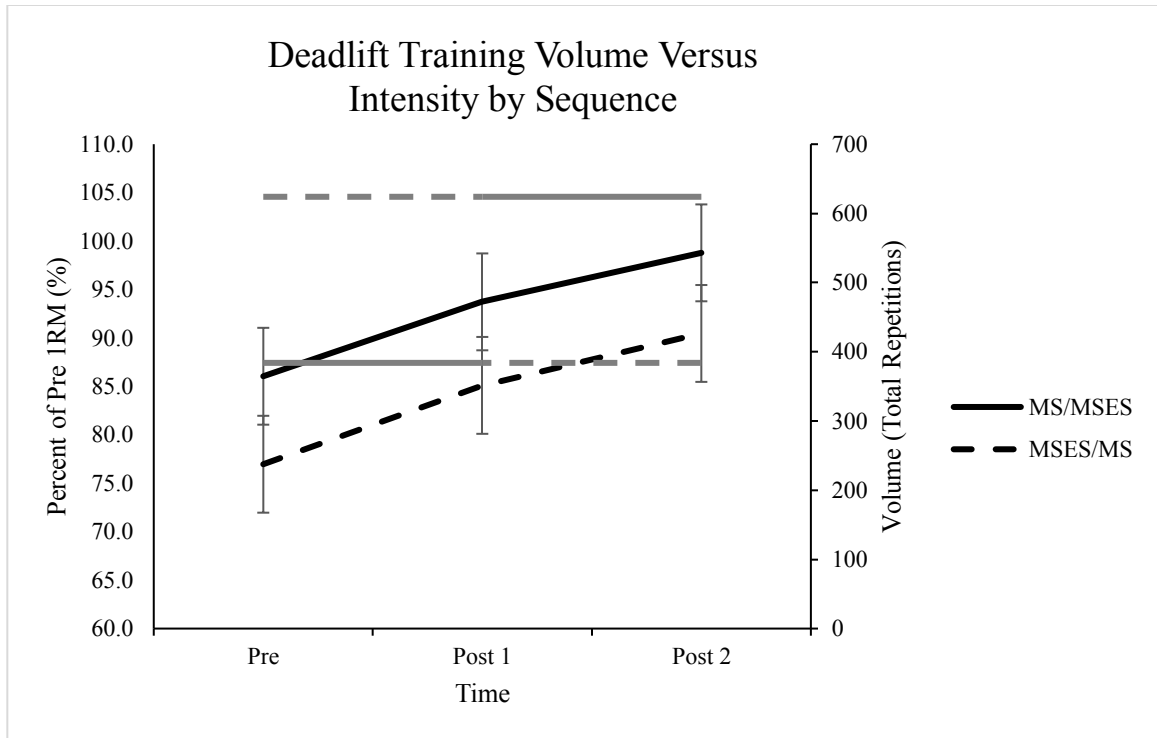


Figure 2. Volume (repetitions) versus training load intensity (%) relative to Pre 1RM (kg) by sequence. Intensity for both sequences ranged between 77.0% to 99.9% of Pre 1RM loads. Error bars represent between-subjects standard deviations.

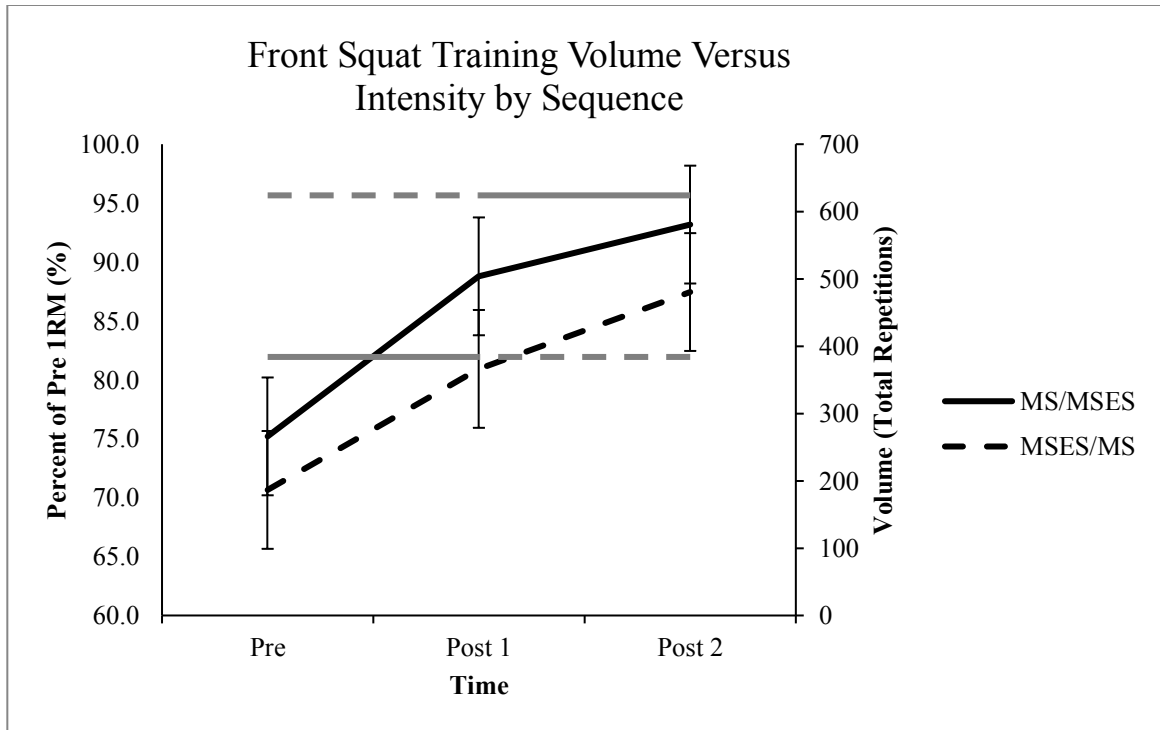


Figure 3. Volume (repetitions) versus training load intensity (%) relative to Pre 1RM (kg) by sequence. Intensity for both sequences ranged between 70.7% to 93.2% of Pre 1RM loads. Error bars represent between-subjects standard deviations.



EFFECT OF MAXIMAL STRENGTH TRAINING

APPENDIX A: Participant Profile Questionnaire

Player Information/Anthropometrics:

Player ID (Number): \_\_\_\_\_ Position: \_\_\_\_\_

Current Team/Level of Play: \_\_\_\_\_

Age: \_\_\_\_\_ Years of skating experience: \_\_\_\_\_

Height: \_\_\_\_\_ Weight: \_\_\_\_\_

Years of resistance training experience: \_\_\_\_\_

APPENDIX B: Physical Activity Readiness Questionnaire

**PAR-Q & YOU**

(A questionnaire for People Aged 15-69)

Regular physical activity is fun and healthy, and increasingly more people are starting to become more active every day. Being more active is very safe for most people. However, some people should check with your doctor before you start.

If you are planning to become much more physically active than you are now, start by answering the seven questions in the box below. If you are between the ages of 15 and 69, the PAR-Q will tell you if you should check with your doctor before you start. If you are over 69 years of age, and you are not used to being very active, check with your doctor.

Common sense is your best guide when you answer these questions. Please read the questions carefully and answer each one honestly: check **YES** or **NO**

YES <input type="checkbox"/>	NO <input type="checkbox"/>	<b>1. Has your doctor ever said that you have a heart condition <u>and</u> that you should only do physical activity recommended by a doctor?</b>
YES <input type="checkbox"/>	NO <input type="checkbox"/>	<b>2. Do you feel pain in your chest when you do physical activity?</b>
YES <input type="checkbox"/>	NO <input type="checkbox"/>	<b>3. In the past month, have you had chest pain when you were not doing physical activity?</b>
YES <input type="checkbox"/>	NO <input type="checkbox"/>	<b>4. Do you lose your balance because of dizziness or do you ever lose consciousness?</b>
YES <input type="checkbox"/>	NO <input type="checkbox"/>	<b>5. Do you have a bone or joint problem (for example, back, knee or hip) that could be made worse by a change in your physical activity?</b>
YES <input type="checkbox"/>	NO <input type="checkbox"/>	<b>6. Is your doctor currently prescribing drugs (for example, water pills) for your blood pressure or heart condition?</b>
YES <input type="checkbox"/>	NO <input type="checkbox"/>	<b>7. Do you have a diabetes or thyroid condition?</b>
YES <input type="checkbox"/>	NO <input type="checkbox"/>	<b>8. Do you know of <u>any other reason</u> why you should not do physical activity?</b>

	<b>YES to one or more questions</b>
<b>If you answered “Yes”:</b>	<p>A medical clearance form is required of all participants who answer ‘yes’ to any of the eight PAR-Q questions.                  Note: Personal training staff reserve the right to require medical clearance from any client they feel may be at risk.</p> <ul style="list-style-type: none"> <li>• Discuss with your personal doctor any conditions that may affect your exercise program.</li> <li>• All precautions must be documented on the medical clearance form by your personal doctor.</li> </ul>

<b>NO to all questions</b>
<p>If you answered NO honestly to <u>all</u> PAR-Q questions, you can be reasonably sure that you can:</p> <ul style="list-style-type: none"> <li>• start becoming much more physically active - begin slowly and build up gradually. This is the safest and easiest way to go.</li> <li>• take part in a fitness appraisal - this is an excellent way to determine your basic fitness so that you can plan the best way for you to live actively. It is also highly recommended that you have your blood pressure evaluated. If</li> </ul>

<b>DELAY BECOMING MUCH MORE ACTIVE:</b>
<ul style="list-style-type: none"> <li>• If you are not feeling well because of a temporary illness such a cold or a fever - wait until you feel better; or</li> <li>• If you are or may be pregnant - talk to your doctor before you start becoming more active.</li> </ul>

<p><b>PLEASE NOTE:</b> If your health changes so that you then answer YES to any of the above questions, tell your fitness or health professionals. Ask whether you should change your physical</p>
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# EFFECT OF MAXIMAL STRENGTH TRAINING

your reading is over 144/94, talk with your doctor before you start becoming much more physically active.

activity plan.

Informed Use of the PAR-Q: The Canadian Society for Exercise Physiology, Health Canada, and their agents assume no liability to persons who undertake physical activity, and if in doubt after completing this questionnaire, consult your doctor prior to physical activity.

NOTE: If the PAR-Q is being given to a person before he or she participates in a physical activity program or a fitness appraisal, this section may be used for legal or administrative purposes.

**“I have read, understood and completed this questionnaire. Any questions I had were answered to my full satisfaction.”**

NAME \_\_\_\_\_

SIGNATURE \_\_\_\_\_

DATE \_\_\_\_\_

SIGNATURE OF PARENT \_\_\_\_\_

WITNESS \_\_\_\_\_

or GUARDIAN (for participants under the age of majority)

**Note: This physical activity clearance is valid for a maximum of 12 months from the date it is completed and becomes invalid if your condition changes so that you would answer YES to any of the seven questions.**



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Physical

(revised  
2006 by CW)

APPENDIX C: Participant Informed Consent

The Effects of Concurrent Electrostimulation and Strength Training on Lower Body Strength and Skating Speed in Ice Hockey Players

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**INVITATION:** You are being invited to participate in a Master's thesis research project examining the effects of concurrent electrostimulation and strength training on lower body strength and on ice skating speed.

**WHAT'S INVOLVED:** Participation in the study requires you to complete a supervised TEN WEEK training program that includes strength and electrostimulation training THREE times per week before or after practices. Additionally, there will be THREE off ice fitness assessment sessions and THREE on ice skating assessment sessions before, midway, and at the end of the study that will allow us to determine the effects of concurrent electrostimulation training and strength training on lower body strength and skating speed. All sessions will be scheduled through your coach to ensure that the research will not conflict with your practice and game schedule. Only players who are injury free are eligible to participate. Details of the training and assessment sessions are as follows:

**Training:** All strength and electrostimulation training sessions will be supervised by the student researcher and conducted at: Seymour-Hannah Sports and Entertainment Centre, 240 St Paul St W, St. Catharines. Prior to the beginning of the study, participants will be required to complete a Physical Activity Readiness Questionnaire and a brief questionnaire that includes hockey experience (years) and training experience (years). Participants will be randomly assigned to one of two groups but will complete both four-week interventions: strength training or strength training plus electrostimulation training. These sessions will take approximately 45 and 60 minutes respectively. All training sessions will have a maximum 4:1 ratio of participant to trainer to ensure proper supervision.

- Strength training will consist of three lower body weight training exercises per session using barbells and dumbbells with loads individualized for each participant based on current strength levels.
- Electrostimulation training will occur immediately following strength training and consist of electrically stimulated contractions of the quadriceps while the participant is at rest. Small patches of skin will be dry shaved before three electrodes are placed on each leg. This will allow proper skin contact with the adhesive electrode. Quadriceps stimulation will take place in a seated position. Participants can expect to feel their muscles contracting strongly during the stimulation. This may initially feel uncomfortable however the discomfort typically lessens as the participants acclimatize. Participants will be taught how to

control the strength of the contraction using the portable unit interface. Participants will be encouraged to increase the strength of the contraction to the highest level they can comfortably tolerate. If the stimulation becomes too uncomfortable, participants will be free to decrease the strength of the contraction or shut off the stimulation completely. The participants will undergo 30 stimulated contractions of the quadriceps over a period of 15 minutes. Preparation of each muscle group will take approximately 5 minutes making the electrostimulation training a total of 20 minutes.

- Participants will be required to fill out training logs following each session to track loads used during strength training, intensity during electrostimulation training and perceived exertion. Training logs should take fewer than 5 minutes to complete.

**Off Ice Assessments:** The off ice assessments will be scheduled and conducted Seymour-Hannah Sports and Entertainment Centre, 240 St Paul St W, St. Catharines, ON. These sessions will take approximately 60 minutes and with groups of eight participants or fewer simultaneously. Participants will be required to complete a battery of lower body strength assessments including (1) squat jump, (2) horizontal jump, (3) 30-m sprint, and (4) 5 repetition maximums of the squat and deadlift exercises.

**On Ice Assessments:** The on ice assessments will be scheduled and conducted at Seymour-Hannah Sports and Entertainment Centre, 240 St Paul St W, St. Catharines, ON. These sessions will take approximately 75 minutes and with a group of 16 or fewer participants simultaneously. Each assessment will include a battery of eight on ice skating drills representing skating skills commonly used in game play. Time to complete each of the skating drills and 5-m interval time will be recorded.

### **POTENTIAL BENEFITS AND RISKS**

Possible benefits of participation include the opportunity complete a supervised 8-week periodized strength training program that has potential to increase lower body strength and on ice skating speed. In addition, participants will be exposed to a novel training modality, namely electrostimulation, that has been associated with enhancing strength in athletes. During assessments, participants may experience physical risks associated with any intense physical activity including: muscular fatigue, muscular soreness following training, bodily injury to the muscles, ligaments, tendons, and joints, and possible feelings of nausea. Rare occurrences of dizziness, chest pain, fainting, or, very rarely, cardiac arrest are also risks associated with extreme intensity levels. However, these assessments are consistent with high intensities performed in regular on ice practices and games, meaning players will have been previously exposed to similar levels of exertion. Electrostimulation training may cause minor redness of the skin beneath the electrodes in certain people with sensitive skin. Generally, this redness is harmless and disappears within 10-20 minutes. If a minor injury (i.e. scrape, cut, minor muscle strain, etc.) should occur during an assessment or training session, standard first aid will be administered by the student researcher. Although unlikely, if a more significant injury should occur (i.e. suspected broken bone, soft tissue rupture, etc.) the participant will be taken to the nearest hospital by the parent or ambulance if necessary.

Although players will be recruited based on team involvement, participation in the study will be voluntary on an individual basis and each player may choose to accept or refuse participation. Players who do not wish to participate will suffer no penalty within the team. Coaches will not see results pertaining to any player.

### **CONFIDENTIALITY**

To avoid exposure of personal data and ensure confidentiality of data collection, participants will be fitted with a Radio Frequency Identification (RFID) tags for all on ice assessments. Data from off ice assessments and questionnaires will be cross-referenced with RFID identifiers by the researcher so that names will not appear on the data forms. All data is confidential and only the principal and student investigator will have access. Following publication, electronic copies of data will be distorted to remove participant names and retained for a period of five years. The data will be stored on a research dedicated portable hard drive that is password protected by the principal researcher.

### **VOLUNTARY PARTICIPATION**

Participation in this study is voluntary and not a mandatory team activity. Should the participant wish to withdraw from this study, they may do so by verbally informing the principal investigator or student investigator, without any penalty. If the participant chooses to withdraw, their data will be destroyed by deleting any file and shredding any training log related to their participation at the end of the training or assessment session. Data will not be shared or used for further analysis.

### **PUBLICATION OF RESULTS**

A summary of the results of this study will be available and distributed to all participants approximately one month after the final assessment session is completed. This will include a personalized summary with both individual results and a comparison to average group scores. Furthermore, scientific results of this study may be published in academic or practitioners journals and/or presented at scientific conferences to advance our knowledge of the effects of strength and electrostimulation training on lower body power and on ice skating speed. Only age group and playing positions of the participants will be utilized as possible identifiers in the analysis and publication of results.

### **CONTACT INFORMATION AND ETHICS CLEARANCE**

If you have any questions about this study or require further information, please contact Dr. Kelly Lockwood or Vicki Bendus using the contact information provided above. This study has been reviewed and received ethical clearance through the Research Ethics Board at Brock University. If you have any comments or concerns about your rights as a research participant, please contact the Research Ethics Office at (905) 688-5550 Ext. 3035, [reb@brocku.ca](mailto:reb@brocku.ca).

If you are interested in participating please complete the attached Informed Consent and submit it to Dr. Kelly Lockwood or Vicki Bendus using the contact information provided above. Please keep a copy of this form for your records. Thank you for your assistance in this project.

Vicki Bendus and Dr. Kelly Lockwood

**Informed Consent**

I agree to participate in the study as described above. I have made this decision based on the information provided through reading this document and assent that:

- I have had the opportunity to receive any additional details.
- I understand that I may ask questions at anytime with regard to the study.
- I understand that I may withdraw this consent at any time during the study.
- I do not have a pacemaker, epilepsy or an abdominal hernia.
- I understand that this is not a team-required activity and I am not obligated as a team member to participate in the study.
- I understand that on and off ice assessments will take place in groups with other participants viewing my performance. However, only the researchers will see my scores.

**Participant Consent:**

I agree to participate in this study described above. I have made this decision based on the information I have read in the Information-Consent Letter. I have had the opportunity to receive any additional details I wanted about the study and understand that I may ask questions in the future. I understand that I may withdraw this consent at any time.

**Photo Permission:**

In signing this form, I \_\_\_\_\_ (Participant's Name) and \_\_\_\_\_ (Guardian's Name) give permission to for photos and videos of \_\_\_\_\_ (Participant's Name) to be used by Dr. Kelly Lockwood to in presentations of the research (E.g. poster presentation at a conference). (NOTE: Photo permission is NOT required to participate.)

**Participant's Name:** \_\_\_\_\_

**Participant's Signature:** \_\_\_\_\_

**Guardian's Signature (if under 18):** \_\_\_\_\_

**Date:** \_\_\_\_\_

APPENDIX D: On Ice Drill Descriptions

For all skating drills, a timing light will signal participants to begin and verbal support will be given to encourage maximal effort. All drills will be completed in the same order for each assessment throughout the study.

*Forward Linear Speed Drill:* The linear speed drill is a straight maximal sprint.

Participants will begin at the starting mark in a two-foot stance and facing the direction of travel. Following the light signal, participants will skate at maximal speed from the starting mark to the far blue line.

*Backward Linear Speed Drill:* The backward linear speed drill is a straight maximal sprint skating backwards. The assessment exactly mirrors the forward linear speed drill described above. Participants begin with their heels on the starting line facing in the opposite direction of travel skate maximally backwards for the duration of the drill.

*Stop/Start Drill:* Participants will begin on the starting mark facing perpendicular to the direction of travel. Following the light signal, participants will cross over quickly and accelerate to the near blue line. They will stop with both feet over the blue line and skate as fast as possible back to the starting mark. Participants will repeat this test facing the opposite direction.

*Combination Test:* Participants will combine forward acceleration, backwards speed, agility and maximal linear speed in this test. Participants will start on the goal line in one end zone, facing the direction of travel. Following the light signal, participants will accelerate to the first blue line and pivot backwards. They will then skate backwards to the far blue line where they will pivot back to forwards. From there, participants will enter the opposite end zone from where they began and skate through a five-pylon agility



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course. After the agility section, participants will skate as fast as possible the length of the ice to the starting mark.

### APPENDIX E: Training Programs

	<b>TRAINING BLOCK 1 – 4 WEEKS</b>	<b>TRAINING BLOCK 2 – 4 WEEKS</b>
<b>FREQUENCY</b>	2x/ week	2x/week
<b>INTENSITY</b>	3 x 5-6 @ 75-85% of 1RM	3 x 5-6 @ 75-85% of 1RM
<b>TYPE</b>	Strength training	Strength training
<b>TIME</b>	40 minutes	40 minutes

**Sample Week:**

Monday: Workout A

Wednesday: Workout B

**Training Block 1 MS Training Program:**

<b>Workout A</b>	<b>Workout B</b>
1) Front Squat	1) Deadlift
2) Romanian Deadlift	2) Goblet Squat
3) Dumbbell Split Squat	3) Single Leg Romanian Deadlift
<i>Sets and Reps:</i> 3 x 5-6 @ 75-85% of 1RM <i>Rest:</i> 2 min after each exercise	<i>Sets and Reps:</i> 3 x 5-6 @ 75-85% of 1RM <i>Rest:</i> 2 min after each exercise
<i>Overload:</i> 2-for-2 rule for all exercises. Core exercises will be overloaded with time or repetitions.	<i>Overload:</i> 2-for-2 rule for all exercises. Core exercises will be overloaded with time or repetitions.

**Training Block 2 MS Training Program:**

<b>Workout A</b>	<b>Workout B</b>
1) Front Squat	1) Deadlift
2) Rack Pulls	2) Back Squat
3) Dumbbell Step Ups	3) Dumbbell Reverse Lunge
<i>Sets and Reps:</i> 3 x 5-6 @ 75-85% of 1RM <i>Rest:</i> 2 min after each exercise	<i>Sets and Reps:</i> 3 x 5-6 @ 75-85% of 1RM <i>Rest:</i> 2 min after each exercise
<i>Overload:</i> 2-for-2 rule for all exercises.	<i>Overload:</i> 2-for-2 rule for all exercises.

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Core exercises will be overloaded with time or repetitions.	Core exercises will be overloaded with time or repetitions.
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EFFECT OF MAXIMAL STRENGTH TRAINING

APPENDIX F: Training Logs

*Sample Training Log*

<b>Workout A</b>	<b>Set</b>	<b>Rep</b>	<b>%1RM</b>	<b>Date</b>						
	<b>Desired</b>			<b>S 1</b>	<b>S2</b>	<b>S3</b>				
1) Front Squat	3	5	85%							
2) Romanian Deadlift	3	6E	80%							
3) Dumbbell Split Squat	3	6	85%							
On a scale of 1-10, rate your effort during today's strength session:	1	2	3	4	5	6	7	8	9	10

EFFECT OF MAXIMAL STRENGTH TRAINING

*Sample Electrostimulation Training Log*

Date	Maximum Intensity Reached	Average Intensity of Session	On a scale of 1-10, rate your effort during today's electrostimulation session:				
Familiarization Session #1:			1 6	2 7	3 8	4 9	5 10
Session #1:			1 6	2 7	3 8	4 9	5 10
Session #2:			1 6	2 7	3 8	4 9	5 10
Session #3:			1 6	2 7	3 8	4 9	5 10
Session #4:			1 6	2 7	3 8	4 9	5 10
Session #5:			1 6	2 7	3 8	4 9	5 10
Session #6:			1 6	2 7	3 8	4 9	5 10
Session #7:			1 6	2 7	3 8	4 9	5 10
Session #8:			1 6	2 7	3 8	4 9	5 10